A Systematic Approach to Enterprise Risk Management

by

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DECLARATION

I, Nicolas James Benjamin, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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ABSTRACT

In the current economic climate where credit crises, fluctuating commodity prices, poor governance, rising unemployment and declining consumer spending exist, risk management is of utmost importance. Proclaiming the existence of a risk management strategy is not enough to ensure that an enterprise achieves its objectives. The implementation of a holistic enterprise-wide risk management framework is required in order to execute strategies and achieve objectives effectively and efficiently

Two types of risk management have emerged in industry, namely quantitative and qualitative risk management. On the one hand, qualitative analysis of risk can be done quickly and with minimal effort. However, these methods rely on the opinion of an individual or group of individuals to analyse the risks. The process may be highly subjective and does not fully consider the characteristics of the enterprise. This renders qualitative risk analysis as an ineffective singular strategy although it has been shown to be effective when the risks are well understood.

Quantitative analysis, on the other hand, is particularly effective when the risks are not well understood. These methods have been shown to provide substantially more information regarding risks compared to qualitative analysis. However, many quantitative risk management methods presented in literature are studied in isolation and not within the context of a holistic risk management process. Furthermore, quantitative methods tend to be complex in nature and require a reasonable understanding of mathematical and statistical concepts in order to be used effectively.

In view of this, there is a need for an enterprise risk management framework that emphasises the use of qualitative methods when the risks are well understood and quantitative methods when in-depth analyses of the risks are required. In this study, a systematic enterprise-wide risk management framework that incorporates both quantitative and qualitative methods was developed. The framework integrates these methods in a logical and holistic manner. The quantitative methods were found be to be largely practical while the qualitative methods presented are simple and easy to understand.

OPSOMMING

In die huidige ekonomiese klimaat waar krediet krisisse, wisselende kommoditeitspryse, swak bestuur, stygende werkloosheid en dalende verbruikersbesteding bestaan, is risikobestuur van die uiterste belang. Die verkondiging van die bestaan van 'n risiko bestuurstrategie is nie genoeg om te verseker dat 'n onderneming sy doelwitte bereik nie. Die implementering van 'n holistiese ondernemings- breë risikobestuursraamwerk is nodig om strategieë en doelwitte doeltreffend en effektief te bereik.

Twee tipe risikobestuur het na vore gekom in die bedryf, naamlik kwantitatiewe en kwalitatiewe risikobestuur. Aan die een kant , kan kwalitatiewe ontleding van risiko vinnig en met minimale inspanning gedoen word. Hierdie metode is gewoontlik die mening van 'n individu of 'n groep individue wat die risiko ontleed. Die proses kan hoogs subjektief wees en nie ten volle die eienskappe van die onderneming in ag neem nie. Kwalitatiewe risiko-analise kan dan gesien word as 'n ondoeltreffende enkelvoud strategie maar dit is wel doeltreffend wanneer daar verstaan word wat die onderneming se risiko is.

Kwantitatiewe analise, aan die ander kant, is veral effektief wanneer die risiko's nie goed verstaanbaar is nie. Hierdie metode het getoon dat daar aansienlik meer inligting oor die risiko's, in vergelyking met kwalitatiewe ontleding, verskaf word. Daar is egter baie kwantitatiewe risikobestuur metodes wat in literatuur verskaf word, wat in isolasie bestudeer word en nie binne die konteks van 'n holistiese risikobestuur proses nie. Verder is, kwantitatiewe metodes geneig om kompleks van aard te wees en vereis 'n redelike begrip van wiskundige en statistiese konsepte sodat kwantitatiewe analise effektief kan wees.

In lig hiervan, is daar 'n sterk behoefte vir 'n onderneming om 'n risikobestuursraamwerk in plek te het. Die risikobestuursraamwerk sal beide die gebruik van kwalitatiewe metodes, wanneer die risiko goed verstaan word, en kwantitatiewe metodes, wanneer daar in diepte-ontledings van die risiko is, beklemtoon. In hierdie studie was 'n sistematiese onderneming-breë risikobestuursraamwerk ontwikkel wat beide kwantitatiewe en kwalitatiewe metodes insluit. Die raamwerk integreer hierdie metodes in 'n logiese en holistiese wyse. Die kwantitatiewe metodes is gevind om grootliks prakties te wees, terwyl die kwalitatiewe metodes wat aangebied word, eenvoudig en maklik is om te verstaan.

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NOMENCLATURE

Symbol	Parameter	Unit
μ	Mean	N/A
$\boldsymbol{\sigma}$	Standard Deviation	N/A
$\boldsymbol{P_1}$	Risk likelihood before control	%
$\boldsymbol{L_1}$	Risk impact before control	Rands (R)
$\boldsymbol{R_1}$	Unacceptable expected loss	Rands (R)
$\boldsymbol{P_2}$	Risk likelihood after control	%
$\boldsymbol{L_2}$	Risk impact after control	Rands (R)
$\boldsymbol{R_2}$	Acceptable expected loss	Rands (R)
$\boldsymbol{\varphi}$	Ratio of $\mathbf{R_1}$ to $\mathbf{R_2}$	
$\boldsymbol{\omega}$	Irremovable uncertainty	N/A
$\boldsymbol{r}$	Insurance rate	%
$\boldsymbol{k}$	Unit prevention cost	Rands (R)
$\boldsymbol{p_s}$	Probability of Success	%
$\boldsymbol{p}$	Probability of observing a given number of successes	%
$\boldsymbol{\alpha}$	Beta distribution shape parameter	N/A
$\boldsymbol{\beta}$	Beta distribution shape parameter	N/A
$\boldsymbol{\alpha_e}$	Error	%
$\boldsymbol{N_i}$	Number of *i*	N/A

ABBREVIATIONS

Abbreviation	Explanation
AHP	Analytical Hierarchy Process
ERM	Enterprise Risk Management
RDM	Risk Diagnosing Methodology
PDF	Probability Density Function
GoF	Goodness-of-Fit
MCS	Monte Carlo Simulation
MCDA	Multi Criteria Decision Analysis
PERT	Project Evaluation Review Technique
PPE	Personal Protective Equipment
S	Safe risk
L	Low risk
H	High risk
F	Fatal risk

CHAPTER 1 INTRODUCTION

1.1 Background

The need for enhanced corporate governance and effective enterprise risk management (ERM) in the wake of large corporate failures and the ensuing losses has become evident in the last few years. These losses can be partially attributed to uninformed decision making and poor risk management (Steinberg et al. 2004). Although most enterprises recognise the need for risk management and benefits thereof, formal risk analysis techniques are seldom used owing to a lack of knowledge and doubts of the suitability of those methods to their specific enterprise (Dey 2010).

1.1.1 Risk Defined

Risk is an uncertain event that, should it occur, will have an effect on the achievement of the enterprise objectives (Steinberg et al. 2004; ISO 31000:2009, Risk Management—Principles and Guidelines 2009). An effect is a deviation from the normal or expected conditions. In terms of risk, this effect can be positive or negative (Al-Bahar & Krandall 1990). Thus, mitigating the effects of negative risk and enhancing the effect of positive risk ensures that objectives are achieved. Risk is intrinsic in all enterprise operations (Kwak & LaPlace 2005). Thus it is crucial to identify and analyse the associated uncertainty (Ward 2003).

1.1.2 Risk Management

Risk management is defined as the systematic process of identifying, assessing and responding to events that may potentially affect objectives (PricewaterhouseCoopers 2008). Risk assessment has been defined as the measurement of the risk impact and likelihood (ISO 31000:2009, Risk Management—Principles and Guidelines 2009). The expected loss or threat level of a risk is calculated as the product of the risk impact and probability (INCOSE 2007). Risk management can be applied throughout an enterprise as well as within specific functional groups such as projects or departments. While all enterprises implement risk management to some extent, establishing principles and guidelines that should be satisfied when performing risk management increases the effectiveness of the process (ISO 31000:2009, Risk Management—Principles and Guidelines 2009).

1.1.3 Qualitative and Quantitative Risk Management

Regardless of the extent of implementation or established principles, business owners frequently rely solely on experience and intuition to manage risks (Smit & Watkins 2012). In many cases, this approach is sufficient. However, as the risks increase in complexity, further analysis is required. Quantitative methods can be used to provide further analysis (Azari et al. 2011). Incorporating both qualitative and quantitative methods into a systematic enterprise risk management approach, makes it possible to identify risks that require further analysis (Turner & Ketelaar 2005).

Risks that require further analysis are called critical risks. By contrast, non-critical risks do not require further analysis (Keizer, Vos & Halman 2005). Through identification of critical risks, management is able to allocate more resources to the control of these risks while simultaneously ensuring that non-critical risks are not over-analysed (See Figure 1-1).

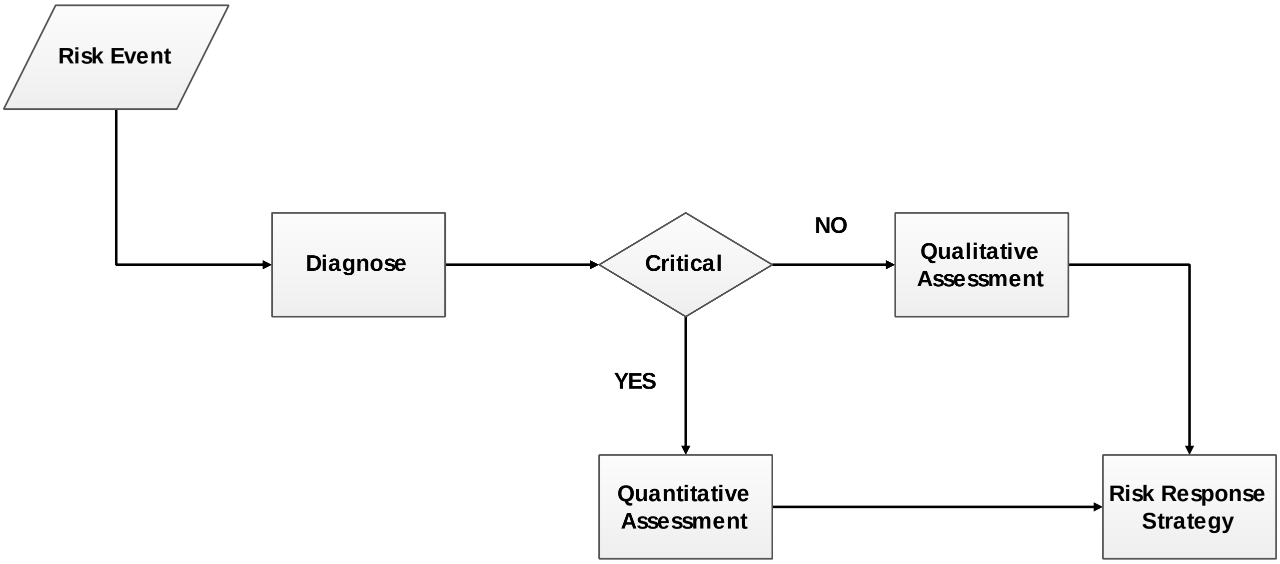

Figure 1-1: Diagnosing risks for qualitative or quantitative assessment

It must be noted that it is impossible to completely remove the qualitative aspects of risk management since the uncertainty associated with risks is rooted in human influences and behaviour. Thus, risk management will always include an inherent subjective and qualitative aspect (Chapman 1990).

1.1.4 Core Risk Management Functions

In general, three core risk management actions exist, namely risk identification, risk assessment and risk response strategy (See Figure 1-2). Thus these actions will be the focus of this thesis.

Figure 1-2: Core risk management functions

Identification and assessment of the risks are the most important steps, and usually a major source of difficulty (Azari et al. 2011). As such, risk identification and assessment will determine the importance and subsequently the amount of attention that a particular risk is given (Zhi 1995). Assessment of the risk also determines the risk response strategy to be adopted. Thus, it is important to properly identify and assess the threat level of all risks (Stewart & Fortune 1995).

The current approaches towards risk identification are diverse and range from using past experience, brainstorming sessions and interviews. Although these approaches are widely accepted, the risk manager should be aware of factors affecting each approach and which would most be appropriate for a specific working environment. It is often the case that the factors that affect these approaches' processes are not considered (Chapman 2001).

A common method used to determine the risk likelihood and impact is rating systems. This method involves scoring the risk likelihood and impact a given scale, usually 1 to 5.

The risk response strategy is chosen by calculating the risk threat level, which is the product of the likelihood and impact. Depending on whether the threat level is high, medium or low, a manager would be advised to select a specific risk response strategy (PricewaterhouseCoopers 2008).

Industry studies have shown that the choice of a risk response strategy is primarily associated with attitude of management towards the perceived threat and not empirical (Fan, Lin & Sheu 2008).

1.2 Enterprise Risk Management Processes

Risk management has evolved and been adapted for use in specific industries over the years. However, the 3 core functions (See Figure 1-2) of risk management have always been included in some form or the other. Steinberg et al. have developed a risk management process that can be implemented at every level within an enterprise. This process is aptly named Enterprise Risk Management (Steinberg et al. 2004). The Enterprise Risk Management (ERM) model incorporated the core risk management functions and was used as a guideline to identify the steps required in an effective risk management process.

There are eight important and interrelated concepts that encompass ERM. These are:

1. Internal Environment

Internal environment is determined by the behaviour of individuals within an enterprise as well the values and ethics embodied within the enterprise. These attributes include integrity, honesty and competence.

2. Objective Setting

Objectives must exist before the effect of risks can be measured. ERM objective setting processes help management set objectives that are consistent with the enterprise's mission.

3. Risk Identification

Risks that may affect objectives are identified. This process can involve using data from internal and external sources. Identification of risks also includes risk classification.

4. Risk Assessment

Identified risks are first prioritised and then their criticality is determined. Thereafter, the impact and likelihood of the risks is determined.

5. Risk response strategy

Risks are usually responded to in one of four general ways, namely avoiding, reducing, sharing and accepting the risk. The appropriate response can be chosen by either qualitative or quantitative methods.

6. Control Activities

These are procedures that are developed to ensure that the risk is mitigated according to the risk response strategy. When the risk is accepted no actions are taken.

7. Information and communication

Information is needed at all stages in the ERM process. Communication ensures the acquisition of new and relevant data (Gray & Balmer 1998).

8. Monitoring

The ERM process must be monitored to keep track of progress, and to measure performance against the specified criteria so that changes can be made if and where necessary.

Figure 1-3: The enterprise risk management process

1.1 Limitations of Enterprise Risk Management

Enterprise risk management does not make decisions for the business. However, ERM can aid in decision-making by providing insights into possible outcomes of certain paths that may be taken.

In this regard, risk assessments should attempt to identify all significant risk although it is limited by the resources allocated, information available and time constraints.

The use of any risk management strategy does not guarantee the absence of all risk. It is possible to predict and summarily plan for a variety of risks. Even so, the possibility of a risk event is always present but effective risk controls reduce the impact of risks. As such, people make mistakes, it is part of being human, thus even when a particular risk is planned for, and it does not guarantee that accidents will not happen.

1.2 Rationale

Steinberg et al. and ISO 31 000 introduce risk management frameworks, and the steps required in an effective risk management process (Steinberg et al. 2004; ISO 31000:2009, Risk Management—Principles and Guidelines 2009). These steps are generic and act as a guideline for managing risks. While useful, these frameworks do not provide a detailed analysis of the available methods that can be used to complete each step.

Previous research has focussed extensively on qualitative analysis of risk (Fan, Lin & Sheu 2008). Qualitative risk management involves using intuitive knowledge and experience to assess and respond to risks. In many cases, intuitive knowledge and experience may be sufficient to complete the risk management process but as the risks become more complex, using intuition may not always be an effective strategy (Wang, Dulaimi & Aguria 2004).

In contrast, quantitative risk management techniques rely on data, probabilistic modelling and statistical analysis. Ideally, a risk management process should be predominantly quantitative but as stated previously, risk is inherently subjective, hence giving qualitative techniques merits in the risk management process.

There are very few studies presenting an integrated risk management approach accompanied by detailed analysis of the tools and techniques available. Although there are studies that present the quantitative analysis of risk, limited studies exist that present how risk response and risk analysis are linked quantitatively (Dey 2010).

Moreover, a purely quantitative approach requires a considerable allocation of time and resources which may not be practical. Risk is generally assessed subjectively because statistical data is rarely available (INCOSE 2007). This study will show that quantitative analysis is possible even when data are sparsely available.

1.3 Research Problem

Qualitative analysis of risk can be done quickly and with minimal effort. However, this approach relies on intuition and experience which, is sufficient for non-critical risks that are well understood. Critical risks that are not well understood require further analysis. Quantitative analysis provides an in-depth analysis of the risks. However, a predominantly quantitative approach can become overly complex and requires significant time and resources, thus it may not always be practical.

Owing to this, the research problem is that there is no systematic, enterprise risk management framework that includes an in-depth presentation of qualitative risk analysis methods for risks that are non-critical and quantitative methods for critical risks. Any effective ERM framework must be practical. This means that an enterprise must be able to use the methodology with existing personnel, skills and knowledge. The process must follow a structured, sequential and logical format. Moreover, an ERM framework should establish to what extent is risk management understood in an enterprise, the perception of risk management within the company and determine how the enterprise characteristics affect the risk management processes.

1.4 Research Goal and Objectives

1.4.1 Research Goal

From the research problem it was proposed that, a systematic enterprise-wide risk management framework that incorporates quantitative as well as qualitative techniques such that an in-depth analysis is provided when the risks are critical and simpler experience and intuition based analysis when the risks are non-critical.

Thus, the main goal of this research is to develop an enterprise risk management framework that incorporates both qualitative and quantitative risk management techniques in a practical and systematic manner.

1.4.2 Research Objectives

In order to achieve the stated research goal, this study will seek to meet the following objectives:

- Define the steps of the enterprise risk management process
- Identify qualitative and quantitative risk management techniques
- Formulate and test the framework in a case study
- To show that risk management does not have to be overly simple to be implemented, or overly complex to be performed effectively.

1.5 Research Design and Methodology

1.5.1 Research Design

Research Design can be classified into 3 main categories, namely non-empirical, empirical and mixed method research design. Non-empirical research involves analysing characteristics of a system that cannot be defined numerically. In contrast, empirical research is used when the system can be defined numerically. Mixed methods research is the use of both empirical and non-empirical analysis to form conclusions (Leedy & Ormrod 2013).

This study employed both empirical and non-empirical methods. As stated in section 1.1.3, it is impossible to completely model the risk management process empirically because uncertainty is rooted in human behaviour and perceptions which are inherently non-empirical by most standards.

1.5.2 Research Methods

The following research methods were used when carrying out the study:

- Comprehensive Literature Review

A comprehensive review of literature on existing risk management processes was done to establish the steps required in a risk management process. The review of literature provided useful insights into the available methods for completing each step. Once the process and methods were understood, the scope of the study was defined, and the most appropriate risk management methods were chosen.

- Case Study and data processing

Historical data in the form of a list of risks was obtained from the company in the case study (See Appendix B). Following this, questionnaires were given to key personnel at the company (Appendix A).

- Data processing

The data was processed using statistical analysis, Monte Carlo simulation and analytical hierarchy processes among others.

- Conclusions

The proposed framework is validated through a discussion on its practicality and logical format.

1.6 Thesis Outline

Chapter 1: Introduction - provides background information on enterprise risk management and presents the proposed research.

Chapter 2: Presents the methods to measure the effect the internal environment on enterprise risk management.

Chapter 3: Presents risk identification procedures using working group and interview techniques.

Chapter 4: Establishes qualitative and quantitative techniques for risk assessment

Chapter 5: Describes the procedure for selecting a risk response strategy qualitatively and quantitatively.

Chapter 6: Provides a brief description of case study and confidentiality limitations and presents the analysis of results from each risk management step.

Chapter 7: Conclusions and recommendations - summarises the main findings of the research and establishes whether the research goal has been achieved.

1.7 Scope

In this section, the boundaries of the research will be clearly defined. The ERM process consists of a number of well-defined steps. Although interrelated, each step is a separable and unique part of the process that can be discussed conceptually. This study has been limited to the exploration of the following steps:

- Internal Environment
- Risk Identification
- Risk Assessment
- Risk Response Type

Control strategies are excluded from the discussion as this is a highly specific research area. Control strategies depend on the type of industry, company policies, environment, management preferences and most importantly, the identified risk. The variation is too radical to formulate standardised risk control strategies. Even when companies face similar risks, the control strategies may differ for various reasons.

Communication and Monitoring are important parts of ERM but these too are excluded from this discussion because extensive research has been done in developing effective methods of communication and monitoring (Steinberg et al. 2004).

Implementation of risk management plans into the business policies is separable from the risk management process itself and is not required in order to complete a risk management process. Thus it is excluded from this study. Moreover, the efficacy of implementation cannot be measured within the time constraints of this study.

The success or failure of a specific objective is usually measured over a number of years. Since the effectiveness of using a given objective setting technique is related to the success or failure of objectives, performance of an objective setting technique cannot be measured within the time constraints of this study.

It was stated that risk can have a positive or negative result. Risk opportunities have positive results and risk threats have negative results. This thesis will be limited to the study of risk threats as data is readily available for this type of risk. The methodology can be extended to risk opportunities in future studies.

The loss associated with risks will be measured using monetary values only. While schedule losses and other losses such reputation impact can be measured, the most frequently utilised and recorded loss is associated with monetary values.

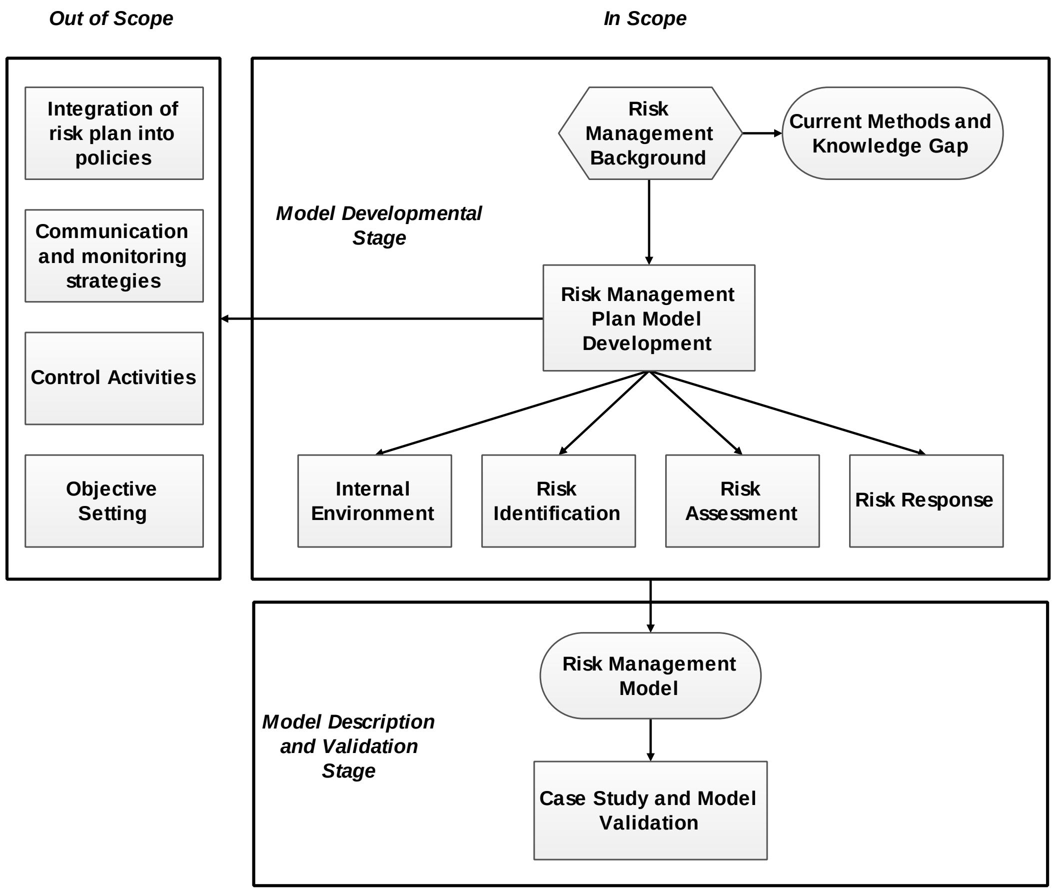

Figure 1-4: Scope of the study

1.8 Summary

Risk and risk management was defined in this chapter. The enterprise risk management processes that were presented will serve as guideline to develop the methods required to complete a risk management process. Chapter 2, Chapter 3, Chapter 4 and Chapter 5 will present these methods in logical and systematic sequence. Considering that there is no complete substitution for the experience and expertise of individuals, the proposed framework will include both qualitative and quantitative techniques.

CHAPTER 2 INTERNAL ENVIRONMENT

2.1 Introduction

Chapter 1 introduced the enterprise risk management processes, defined the scope of the research and presented the research. This chapter presents the first step in the ERM process, which is evaluating the internal environment of an enterprise.

2.2 Evaluating Internal Environment

The effect of the internal environment can be seen in the findings of the Columbia Space Shuttle Accident Investigation board report. The report states:

"…Cultural traits and organisational practices detrimental to safety were allowed to develop, including: reliance on past success as a substitute for sound engineering practices." (Steinberg et al. 2004).

It is the case that internal environment influences how effectively risk is identified and determines management's philosophy for handling risk. Therefore, assessing the internal environment can provide insight into the level of risk management deployment and how well employees understand the risk management processes (Cravens, Oliver & Ramamoorti 2003).

Moreover, evaluating the internal environment can be used to identify subjects relating to ethics and values within the enterprise which need improvement.

2.2.1 Factors Affecting the Internal Environment

Several factors have been shown to be vital in the implementation of ERM (Beasley, Clune & Hermanson 2005). Collectively, these results demonstrate that it is the attitude within senior management which ultimately determines the extent of ERM implementation and level of commitment to risk management.

2.2.1.1 Risk Appetite

The risk appetite refers to the level of risk the enterprise is willing to accept in order to achieve its objectives (PricewaterhouseCoopers 2008). The risk appetite can be seen as a reflection of risk management philosophy. Sometimes an enterprise may be willing to take unethical risks to achieve objectives such as acts of dishonestly, placing employees in unsafe conditions without consideration of the risks involved and falsifying reports (Steinberg et al. 2004). In order to avoid such instances of unethical behaviour, good corporate culture should be established that removes or at least reduces the willingness to engage in these types of behaviour (See section 2.2.1.2).

2.2.1.2 Integrity and Ethical Values

Ethical beliefs and norms can vary widely across an enterprise. It is the duty of management to ensure that good standards for ethical behaviour are in place, that employees understand them and that these standards are enforced within the enterprise (ISO 31000:2009, Risk Management—Principles and Guidelines 2009).

In this regard, formal codes of conduct are encouraged as they provide a foundation upon which good corporate culture and ethical values can be built. Employees should receive such documentation and understand it. Formal codes of conduct provide benchmarks against which values such as integrity, honesty and professional conduct can be measured (Cravens & Oliver 2006).

In the same vein, management should demonstrate its commitment to good corporate culture by always striving to act ethically and with integrity as employees are likely to embody these same values (PriceWaterhouseCoopers 2011).

The way in which management is perceived by the employees of an enterprise is an indication of the corporate culture. Analysing this perception and reporting any issues that arise is a useful technique to gain an understanding of corporate culture.

Since risk management relies on honesty and integrity, withholding or providing false information reduces the effectiveness of the process. Thus, the effectiveness of ERM cannot be fully realised if integrity and honesty is lacking among people who create, delegate and monitor the day-to-day operations within an enterprise (Steinberg et al. 2004).

2.2.1.3 Commitment to Competence

Competence is a representation of the knowledge and skills needed to complete allocated tasks. A trade-off will exist between competence levels and cost. Management will, as a result, decide how well the task needs to be done versus the cost (Steinberg et al. 2004).

2.2.1.4 Assignment of Authority and Responsibility

Accountability in ERM refers to ownership and control of risks. The accountability for risk controls should be with management and other designated employees given the authority to address risk (PriceWaterhouseCoopers 2011).

Risk owners should be adequately skilled so as to handle their responsibility. The risk owners should also be provided with the necessary resources to control, monitor and report on risks to all stakeholders (Steinberg et al. 2004).

2.2.2 ISO 31 000 Principles for Effective Risk Management

The eleven principles of risk management as described by ISO 31 000, provide a basis for developing the questionnaire relating to the level of understanding and implementation of risk management in the company (ISO 31000:2009, Risk Management—Principles and Guidelines 2009). This questionnaire can be seen in Appendix A

1. Risk management creates and protects value.

A challenge that every risk manager faces is to show that risk management adds value to the enterprise. Inclusion of this principle ensures that there is a formal requirement for the risk management to create value. The benefits of risk management include increasing the likelihood of achieving objectives, minimising losses, and making an environment a better place to work in.

2. Risk Management is viewed as part of the enterprise management processes.

This principle implies that risk management processes should be part of the main activities and procedures of the enterprise.

3. All decision making within the enterprise involves the consideration of risks and subsequent application of risk management to the appropriate degree.

Risk is a pervasive part of any decision (Al-Bahar & Krandall 1990). By implementing risk management as part of every major strategic and operational decision, the enterprise ensures that the risks involved are wholly understood.

4. Risk management explicitly addresses uncertainty

Identifying and analysing a wide range of risks allows management to better implement controls so as to reduce the likelihood and/or impact of the risk, thereby creating an enterprise that is more resilient to risks.

5. Risk Management should be systematic, structured and timely

Planning and control of risk management processes is required to achieve consistent and reliable results. Structured, systematic risk management that is scheduled regularly ensures this process is made simpler.

6. Risk management is based on the best information available.

Information is often limited and imperfect. However, good risk management practice should include information from all possible sources including, but not limited to, observation, experience, expert opinion and historical data.

7. Risk management is personalised to the needs of the enterprise.

Every enterprise is unique. While enterprises may face risks that are similar, risk management processes should be adapted according the enterprise objectives, risk appetite, stakeholder requirements and internal environment.

8. Risk management should take human and cultural factors into account

Management should take into account the cultural attributes of its employees, more specifically, their skills and capabilities. The internal environment determines the cultural factors that must be accounted for.

9. Risk management should be transparent

This principle recognises the need for the risk management processes and the results thereof to be accessible to all internal and external stakeholders. Stakeholders should be included in the process at all times.

10. Risk management should be dynamic and responsive to change

When new information becomes available or the internal/external environment changes, the risk management plan needs to change and adapt accordingly.

11. Risk management facilitates continual improvement

This principle builds on the fact that risk management should be responsive to change. It encourages management to continuously improve the enterprise through the application of risk management.

2.2.3 Key Attributes used to Describe the Internal Environment

The level of risk management understanding, risk appetite, authority, competence and integrity within an enterprise affect the risk management process and thus should be analysed. The state of the following key attributes should be established in order to evaluate the internal environment (Steinberg et al. 2004):

- Leadership and Strategy
- People and Communication
- Accountability and Reinforcement
- Risk Management and Infrastructure

Appendix A provides the questionnaire that was used in this study to establish the attributes of the internal environment within an enterprise.

CHAPTER 3 RISK IDENTIFICATION

3.1 Introduction

The previous chapter introduced the state of the internal environment as a factor in the risk management process. The current chapter will describe the nature of risk identification and its importance in the risk management process as well as present various techniques for identifying risk.

3.2 The Importance and Nature of Risk Identification

It is universally recognised that risk identification and assessment are the most vital steps in the risk management process (Chapman & Ward 2003). In this study, the risk identification process will include the identification and classification of risks. The identification of risks should be as thorough as possible since risks that are not identified will not undergo scrutiny in the assessment stage (Al-Bahar & Krandall 1990).

Since the identification of risk is predominantly subjective and wholly qualitative, the methods through which risks are identified are central to the success of the whole process. However, before selecting an identification technique, it is crucial to understand the available techniques.

Risk identification is often done through working group techniques and interviews. Working group techniques include the Delphi method, brainstorming and nominal group techniques.

3.2.1 Working Group Techniques

Working groups are collective groups of individuals who are familiar with the topic that is to be discussed. When the topic is risk management, the working group should consist of risk management experts within the enterprise. The purpose of the working group in risk identification is to produce a comprehensive list of risks.

Three working group techniques are presented in this study:

- Brainstorming
- Nominal Group Technique
- Delphi Method

While brainstorming is the most frequently used working group technique, several other working group techniques are available.

3.2.1.1 Identification Methods for Working Group Techniques

(i) Delphi Technique

The Delphi technique is a method for systematic collection of data from isolated and anonymous respondents using a questionnaire. The core of the Delphi technique is the elimination of direct social contact when answering the questions (Chapman 1998).

Supplementary information may be provided to participants to assist in answering the questions. In terms of risk identification, the participants can be supplied with a process diagram or a trigger list to help in the risk identification process (See Appendix C).

(ii) Brainstorming Technique

Creativity in risk identification is of utmost importance as it yields a wide range of risks and critical thinking. In order to promote creativity in brainstorming sessions, the following four rules must be strictly adhered (Chapman 1998):

- Criticism is not allowed during the idea formulation process. Evaluation of ideas that emerge from brainstorming is done at a later stage.
- Participants are encouraged to think creatively.
- The greater the number of ideas presented, the better the process becomes.
- Combination and improvement is encouraged where participants build on each other's ideas.

The participant would typically be supplied with process analysis tools and/ or trigger list as supplementary material (See Appendix C for examples).

(iii)Nominal Group Technique

The Nominal Group Technique starts with the participants writing down their ideas on paper. After a predetermined length of time, a participant is allowed to share one idea with the group. The idea presented by the participant is then recorded on a chart in full view of all members. Once the recording is done, a different participant presents an idea. This process is repeated until each participant has presented all their ideas (Chapman 1998). The method is called round-robin listing.

Once all the ideas have been listed, each idea is discussed and the most relevant ideas are identified. The Nominal Group Technique procedure is listed below:

- Silent listing of ideas
- Round-robin listing of ideas
- Discussion of each idea
- Individual voting on the priority of risk

3.2.2 Interview Techniques

Expert interviews are the acquisition of judgements regarding a particular field of study through one-on-one discussions with subject matter experts. Experience and adequate interviewing skills are required to elicit the required data.

An interview can take between 45-75 minutes (Keizer & Vos 2003). Thus, it may not be feasible to conduct individual interviews when the number of participants in the study is large but instead a combination of working group techniques and individual interviews can be used. Other typical problems associated with expert interviews are identifying the wrong participant, obtaining irrelevant data, unwillingness of the expert to co-operate and personal biases (Keizer & Halman 2009).

The factors affecting expert interviews and the procedure to conduct an effective interview will be discussed in this section. The underlying assumption in the discussion is that correct participants have been chosen and that they are willing to co-operate.

3.2.2.1 Prior to Interview

Prior to the interviews, the participants in the risk management study are asked to perform the following tasks:

- An initial kick-off meeting to inform participants that the objective of the interview process is to develop comprehensive list of risks (Keizer, Halman & Song 2002).
- The participants should be asked to prepare themselves by thinking about the processes that involve risk.

3.2.2.2 Biases affecting the Interview Process

Since it was assumed that the correct experts have been chosen, and that they are co-operative, this study has been limited to discussing personal bias within an expert interview. Apart from selecting the most appropriate participants for the interviews, two sources of bias can be observed in an interview process, these are motivational and cognitive bias (Spetzler & Holstein 1975).

(i) Motivational Bias

Motivational biases are cognisant or incognisant modifications of the participant's opinion for personal gain. For example, the participant may want to highlight a specific risk by providing non-representative information about the risk.

The participant may also want to bias their response because he/she believes their performance within the enterprise will be evaluated based on the outcome of the interview.

The participant may also deliberately refrain from considering the risks because they consider the events improbable.

(ii) Cognitive Bias

Cognitive biases are is the modification of the participant's opinion based on the manner in which the participant mentally processes information. For example, a participant may be biased towards providing information simply because that information is the first thing that comes to mind. Five types of cognitive bias exist (Spetzler & Holstein 1975):

- Availability
- Adjustment and Anchoring
- Representativeness
- Unstated Assumptions
- Coherence

3.2.2.3 The Interview Process

According to Keizer & Vos, all interviews should follow a standard procedure (Keizer & Vos 2003):

- A short introduction of the interviewer and interviewee. The interviewer then clarifies any uncertainty regarding the objective of the interview. Possible motivational biases are explored. (See Appendix E)
- Structuring - the structure of the interview process is communicated to the subject.
- Opening questions - the interviewee is asked to provide clarification of their position within the enterprise and tasks that they are responsible for. Cognitive biases are explored. (Appendix E)
- The participant is then asked to identify possible sources of risk based on a systematic description of all their task responsibilities
- Verification of results

3.2.3 Classification of Risks

After the risks have been identified using a particular method, they are classified. Risk classification provides insight into how the risk affects the enterprise. Several sources provide comprehensive categories under which a myriad of risks can be classified (Dorofee et al. 1996; Mustafa & Al-Bahar 1991; Beasley, Clune & Hermanson 2005). Figure 3-1 shows the classification structure that was used in this study.

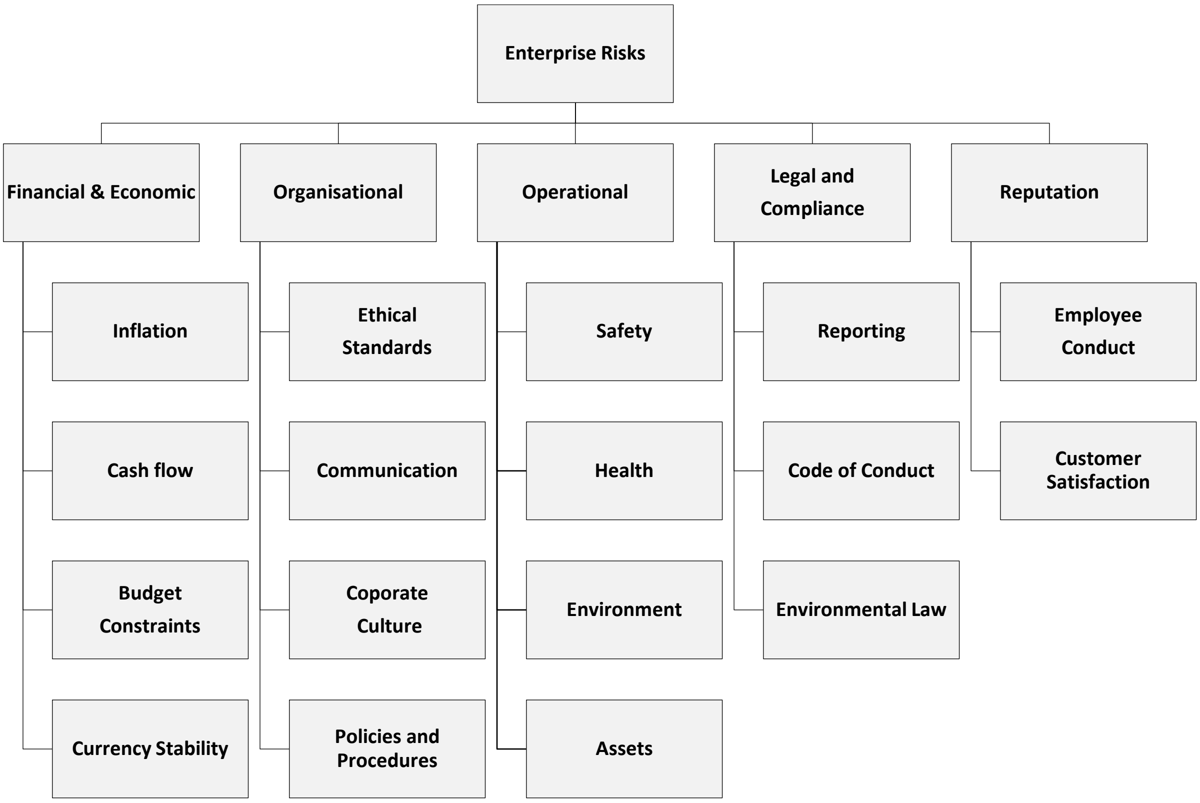

Figure 3-1: Risk Classification Scheme adapted from (Mustafa & Al-Bahar 1991)

CHAPTER 4 RISK ASSESSMENT

4.1 Introduction

Chapter 3 presented the procedure to identify risks. These risks are then assessed according to the methodology in the current chapter. Risk assessment methods presented here will include both qualitative and quantitative methods.

The proposed assessment framework includes risk prioritisation, risk criticality designation and impact and likelihood estimation.

4.1.1 Prioritisation of Risks

Multi Criteria decision analysis (MCDA) offers a method to structure and analyse complex decision making problems (Azari et al. 2011). The MCDA problem can consist of multiple criteria to achieve a goal and many alternatives which satisfy criteria (See Figure 4-1). MDCA will be used in this study to obtain a ranked list of risks.

4.1.1.1 Prioritisation of Risks using the Analytical Hierarchy Process

Non-critical risks that have clear, easily implemented solutions should be assessed quickly (Dorofee et al. 1996). Prioritisation of risks enables the enterprise to focus on the more important risks first and reduce over-management of insignificant risks.

The Analytical Hierarchy Process (AHP) is an effective MCDA tool for handling complex decisions. The AHP is presented in this section as tool to create a ranked list of risks (Saaty 1987).

4.1.1.2 The Analytical Hierarchy Process

(i) Step 1: Structure the Decision Making Problem as a Hierarchy.

The hierarchy starts with the goal at the top level. Following this the criteria are listed. In the third tier, the alternatives are listed. Figure 4-1 illustrates a 3-tier Analytical hierarchy process. While more tiers and sub-criteria can be added to the hierarchy, the method that will be used for risk analysis in this study will only require 3 levels.

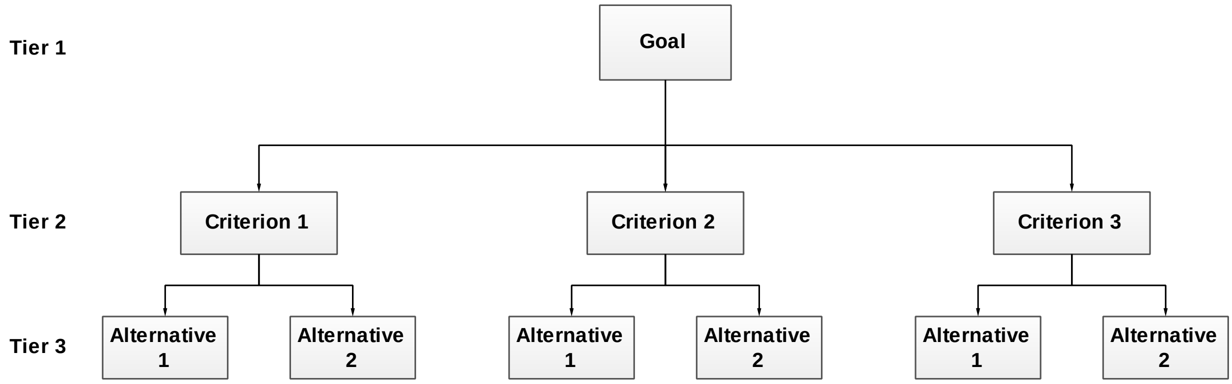

Figure 4-1: A 3-Tier AHP Hierarchy Structure

(ii) Step 2: Preference Encoding

Preference encoding is the elicitation of preference ratings for one alternative or criteria over another. In this study, the preference encoding was completed by using a questionnaire in which the participants were asked to rate various risks based on impact and likelihood. See Appendix A for the impact and likelihood rating questionnaire.

(iii)Step 3: Pairwise Comparison

Perform pairwise comparisons between each element on a specific tier in the hierarchy based on the preference encoding. At the second tier, the criteria are compared to each other with respect to the goal. At the third tier each alternative is pairwise compared with respect to a specific criterion (Saaty 1990).

In order to compute the priority of the various elements in the hierarchy, a pairwise comparison matrix $\boldsymbol{A}$ is formed. The matrix $\boldsymbol{A}$ is a $n \times n$ real matrix, where n represents the number of alternatives to be evaluated.

Each entry $\boldsymbol{a_{ij}}$ of the matrix $\boldsymbol{A}$ represents what the relative importance of the $\boldsymbol{i^{th}}$ element is, versus the $\boldsymbol{j^{th}}$ element. The following rules apply when comparing elements:

- If the entry $\boldsymbol{a_{ij}} > \boldsymbol{1}$, then the $\boldsymbol{i^{th}}$ element is more important than the $\boldsymbol{j^{th}}$ element.
- If $\boldsymbol{a_{ij}} < \boldsymbol{1}$ then the $\boldsymbol{i^{th}}$ element is less important than the $\boldsymbol{j^{th}}$ element. If two elements have the same importance, then $\boldsymbol{a_{ij}} = \boldsymbol{1}$.
- Furthermore, for all $\boldsymbol{i} = \boldsymbol{j}$ it necessary that $\boldsymbol{a_{ij}} = \boldsymbol{1}$.
- and $\boldsymbol{a_{ji}} = {}^{\boldsymbol{1}}/_{\boldsymbol{a_{ij}}}$

The relative importance among elements is measured according to a numerical scale (see Table 4-1). In this scale, it is assumed that the $\boldsymbol{i^{th}}$ element is equally or more important than the $\boldsymbol{j^{th}}$ element (Saaty 1990).

Table 4-1: Description of Pairwise Comparison Scoring Scheme

Weight Value (a_{ij})	Definition	Explanation
1	Equal Importance	Two risk have same impact
3	Slight Importance	One risk is slightly more important than another
5	More important	One risk is more important than another
7	Strong importance	Experience and judgement strongly favour one risk over another
9	Absolutely important	Highest possible order of importance of one risk over another
2, 4, 6, 8	Intermediate values	Represents compromise between the priorities listed above
Reciprocals of above	If activity i has one of the above weights assigned when compared to j, then element j has the reciprocal when compared to element i	

Finally, the pairwise comparison matrix $\boldsymbol{A}$ for n elements is formed:

$$A = \begin{Bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{Bmatrix}$$

(iv) Step 4: Normalisation

The matrix $\boldsymbol{A}$ is then normalised. This is done first by summing the entries in each column. Each entry $\boldsymbol{a_{ij}}$ is then divided by the sum of column $\boldsymbol{j}$. This results in a new matrix called $\boldsymbol{A_{norm}}$, the normalised matrix of pairwise comparisons:

$$A_{norm} = \begin{pmatrix} \frac{a_{11}}{\sum_{k=1}^{n} a_{k1}} & \cdots & \frac{a_{1j}}{\sum_{k=1}^{n} a_{kj}} \\ \vdots & \ddots & \vdots \\ \frac{a_{i1}}{\sum_{k=1}^{n} a_{k1}} & \cdots & \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \end{pmatrix}$$

Where

$$\sum_{k=1}^{n} a_{kj} = sum\ of\ j^{th} column\ \ for\ all\ j = 1,2,3 \ldots n$$

$$\bar{a}_{ij} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} = normalized\ pairwise\ comparision\ for\ j = 1,2,3..n$$

(v) Step 5: Priority Weight Vector

The priority vector (eigenvector) is a column vector, $\boldsymbol{B}$ in which the entries $\boldsymbol{b_i}$ represent the relative importance of elements that were evaluated. The largest entry in the eigenvector $\boldsymbol{B}$ is the most important element and the smallest is the least important. The entries $\boldsymbol{b_i}$ of vector $\boldsymbol{B}$ are developed by taking the average of each row in $\boldsymbol{A_{norm}}$ according to:

$$b_i = \frac{\sum_{j=1}^{n} \bar{a}_{ij}}{n} \; for\ all\ i = 1,2,3 \ldots n$$

Where:

$$\bar{a}_{ij} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}$$

$n = number\ of\ elements\ to\ be\ evaluated$

Then the Matrix $\boldsymbol{B}$ becomes:

$$B = \left\{ \begin{matrix} \dfrac{\frac{a_{11}}{\sum_{k=1}^{n} a_{k1}} + \frac{a_{12}}{\sum_{k=1}^{n} a_{k2}} + .. + \frac{a_{1j}}{\sum_{k=1}^{n} a_{kj}}}{n} \\ \vdots \\ \dfrac{\frac{a_{i1}}{\sum_{k=1}^{n} a_{k1}} + \frac{a_{i1}}{\sum_{k=1}^{n} a_{k2}} + .. + \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}}{n} \end{matrix} \right\} = \left\{ \begin{matrix} b_1 \\ \vdots \\ b_n \end{matrix} \right\}$$

Steps 1 to 4 are completed for criteria with respect to the goal and for alternatives with respect to each criterion, thus several priority vectors will exist. The next step in the AHP is to check for consistency of the priority vectors.

(vi) Step 6: Checking for Consistency

When the number of comparisons to be made is numerous, inconsistencies may arise (Lamata & Pelaez 2002). Inconsistencies arise when an incorrect comparison is made. Saaty's eigenvector method will be used to evaluate the consistency of the priority vectors (Saaty & Vargas 1984).

The Eigen vector method is a two part process.

(a) Part 1: The Consistency Index

The consistency index, *CI* is a measure of the degree of consistency among the pairwise comparisons. The procedure to calculate CI is shown below:

$$\boldsymbol{CI} = \frac{\lambda_{max} - n}{n - 1}$$

In this equation n is the number of comparisons to be made and $\boldsymbol{\lambda_{max}}$ is a Eigen value scalar. The closer $\boldsymbol{\lambda_{max}}$ is to n, the more consistent is the result.

The maximum Eigen value ($\boldsymbol{\lambda_{max}}$) is calculated using the row average technique (Alexander 2012) as follows:

First, the original non-normalised comparison matrix $\boldsymbol{A}$ is multiplied by its respective priority vector $\boldsymbol{B}$ to yield a new matrix $\boldsymbol{C}$:

$$\boldsymbol{C} = \boldsymbol{A} \cdot \boldsymbol{B}$$

$$C = \begin{Bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{Bmatrix} \cdot \begin{Bmatrix} b_1 \\ \vdots \\ b_n \end{Bmatrix} = \begin{Bmatrix} c_1 \\ \vdots \\ c_n \end{Bmatrix}$$

Next each entry $\boldsymbol{c_i}$ in matrix $\boldsymbol{C}$ is divided by the corresponding entry $\boldsymbol{b_i}$ in matrix $\boldsymbol{B}$

$$\begin{Bmatrix} c_i \\ \vdots \\ c_n \end{Bmatrix} \; element\ by\ element\ division \begin{Bmatrix} b_i \\ \vdots \\ b_n \end{Bmatrix}$$

$$X = \begin{Bmatrix} c_i/b_i \\ \vdots \\ c_n/b_n \end{Bmatrix}$$

This will yield a final matrix $\boldsymbol{X}$. The average of the entries, $\boldsymbol{x_i}$ in the matrix $\boldsymbol{X}$ is the maximum Eigen value.

$$\lambda_{max} = \frac{x_1 + x_2 + \cdots + x_n}{n}$$

Ideally, $\boldsymbol{\lambda_{max}} = \boldsymbol{n}$. However, perfect consistency is difficult to achieve when the number of comparisons is large.

(b) Part 2: Consistency Ratio (CR)

The consistency ratio is a measure of the total inconsistency in the judgements. A large consistency ratio indicates that the comparisons are inconsistent. As the consistency ratio decreases, the comparisons become more consistent (Saaty 1987). The consistency ratio is calculated as follows:

$$CR = \frac{CI}{RI}$$

where *CI* is the consistency index calculated in Part 1 and *RI* is the random index. *RI* is the average CI value of randomly generated comparison matrices. The values for *RI* are shown in Table 4-2 (Saaty 1987).

Table 4-2: Random Index values for *n* comparisons

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

A consistency ratio below 10% indicates that the priority vector ***B*** is a reliable indication of the order of importance of elements (Saaty & Vargas 1984) .

Thus for,

$$\frac{CI}{RI} < 10\%$$

the inconsistency in the pairwise comparisons is small enough to ensure that judgements are reliable. If the consistency ratio exceeds 10%, it may be necessary to revise the pairwise comparisons and ascertain the source of inconsistency.

(c) Part 3: Improving the Consistency Ratio

If a comparison matrix ***A*** is consistent, then $CR < 10\%$. However, in practice, the matrix ***A*** is rarely consistent (Zeshui & Cuiping 1999). Thus, for $CR > 10\%$, the inconsistency is unacceptable.

A practical method for revising judgements is as follows:

First, calculate the absolute value difference:

$$|a_{ij} - b_i/b_j|$$

Where

$a_{ij} = entries\ in\ comparison\ matrix\ A$

$b_i, b_j = priority\ weights\ for\ i^{th}\ and\ j^{th}\ component\ respectively$

The comparisons which have the largest absolute difference are then revised. Once the consistency for all priority vectors has been established, the global priority is determined.

(vii) Step 7: Calculate Global Priority

When step 6 has been completed, the decision-maker should have the following priority vectors:

- A priority vector which describes the order of importance among the criteria.
- Several priority vectors which describe the order of importance of alternatives with respect to a specific criterion.

The first step in determining the global priority is the formation of a matrix $\boldsymbol{S}$. Matrix $\boldsymbol{S}$ is the combined priority eigenvectors for alternatives. Each entry $\boldsymbol{s_{ij}}$ in matrix S represents the priority of an alternative $\boldsymbol{i}$ against a particular criterion $\boldsymbol{j}$:

$$S = \begin{Bmatrix} s_{11} & \cdots & s_{1j} \\ \vdots & \ddots & \vdots \\ s_{i1} & \cdots & s_{ij} \end{Bmatrix}$$

Therefore, the first column in $\boldsymbol{S}$ will represent the priority of alternatives with respect to the first criterion and the second column will represent the priority of alternatives with respect to the second criterion and so forth.

Next, matrix multiplication of the criteria priority eigenvector $\boldsymbol{B_{criteria}}$ with the derived alternatives matrix $\boldsymbol{S}$ will yield the final global priority $\boldsymbol{W}$:

$$W = S \cdot B_{criteria}$$

$$W = \begin{Bmatrix} s_{11} & \cdots & s_{1j} \\ \vdots & \ddots & \vdots \\ s_{i1} & \cdots & s_{ij} \end{Bmatrix} \cdot \begin{Bmatrix} b_i \\ \vdots \\ b_n \end{Bmatrix} = \begin{Bmatrix} w_i \\ \vdots \\ w_n \end{Bmatrix}$$

(viii) Step 8: Sensitivity analysis

The final step in the AHP technique is a sensitivity analysis in which the global priority vector $\boldsymbol{W}$ is checked for sensitivity to changes in the criteria priority weight.

The procedure for performing a sensitivity analysis is as follows:

- Alter the entries $\boldsymbol{b_i}$ in Matrix $\boldsymbol{B_{criteria}}$
- Perform step 7 again
- Take note of any significant changes in the final priority matrix $\boldsymbol{W}$

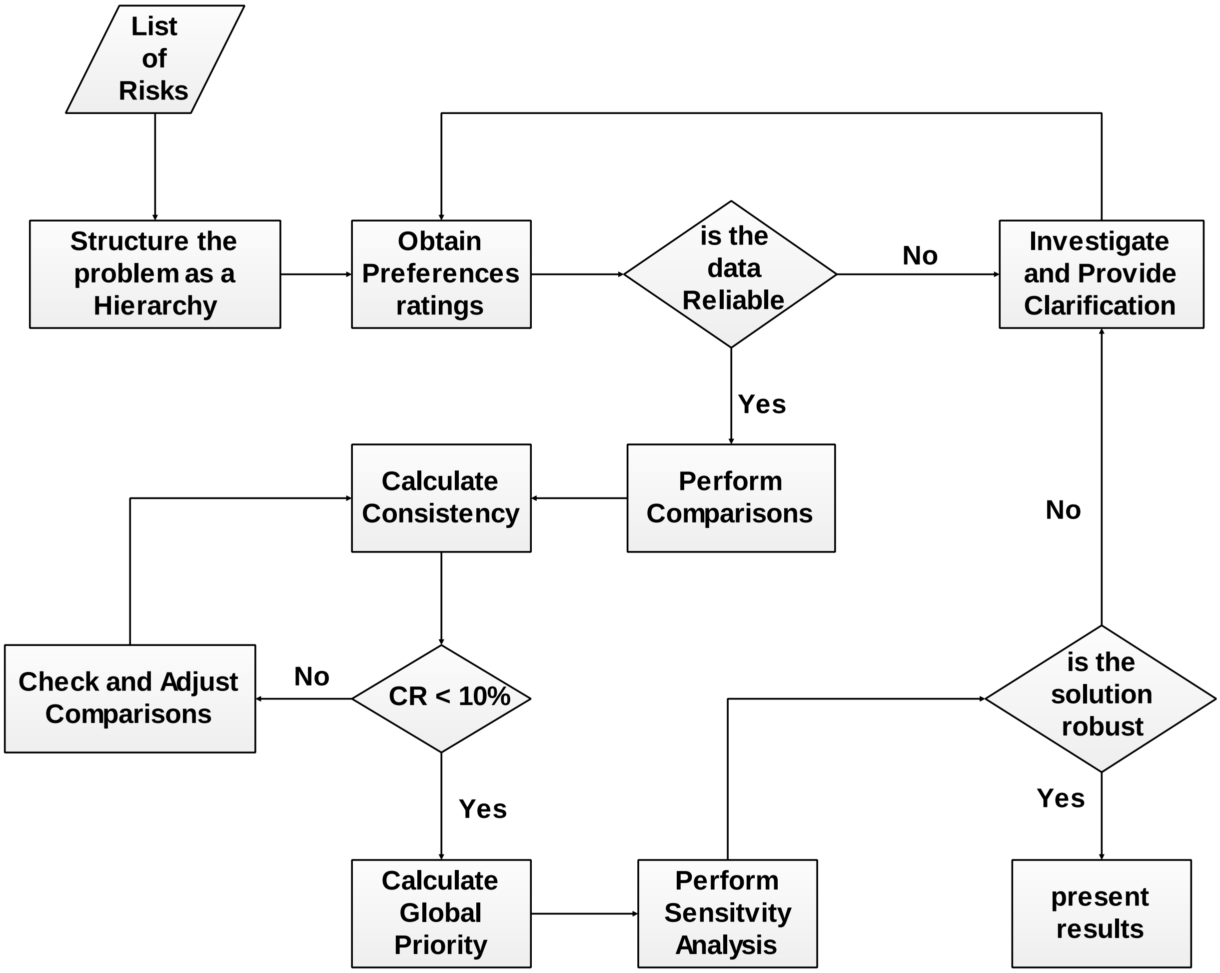

Figure 4-2: Procedure for the prioritisation of risks

4.1.1.3 Analytical Hierarchy Process Assumptions

AHP is based on the following assumptions (Saaty 2008):

- Pairwise comparisons can be made between each of the elements in the hierarchy. Differences in the importance of criteria must be evaluated on ratio scale.
- For each criterion, pairwise comparisons must be made between each of the alternatives. The difference in importance of the alternative is evaluated on a ratio scale.
- The alternatives comparisons and criteria comparisons are performed using common scales.
- The criteria are mutually independent (criteria do not affect one another in terms of the assigned difference)
- The alternatives are mutually independent (alternatives do not affect one another in terms of the assigned difference).

4.1.1.4 Analytical Hierarchy Process Limitations

Like all modelling techniques, AHP has limitations. Firstly, AHP is based on the assumption that all matrices have the same mathematical form. This is known as a positive reciprocal matrix. A positive reciprocal matrix implies that if the decision maker uses the number 9 to describe that element ***i*** is more important than ***j***, then 1/9 must be used to describe the importance of element ***j*** with respect to ***i***.

Another concern is the lack of interaction between elements. The elements within the AHP matrix are mutually independent. This implies that the assigned values in the comparison matrix do not influence one another.

The third concern is the grouping of individual preferences. Two situations can arise, the first of which is a situation where the preference of every participant is weighted equally and thus each opinion in the AHP equally affects the final risk ranking. The second situation is when the preference of each participant has a different weighting. In this case, certain individual preferences will have a larger effect on the final risk ranking. The data will be gathered anonymously from the company (See section 6.2), thus grouping of individual opinions cannot be performed in this study.

The fourth concern is the time it takes to perform the AHP. Dorofee et al. give the following table when evaluating risks against one criterion:

Table 4-3: Time Required for AHP comparisons redrawn from (Dorofee et al. 1996)

Number of risks	Comparisons Required (1 criterion)	Average Time(min)	Comparisons (3 Criteria)	Time(min)
5	10	15	30	25
10	45	30	135	120
15	105	60	315	180+

When the number of criteria increases, the number of comparisons may increase significantly. The number of risks to be ranked should be kept to a maximum of 20 for one criterion or a maximum of 200 comparisons when dealing with multiple criteria (Dorofee et al. 1996).

4.1.2 Identifying Critical Risks using the Risk Diagnosing Methodology

In the previous section, the procedure for the prioritisation of risks using AHP risks was discussed. However, prioritisation only lists the risks in order of importance. A technique is required to determine at which point risks can be diagnosed as critical or non-critical.

Once the criticality of risks is known, qualitative risk assessment can be performed on non-critical risks and quantitative assessment on more critical risks. In this study, the Risk Diagnosing Methodology (RDM) will be used to identify critical risks.

The ability to diagnose the criticality of risks is crucial in high-risk, time constrained situations (Keizer, Halman & Song 2002). The RDM was developed to identify and diagnose business risk within the product innovation sphere. In this study, the RDM methodology was adapted for use within the ERM field. RDM consists of nine steps which are divided into three distinct sections as shown here, in Figure 4-3:

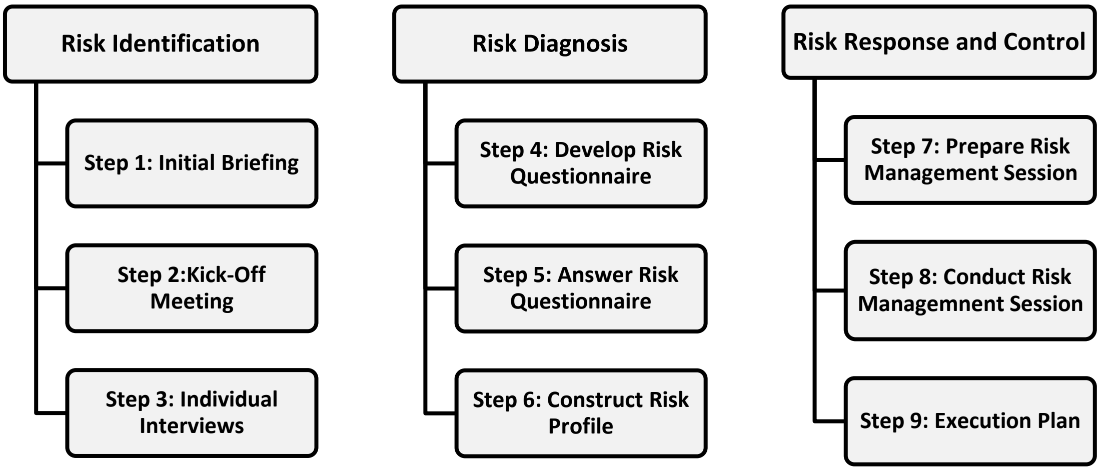

Figure 4-3: Risk Diagnosing Methodology adapted from (Keizer, Halman & Song 2002)

In this study, RDM will only be used to determine the risk criticality. For this reason, only the Risk Diagnosis section of this methodology is developed further.

4.1.2.1 The Truncated Risk Diagnosing Methodology

Starting with step 4 in Figure 4-3, the RDM can be completed as follows:

(i) Step 4: Developing the Risk Questionnaire

RDM in its current form was formulated for new product development. In order to adapt the process for enterprise risk management, changes to step 4 were made. The risks examined in this study will typically be risks that have previously occurred. In new product development, the risks are unknown.

When unknown risks are being identified and subsequently diagnosed, the plausibility of the risk statement is evaluated. This type of evaluation is not required for the risks in this study. Instead of evaluating the plausibility, the participants were asked to rate the likelihood of occurrence. The rest of concepts in the RDM are applicable to the risks evaluated in this study.

(ii) Step 5: Answering the Risk Questionnaire

The questions used to diagnose risks are:

- How often does the risks occur?
- Assuming the risks occur, to what extent is the enterprise able to mitigate the risk?
- How severely does the risk affect the ability of the enterprise to complete objectives?

The participants provide a score for each of the questions with respect to each risk. The details of the scoring system are shown in Table 4-4.

Table 4-4: Description of weight scoring scheme for RDM questions (Keizer, Halman & Song 2002)

Weight	How often does the risk occur?	The enterprise's ability to Influence	Impact on objectives
1	Rare	Abundance of mitigation options, easily implemented at low cost	minimal, almost nothing
2	Unlikely	Mitigation measures exist, easily implemented	Impact noted, but not concerning
3	Possible	Mitigation measures exist, feasible implementation possible.	Objectives can still be achieved with risk controls
4	Likely	Some options exist, difficult or unfeasible to implement	Significant impact, intervention required
5	Almost Certain	Little or nothing can be done	Severe impact, failure of objectives

Once the rating system is understood by all participants, the questionnaire can be completed. The RDM questionnaire can be seen in Figure A-1. The scores are then used to build a profile of the risks. Using the risk profile, the critical risks can be identified (Keizer, Halman & Song 2002).

(iii)Step 6: Constructing the Risk Profile

Determining the risk criticality is a two part process, and can be obtained by following these procedures (Keizer, Halman & Song 2002):

(a) Part 1: Assigning the Question Classes

The cumulative percentage of responses to each question is calculated. For a particular risk, each question is classified into one of four groups based on the cumulative percentages. The rules for classification are as follows:

- (“*”) at least 50% of the scores are at 4 or 5 and there are no scores of 1
- (“0”) at least 50% of the scores are at 1 or 2 and there are no scores of 5
- (“m”) at least 50% of the scores are at 3 and there are no scores of 1 or 5
- (“?”) For all remaining cases, a lack of consensus exists (wide distribution of opinions). Here, a discussion may be used to provide more clarity of the risk and the scores of certain individuals may be changed.

The point at which the responses reach a cumulative percentage of 50% is of importance because it gives an indication of how the majority of participants perceive the risk. The criterion of majority perception can be chosen differently depending on the needs of the enterprise (Keizer, Halman & Song 2002) but for purpose of this study, the criterion will be chosen as 50%.

The distribution of opinions is also important. If opinions vary widely with regards to a certain risk, further investigation may be required to determine the cause of the distribution.

(b) Part 2: Designation of the Risk Category

Designation of the risk category is based on the question classes for each risk. For example, a risk statement where each question is marked with "*" leading to the combination "* * *" would be a fatal risk (designated by ***F***), whereas risks with the "0 0 0" combination would indicate a safe risk (designated by ***S***). Five base categories exist, these are:

- ***S*** = safe: little or no corrective action is required
- ***L*** = low: corrective action can be performed depending on the risk appetite of the enterprise. If action is taken, assessment can be limited to qualitative techniques.
- ***M*** = medium: corrective action is required but the management can decide whether qualitative is sufficient or quantitative assessment is preferential.
- ***H*** = High: Corrective action is required and rigorous quantitative techniques are needed to fully understand the threat level and response strategy.
- ***F*** = Fatal: Corrective action is required and rigorous quantitative techniques are needed to fully understand the threat level and response strategy. If fatal risks occur, the objectives of the enterprise will be severely impacted or may fail completely.

When a lack of consensus exists, the risk category can be represented by a range such as low to medium (L–M) or medium to high (M–H) (Keizer & Halman 2009).

According to Keizer, Halman & Song, there are 64 possible combinations of risk scores. See Table 4-5 for a list of all possible combinations. (Keizer, Halman & Song 2002)

Table 4-5: RDM Risk Classes redrawn from (Keizer, Halman & Song 2002)

Score:		
*	=	At least 50% of the scores are at 4 or 5 and there are no scores of 1
0	=	at least 50% of the scores are at 1 or 2 and there are no scores of 5
M	=	at least 50% of the scores are at 3 and there are no scores of 1 or 5
?	=	For all the remaining cases (wide distribution in opinions or significantly deviating opinions).

SCORE: How often does the risk occur?	SCORE: Ability to reduce number of occurrences	SCORE: Relative Importance to objectives	RISK CATEGORY	SCORE: How often does the risk occur?	SCORE: Ability to reduce number of occurrences	SCORE: Relative Importance to objectives	RISK CATEGORY
*	*	*	F	*	*	?	M-F
*	*	0	L	*	?	*	H-F
*	0	*	M	?	*	*	M-F
0	*	*	H	*	?	?	L-F
0	0	*	L	?	*	?	L-F
0	*	0	L	?	?	*	L-F
*	0	0	L	?	?	?	S-F
0	0	0	S	?	0	0	L
*	*	m	H	0	?	0	L
*	m	*	H	0	0	?	L
m	*	*	H	?	?	0	S-M
*	m	m	M	?	0	?	S-H
m	*	m	M	0	?	?	S-M
m	m	*	M	*	?	0	L-M
m	m	m	M	*	0	?	L-H
0	*	m	M	0	*	?	L-M
*	0	m	M	0	?	*	L-M
0	m	*	M	?	0	*	L-H
*	m	0	M	?	*	0	L-M
m	*	0	M	*	?	m	M-H
m	0	*	M	*	m	?	M-H
0	0	m	L	m	?	*	M-H
0	m	0	L	m	*	?	M-H
m	0	0	L	?	m	*	M-H
0	m	m	M	?	*	m	M-H
m	m	0	M	m	?	0	L-M
m	0	m	M	m	0	?	L-M
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				0	m	?	L-M
				?	0	m	L-M
				?	m	0	L-M
				?	m	m	L-M
				m	?	m	M
				m	m	?	M
				?	?	m	L-H
				?	m	?	L-H
				m	?	?	L-H

Description of risk classification:

F	=	Fatal risk;
H	=	High risk;
M	=	Medium risk;
L	=	Low risk;
S	=	Safe, no risk.

A combination of classes indicates lack of consensus. Narrow distributions may be tolerable. Wide distributions should be discussed further to resolve disagreement. If consensus cannot be achieved, assume the worst case.

The completed risk profile is shown in Table B-5 and Table B-6. Each question is given a classification based on the rules for classifying risk statements. The class of each question is then combined to indicate the risk category.

The criticality of the risk is determined by the designated risk category. Critical risks are then further addressed in the risk management process with the use of quantitative methods (PricewaterhouseCoopers 2008).

Any risks that are categorised higher than medium ($\boldsymbol{M}$) should be considered as critical. Distributions, such as $\boldsymbol{M-H}$, where the upper limit is greater than $\boldsymbol{M}$ should also be considered as critical.

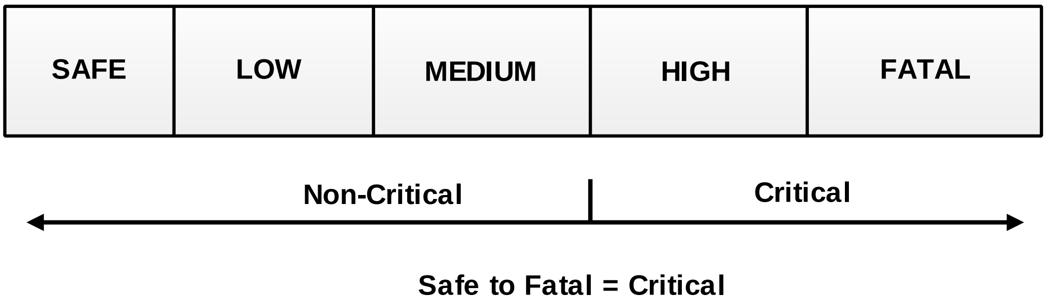

Figure 4-4: Limits of Criticality

4.1.2.2 Additional Functions of the Risk Diagnosing Methodology

The RDM also provides a measure of the level of risk for the enterprise as a whole. This measure is estimated by first assigning weights to each risk category. The weighting assignment of risk categories will follow the method in Halman & Keizer. According to this method, the following assumptions are made (Halman & Keizer 1994):

- The risk categories represent discrete positions on a linear risk dimension within the ranges of safe to fatal
- The discrete positions on the linear risk dimension are equidistant from one another
- The risk category $\boldsymbol{S}$ is assumed to have a weighting of 0

Applying the assumptions, the following weights are assigned to each risk category.

$$S = 0$$

$$L = 1$$

$$M = 2$$

$$H = 3$$

$$F = 4$$

Once this has been completed, the total enterprise risk can be measured on a scale of 0 – 100. First, the risk categories are summed to determine the total number of safe risks, medium risks, high risks etc. Then the number of each type of risk is then multiplied by the respective risk category weighting. The total level of risk is obtained using the following formula:

$$RISK_{TOT} = N_F \cdot F + N_H \cdot H + N_M \cdot M + N_L \cdot L + N_S \cdot S$$

The maximum total risk level ($RISK_{TOT}$) is attained when all the risks are category $\boldsymbol{F}$ risks. The minimum total risk level occurs when all the risks are category $\boldsymbol{S}$ risks. The current level of risk which an enterprise operates within can be determined as:

$$\%\ RISK_{TOT} = \frac{RISK_{TOT}}{MAX\ RISK_{TOT}}$$

The measure of total risk ($\boldsymbol{RISK_{TOT}}$) level is a beneficial technique to give the management an idea of whether the enterprise is operating within the desired risk appetite.

Many of the risks will be categorised as distributions ($\boldsymbol{L - M}$ or $\boldsymbol{H - F}$). For distributions, a pessimistic and optimistic case can be assumed. In the pessimistic case, the risk is assumed to be at the undesired category. For example, $\boldsymbol{L - M}$ would then become $\boldsymbol{M}$. For the optimistic case, the opposite is true.

Figure 4-5 is a graphic representation of the overall level of risk within an enterprise. At the right extreme is the worst case scenario, where all risks are fatal. At the left extreme is the best case scenario, when all risks are safe. The shaded band within the figure represents the distribution of opinions with respect to the total risk level of the enterprise. The width of the band can be a further indication of the dispersion of opinions due to non-consensus.

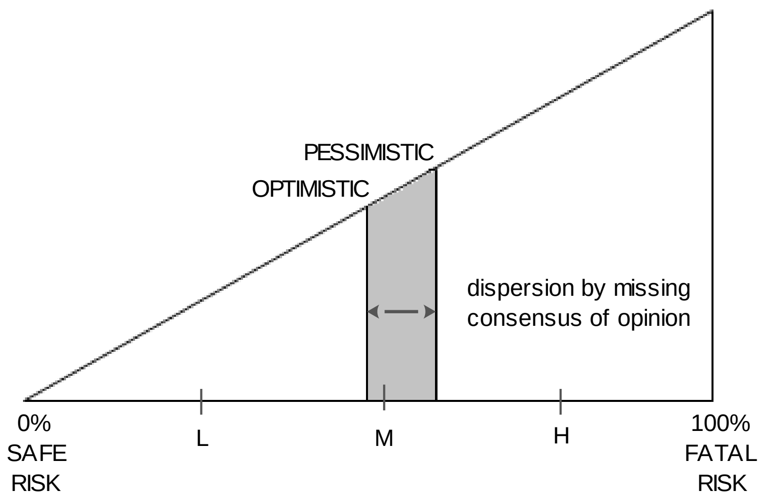

Figure 4-5: Graphical representation of overall enterprise risk redrawn from (Halman & Keizer 1994)

4.1.3 Risk Impact and Likelihood Evaluation

The assessment of any risk typically involves determining the likelihood that the risk will occur and the impact of the risk. The threat level or expected loss of a risk event is calculated using the expected value model (INCOSE 2007). This model states that risk can be calculated as:

$$Threat = Likelihood \times Impact$$

Risk assessment can be performed with varying degree of complexity. Usually, the more complex quantitative techniques are reserved for critical risks, provided that enough information and resources are available. Simpler qualitative techniques are sufficient when the risks are non-critical and well understood, or necessary when lacking data.

4.1.3.1 Qualitative Technique

Qualitative risk assessment is the most basic form of risk assessment. Although the results of qualitative risk management are often subjective, it can be advantageous to use qualitative assessment when the risks are non-critical since this technique is implemented relatively quickly.

4.1.3.2 Qualitative Risk Assessment Process

Qualitative assessment involves evaluating the risk impact and probability on non-empirical weighting scales. The procedure for qualitative assessment of the risk impact and likelihood is shown in this section.

(i) Step: 1 Define the weighting for the Impact and Likelihood

Table 4-6 and Table 4-7 describe the weighting assignment for the likelihood and impact respectively.

Table 4-6: Scoring scheme for Qualitative risk likelihood assessment

Weight	Description	Likelihood of occurrence
1	Rare	Very low
2	Unlikely	Low
3	Possible, 50/50 chance	Medium
4	Highly possible	High
5	Almost Certain	Very high

Table 4-7: Scoring scheme for Qualitative risk impact assessment

Weight	Description	Impact
1	Safe	Insignificant
2	Impact noticeable, not serious	Minor
3	Severe if ignored	Moderate
4	Severe, requires mitigation	Major
5	Crippling for enterprise, avoid if possible	Catastrophic

The following assumptions were made with respect to the impact and probability weighting scales:

- The impact and likelihood weighting are evaluated on common scales.
- Each weighting represents a discrete position on a linear impact or likelihood dimension
- The discrete positions are equidistant
- A rare risk was allocated with a 1. The weighting assignments 2 to 5 were obtained using the equidistant assumption.
- A safe risk was allocated with a 1. The weighting assignments 2 to 5 were obtained using the equidistant assumption.

(ii) Step 2: Setting up the Risk Questionnaire

A questionnaire which contains a list of all the identified risks is drawn up and the participants are asked to rate the risks based on the impact and likelihood.

(iii)Step 3: Completing the Risk Assessment

Each participant provides a score for the risk likelihood and impact according to the scales in Table 4-6 and Table 4-7 respectively. See Appendix A for the risk questionnaire used in this study.

Following this, the results are aggregated to determine the mean impact and probability. The sample standard deviation is then calculated with respect to the assigned weightings

If the standard deviation is greater than 1.5, it implies that a lack of consensus exists. Management may then decide to provide clarification on the risks.

Qualitative analysis is advantageous for the assessment of non-critical risks. Management may have a reasonably good understanding of the risk characteristics. It is also important that non-critical risks, which can be resolved quickly, are not over-managed.

4.1.3.3 Quantitative Techniques

Qualitative assessment of risk is sufficient when the risks are non-critical. However, as the risks become critical, quantitative assessment should be considered. A quantitative assessment provides a more detailed analysis of the risk (Mojtahedi, Mousavi & Makui 2010).

Quantitative risk management is performed on risks that have been categorised as potentially or substantially impacting objectives (Duncan 1996). Using the AHP and the RDM, the enterprise is able to identify the risks that have the potential to severely impact the objectives of the enterprise.

Quantitative analysis of risk usually involves using more complex techniques to assess the impact and probability of the risks. Two categories of quantitative assessment are commonly used. These are:

- Non-probabilistic Models
- Probabilistic Models

A typical non-probabilistic model is sensitivity analysis. In sensitivity analysis, the risk is assumed to have occurred and the impact is calculated. A multitude of risks are simulated and the impact measured. Once the impact of each critical risk is measured, the effect on the objectives is estimated.

Probabilistic modelling involves representing a given data set with a probability density function (PDF). Probability density functions, also called probability models, describe the probability of observing a specific value in a given range (Mojtahedi, Mousavi & Makui 2010). In the absence of sufficient data, a probability density function characterising a given variable can be obtained from expert judgement. Figure 4-6 shows examples of the BETA Probability Density Function.

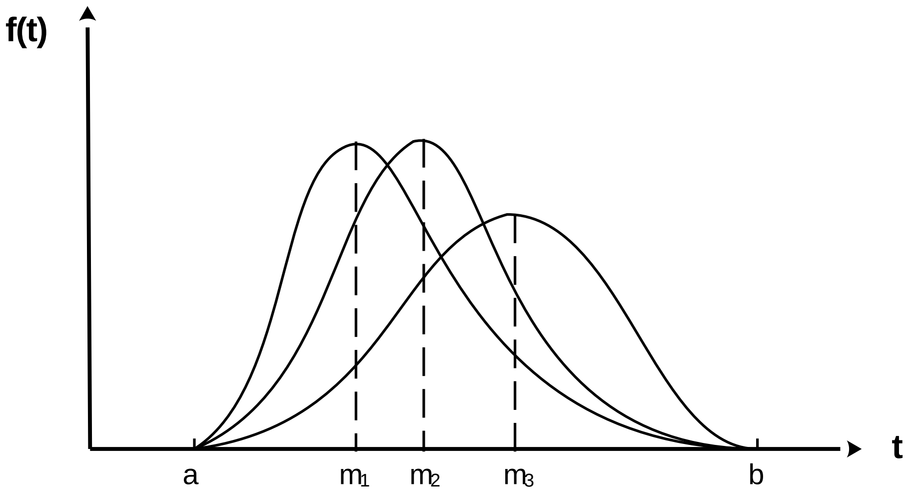

Figure 4-6: Example of Beta Distributions

In this study, the quantitative assessment of risks will be performed using the Monte Carlo Simulation (MCS) probabilistic modelling method. The **MCS** is a modelling technique that can be used to represent the distribution of actual data with a PDF.

MCS can be useful for demonstrating the effect of uncertainty on the estimates of risk factors. Also, MCS analysis may increase the time and effort required to complete an assessment of the risks. However, this information provided by representing a risk distribution surpasses that of point estimation.

The most important function of the MCS is to select the probability density function which represents the data set most appropriately. This process is the most challenging part of MCS. In risk management, the data to be modelled are the risk impact and likelihood. (U.S. Environmental Protection Agency 2001).

4.1.3.4 Estimating Risk Impact using the Monte Carlo Method

Section 4.1.3.4 assumes that sufficient data is present to use probabilistic modelling. Based on this assumption, the MCS method is discussed in the following steps:

(i) Step 1: Determine the impact distribution

A frequency graph is used to visually inspect which probability density function best characterises the data. This method will show the procedure to generate the frequency graph given a set of data:

(a) Part 1: Determine the number of bins

A bin is an interval that is used to partition the data into classes. The number of observations within a particular interval yields the frequency of that class. There are no rules to determine the number of bins. However, a starting point for estimating the number bins required can be calculated as follows:

$$Number\ of\ Bins = 1 + 3.322 \log_{10} n$$

Where $n = number\ of\ observations$

(b) Part 2: Calculate the bin width.

The bin width is the size of the interval. First determine the minimum and maximum of the data set. Then calculate the difference between these values. Next, divide that answer by the number of bin determined in Part 1. Finally, round the number up.

$$Class\ width = Round\left[\frac{Max - Min}{Number\ of\ Bins}\right]$$

When working with hundreds, rounding up to the nearest 10 is advisable, for thousands, round up to the nearest 100.

(c) Part 3: Calculating the lower limit for the intervals

Write down the minimum value of the data set. Next, add the class width to the minimum data value to obtain the lower limit for the next class. Keep adding the class width to each preceding lower limit value until the number of lower limits calculated is equivalent to the number of bins determined in Part 1. For example, assume $\boldsymbol{X}$ bins were calculated in a data set with a maximum of $\boldsymbol{B}$ and a minimum of $\boldsymbol{A}$. The class width would then be $\frac{\boldsymbol{B}-\boldsymbol{A}}{\boldsymbol{X}}$.

The Lower limits for each subsequent class can be calculated as:

$$Lower\ Limit = A + \ Class\ number \cdot \frac{B-A}{X} \qquad for\ Class\ number\ = 1, 2, 3 \ldots . X$$

Table 4-8: Calculation of lower limits for frequency distribution

Class Number	Lower Limit
1	$\boldsymbol{A}$
2	$\boldsymbol{A} + \boldsymbol{2} \cdot (\boldsymbol{B}-\boldsymbol{A})/\boldsymbol{X}$
3	$\boldsymbol{A} + \boldsymbol{3} \cdot (\boldsymbol{B}-\boldsymbol{A})/\boldsymbol{X}$
.	.
.	.
$\boldsymbol{X}$	$\boldsymbol{A} + \boldsymbol{X} \cdot (\boldsymbol{B}-\boldsymbol{A})/\boldsymbol{X}$

(d) Part 4: Calculating the upper limit for the intervals

The upper limit is the highest value that can be located in a particular interval. The upper limit of a particular class is calculated by subtracting 1 from the class width and adding it to the lower limit of that class. Following the explanation of lower limits, assume $\boldsymbol{X}$ bins were calculated in a data set with a maximum of $\boldsymbol{B}$ and a minimum of $\boldsymbol{A}$. The class width would then be $\frac{\boldsymbol{B}-\boldsymbol{A}}{\boldsymbol{X}}$.

The upper limit is then calculated as:

$$Upper\ limit\ (i)\ =\ Lower\ limit\ (i) + \left[\frac{B-A}{X} - 1\right]$$

$i = class\ number$

(e) Part 5: Determining the Frequency Distribution

Each class will now be defined by an interval that has an upper and lower limit. The number of observations that are located within a specific interval is the frequency of that class. A histogram of the frequency can then be plotted (See Figure 6-8).

(f) Part 6: Identifying the Probability Density Function for Risk Impact

The next step is to determine which probability model describes the data. There are many types of probability models in statistics but the more commonly used models are those shown in Figure D-1 in Appendix D.

The most applicable probabilistic density function can then be selected based on visual inspection of the frequency graph for the data set. If the frequency graph resembles a specific PDF, it is possible that the data can be described by that PDF. Before selecting a specific PDF, the mechanistic properties of the PDF's must also be considered.

Mechanistic Considerations

Mechanistic aspects of probability models relate to how it is formed. For example, the normal distribution is the result of adding random variables. The log – normal PDF is formed by the multiplication of random variables. Therefore, mechanistic considerations may necessitate that a given probability model cannot be used to describe a data set even though visual inspection indicates a positive correlation between the data and the PDF shape. Thus the following statement is made (U.S. Environmental Protection Agency 2001):

> *"In all cases, it is incumbent on the risk assessor to explain clearly and fully the reasoning underlying the choice of a probability model for a given variable—primarily from a mechanistic standpoint if possible."*

Table D-1 lists some of the commonly used PDFs. Note that this table is not a comprehensive list of every type of PDF, only those that are commonly used. Mechanistic considerations are presented in the second column of Table D-1.

The Poisson, Weibull, Exponential and Gamma probability are related to the estimation of observing a number of discrete events. The binomial probability model is typically used when one wants to determine the probability of observing a given number of discrete events. The actual risk event is a discrete occurrence, however the impact is not. Thus the Binomial, Poisson, Weibull, Exponential and Gamma PDFs will not be considered for modelling the risk impact. The triangular PDF is only used when very limited information is available. Even when very limited information is available, the use of the triangular PDF can be avoided by assuming a BETA distribution (U.S. Environmental Protection Agency 2001).

For the study of risk impact variability, the mechanistic considerations restrict the applicable PDFs to the following:

- Normal
- Log-Normal
- Beta
- Uniform

The normal probability model and log-normal model are related. For example, if a variable $\boldsymbol{x}$ is described by the log-normal model, then log(x) is described by the normal probability model. In some cases, more than one probability density function can approximate a data set. In general, the preferred choice would be the simplest probability density function.

(ii) Step 2: Calculating Distribution Parameters

Once the distribution has been successfully identified, parameters of the distribution need to be calculated. Table 4-9 lists the various parameters that describe the PDFs that are most applicable in impact estimation.

Table 4-9: Distribution Parameters

Distribution	Parameter required
Normal	[μ, σ]
Beta	[α, β, A, B]
Log-normal	[μ, σ, A, B]
Uniform	[A, B]

$A = Minimum$

$B = Maximum$

$\mu = mean$

$\sigma = Standard\ deviation$

$\alpha, \beta = Distribution\ shape\ parameters$

(a) The Minimum and Maximum

The minimum($\boldsymbol{A}$) and maximum ($\boldsymbol{B}$) are the smallest and largest value in the data set respectively.

(b) The Mean and Standard Deviation

In order to calculate the mean and standard deviation for a specific risk, historical data pertaining to the impact of the risk is required. This study will consider the monetary impact of risks. The time schedule impact of risks can also be investigated using MCS. In this study, however, we have delimited the impacts of risks to monetary losses.

(c) Distribution shape parameters

The Beta probability density function requires the estimation of two shape parameters $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$**.** For the general beta probability model defined on the domain $[\boldsymbol{A}, \boldsymbol{B}]$**,** the following equations apply:

$$\mu = \frac{A \cdot \beta + B \cdot \alpha}{\alpha + \beta}$$

$$\sigma^2 = \frac{\alpha \cdot \beta (B - A)^2}{(\alpha + \beta)^2 (1 + \alpha + \beta)}$$

Rearranging the equations for $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ respectively, yields the following equations:

$$\alpha = \rho \frac{\mu - A}{B - A}, \qquad \beta = \rho \frac{B - \mu}{B - A}$$

where

$$\rho = \frac{(\mu - A)(B - \mu)}{\sigma^2}$$

(iii)Step 3: Testing the Goodness-of-Fit (GoF)

Visual inspection and consideration of the mechanistic properties of a specific PDF is insufficient to ensure that the data will be represented accurately. A statistical test is a necessity. Therefore, once the **PDF** has been chosen, the quality of the model fit must be tested. A Goodness-of-Fit **(GoF)** test is a statistical analysis technique for testing the hypothesis that a specific PDF fits a set of data (U.S. Environmental Protection Agency 2001).

In hypothesis testing, the null ($\boldsymbol{H_0}$) hypothesis is assumed to be true unless proven otherwise. Typically, the objective of hypothesis testing is to reject the $\boldsymbol{H_0}$ in favour of the alternative hypothesis $\boldsymbol{H_1}$.

By contrast, a Goodness-of-Fit, the hypotheses are set up in the following way:

$$H_0: Data\ follows\ chosen\ probability\ density\ function$$

$$H_1: Not\ H_0$$

Since the null hypothesis ($\boldsymbol{H_0}$) states that the data set is described by a specific probability density function and the alternative hypothesis ($\boldsymbol{H_1}$) states that the data cannot be described by the chosen probability density function, it is preferable not to reject the $\boldsymbol{H_0}$.

Several techniques are available to perform a goodness of fit test, namely:

- Shapiro-Wilk
- Kolmogorov-Smirnoff
- Chi-Square
- Anderson Darling

This not an exhaustive list of possible tests, however, these methods can be found in most general statistical literature. The chi-square test was selected to check the goodness-of-fit in this study. The chi-square can be used to test any probability model fit, it is easily implemented and uses the frequency distribution which has been calculated in step 1, reducing the number of computations (Franke, Ho & Christie 2012).

(a) Determine the frequency for the expected values

In the previous step, the frequency distribution of actual observations was calculated. The same procedure should be followed for the expected values. Since the total number of bins, and classes defined by specific intervals have already been calculated in step 1, the only task left is to use the PDF to determine the number of expected observations in each class.

Once the frequency of the observed and expected values have been determined, the Chi-Square test value can be calculated as follows:

$$\chi^2_{calc} = \sum_{i=1}^{X} \frac{(O_i - E_i)^2}{E_i}$$

$O_i = \text{ is the Observed frequency for class } i$

$E_i = \text{ is the Expected frequency for class } i$

$X = \text{total number of bins}$

Two, essentially identical, methods can be used to determine whether to reject the null hypothesis or not. Both methods require the individual performing the test to set the confidence limits. The confidence limits are typically set at 95%. This implies that the rejection or non–rejection of the null hypothesis should be done with a 95% confidence that the correct decision was made. The error ($\boldsymbol{\alpha_e}$) is then 5%.

The methods are as follows:

- Method 1: Comparing the χ^2_{calc} test statistic to a value on the Chi- square distribution tables.

The test statistic $\boldsymbol{\chi^2_{calc}}$ must be compared to a value on the Chi- square distribution **($\boldsymbol{\chi^2_{crit}}$)** table where the value of interest on the table has the following properties:

$$df = X - m - 1$$

$df = Degrees\ of\ freedom$

$$X = total\ number\ of\ bins$$

$m = number\ of\ parameters\ estimated$ (This will be 1 for GoF tests in this study)

With the error value

$$\alpha_e = 5\%$$

χ^2_{crit} can then be found from Chi-Square tables in literature using the df and the error value α_e. The following comparison is then performed:

$$if \quad \chi^2_{calc} > \chi^2_{crit} \quad reject\ H_0$$

$$if \quad \chi^2_{calc} < \chi^2_{crit} \quad cannot\ reject\ H_0$$

Since the objective is not to reject the null hypothesis, the preferable result would be when the calculated test statistic is less than the critical value obtained from the tables.

- Method 2: Comparing the probability of observing χ^2_{calc} test statistic to α.

While the Chi-square distribution tables can be used for this method, it requires some effort to complete. Thus for this method Microsoft EXCEL is used. The CHIDIST function in EXCEL returns the probability given a specific value for $\boldsymbol{\chi^2_{calc}}$ and the degrees of freedom. The degrees of freedom are calculated as in method 1.

The goal is to find the probability of observing a value that is at least as large as the calculated test statistic $\boldsymbol{\chi^2_{calc}}$. The probability of observing $P(\boldsymbol{\chi^2_{calc}})$ is then compared to **α.**

The following conclusion can then be made from the comparison:

$$if \qquad P\left(\chi^2_{calc}\right) < \alpha \qquad reject\ H_0$$

$$if \qquad P\left(\chi^2_{calc}\right) > \alpha \qquad cannot\ reject\ H_0$$

Since the objective is not to reject the null hypothesis, the preferable result would be when the probability of observing a value at least as large as $\boldsymbol{\chi^2_{calc}}$ is greater than α.

Chapter 4 | Risk Assessment

4.1.3.5 Estimating Risk Impact using Expert Judgement

Quantifying the risk using probability models requires reliable data. In the absence data or data that is unreliable, expert judgement can be used to determine the statistics of the data set. It must be noted that judgements elicited from experts are subjective in nature and as such, reflect the preferences of the individual.

The Project Evaluation Review Technique (PERT) can be used to estimate the data set statistics. In this method, a pessimistic, optimistic and most likely estimate of the impact is elicited by expert judgement, after which the mean can be calculated according to:

$$\mu(mean) = \frac{A + 4m + B}{6}$$

The standard deviation is assumed to one-sixth of the range [A, B]

$$\sigma(STDEV) = \frac{B - A}{6}$$

Where

$A\ =\ optimistic\ estimate$

$m\ =\ most\ likely\ estimate$

$B\ =\ Pessimistic\ estimate$

The PERT method is based on the assumption that the data set will approximate a Beta Distribution (Nicholas & Steyn 2008). The shape parameters for the PERT-Beta distribution can be calculated in using the same procedure in section 4.1.3.4. Since it is assumed that a beta distribution approximates the data, there is no need to select a PDF and perform goodness-of-fit tests

If reliable expert judgement cannot be obtained, qualitative assessment should be used until reliable data or expert judgement becomes available.

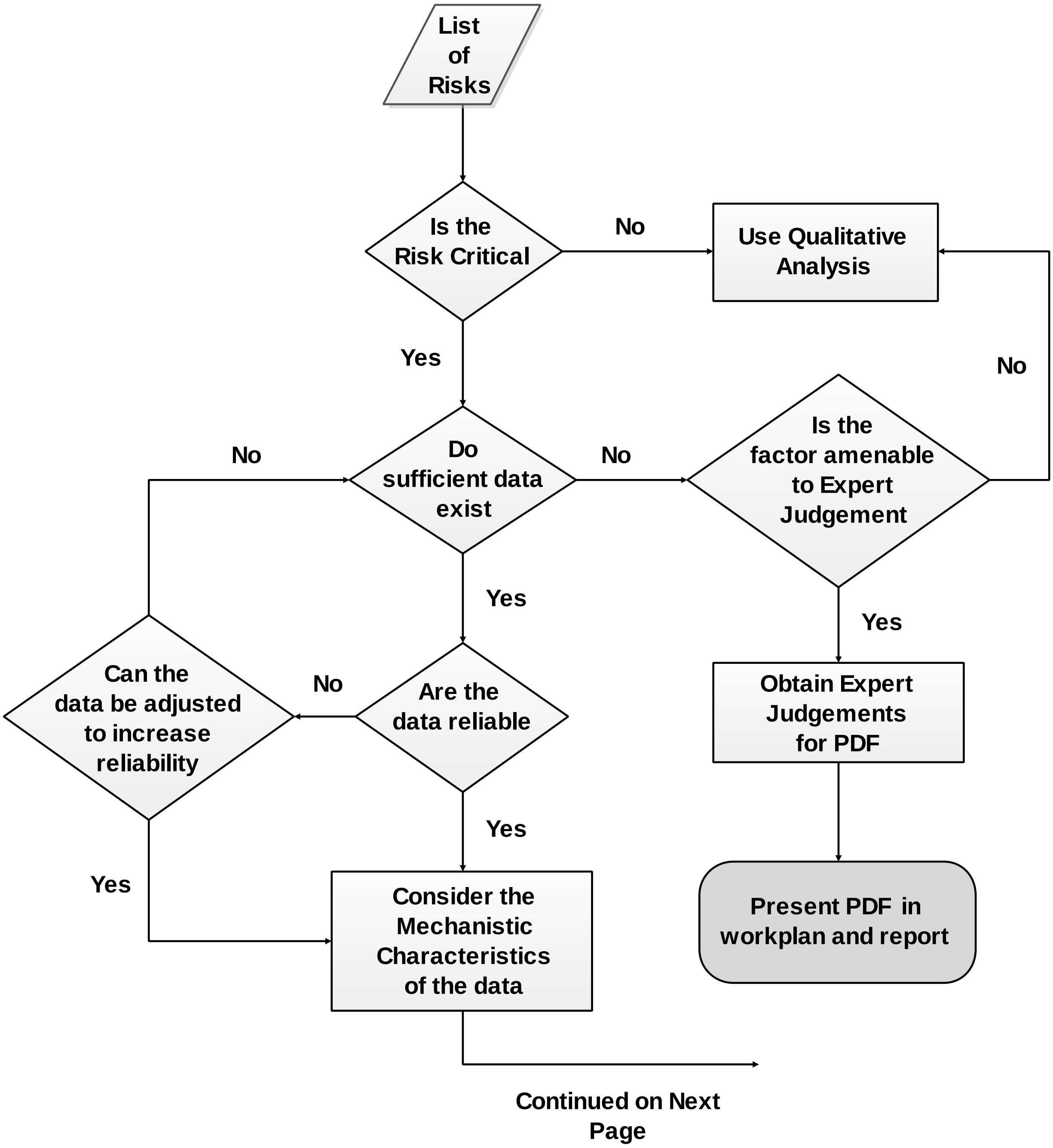

Figure 4-7: Procedure for Quantitative Impact Estimation

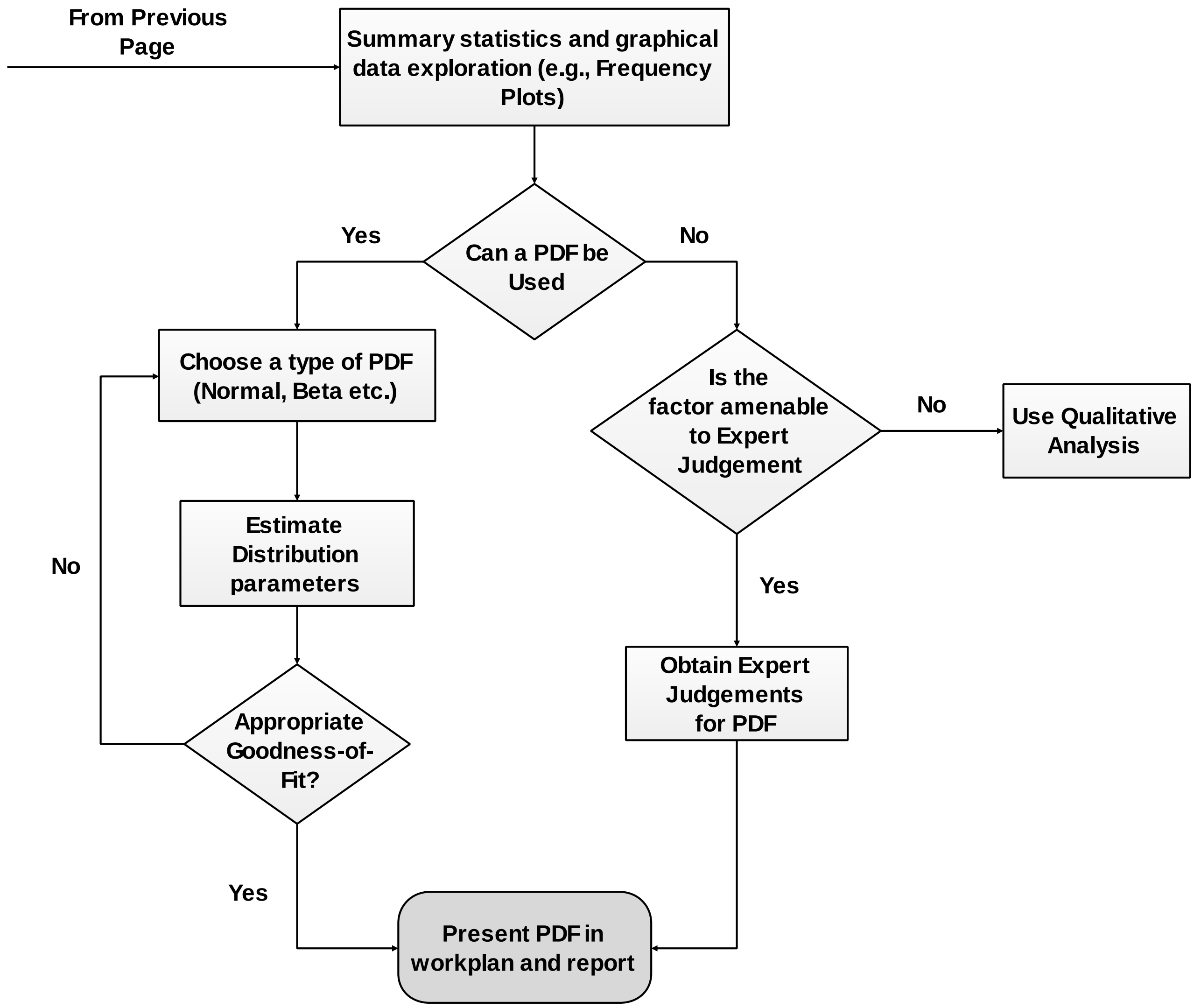

Figure 4-8: Procedure for Quantitative Impact Estimation Continued

4.1.3.6 Estimating Risk Likelihood

The risk likelihood is an indication of how often the risk occurs. While many frameworks provide techniques for evaluating the risk impact, the likelihood assessment is often unclear (U.S. Environmental Protection Agency 2001).

The likelihood estimation is difficult because the concept is not as apparent and easily understood as the risk impact. Furthermore, risk likelihood tends to be influenced not only by the nature of risk but also human behaviour. It becomes very difficult to account for human behaviour in a mathematic model (Hillson & Hulett 2004).

Despite these shortcomings, the ability of the enterprise to model risk likelihood is important, as a wholly subjective estimate or guessing a value tends to undermine the process. Since data regarding risk likelihood is sparse, the distribution is assumed to follow one of the **PDFs** in Table D-1.

(i) Mechanistic Considerations

The Poisson, Weibull, Exponential and Gamma probability are related to the estimation of the time or distance between discrete events. Since desired data is risk likelihood, which is probability of the event occurring and not time between discrete events, these PDFs are eliminated from consideration.

The uniform probability model will assume that the risk likelihood remains the same. This is not true for risk likelihood since it is influenced by human behaviour. Thus, the uniform PDF is eliminated.

The normal and log-normal require the mean and standard deviation. As stated previously, data regarding the risk likelihood are in most cases not available, thus, the mean and standard deviation cannot be calculated empirically. Expert judgement may be used but risk likelihood is not so easily understood and is affected by the nature of risk and human behaviour. Management would be hard-pressed to define reasonably accurate estimates for risk likelihood.

After consideration of the mechanistic properties (See Table D-1), it was found that the beta and binomial distributions are the most applicable for modelling the risk likelihood. Next, the characteristics of any given activity that is analogous to characteristics of the beta and binomial probability models are discussed.

Consider the case when an activity has the following attributes:

- The activity consists of N identical repetitions.

This implies the activity associated with the risk is repeated N times within a given time-frame.

- Each time the activity is repeated, one of two possible outcomes is possible.
- Standards practices dictate that one outcome is failure and the other a success

In terms of risk management, a success occurs when the activity is performed without the risk happening. By contrast, failure is when the risk occurs while performing the activity.

- Independence between each repetition.

Independence implies that each preceding repetition does not affect the current repetition. While slightly inaccurate, this assumption is reasonable if employees follow safety procedures each time an activity is performed.

If an activity can be defined using these characteristics, the value of interest is the probability of success ($\boldsymbol{p_s}$).

Using binomial probability density function, the probability of success ($\boldsymbol{p_s}$) is an input with the output being the probability of observing a given number of successes ($\boldsymbol{p}$) in a defined amount of repetitions, on the one hand. Using the Beta model, the probability of observing a certain number of successes is an input ($\boldsymbol{p}$), with the output being the probability of success($\boldsymbol{p_s}$). Since the output of the beta distribution offers the desired value($\boldsymbol{p_s}$), it is the most appropriate model choice.

The attributes above are particularly useful in characterising operational or day-to-day activities that are routinely performed. If the activity does not have the stated characteristics, such as a once-off activity, then the beta distribution cannot be used. The options available are then:

- Option 1: Use the impact distribution to obtain a point estimate for likelihood
- Option 2: Use expert judgement to obtain a discrete point estimate for the probability
- Option 3: Use qualitative analysis for the impact and likelihood.

(ii) Procedure for using the BETA distribution to model likelihood

When using the beta distribution, the following inputs are required to obtain the desired result:

- Random variable $\boldsymbol{x}$
- Shape parameter $\boldsymbol{\alpha}$
- Shape parameter $\boldsymbol{\beta}$

The random variable $\boldsymbol{x}$ is the probability of observing given success*es* ($\boldsymbol{p}$) when performing $\boldsymbol{N}$ repetitions. The parameters of the beta distribution $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ can be regarded as the number of successes and failures respectively. Recall that a success is defined as the completion of the activity without the risk occurring. A failure is defined by the risk occurring while performing the activity.

Assuming a set of data has a specific number of successes, failures, and probability for observing successes ($\boldsymbol{p}$), the beta distribution will yield the probability for success ($\boldsymbol{p_s}$). The probability of success ($\boldsymbol{p_s}$) is equivalent to the likelihood of performing the activity without the risk occurring. Thus:

$$Risk\ Likelihood = 1 - p_s$$

Where

$$p_s\ =\ probability\ of\ success$$

(a) Number of successes and failures

The number of failures $\boldsymbol{\beta}$ will be determined by the risk appetite of the enterprise. The estimate for the number of failures will be determined by management. Knowing the number of failures, the number of successes ($\boldsymbol{\alpha}$) can be calculated by subtracting the number of failures from the total number of repetitions, $\boldsymbol{N}$.

(b) The probability of observing the given number of successes, p

The probability of observing the number successes (p) will not be known. Instead of using a discrete point estimate for p, Monte Carlo Simulation is used to generate random values for p.

(c) The Risk Likelihood

Using MCS, each randomly generated value of p, will yield a value for p_s from the beta probability model. The risk likelihood can then be calculated according to:

$$Risk\ Likelihood = 1 - p_s$$

Since multiple values for p_s will be calculated, the risk likelihood will not be a discrete value but a distribution of values described by the beta probability density function.

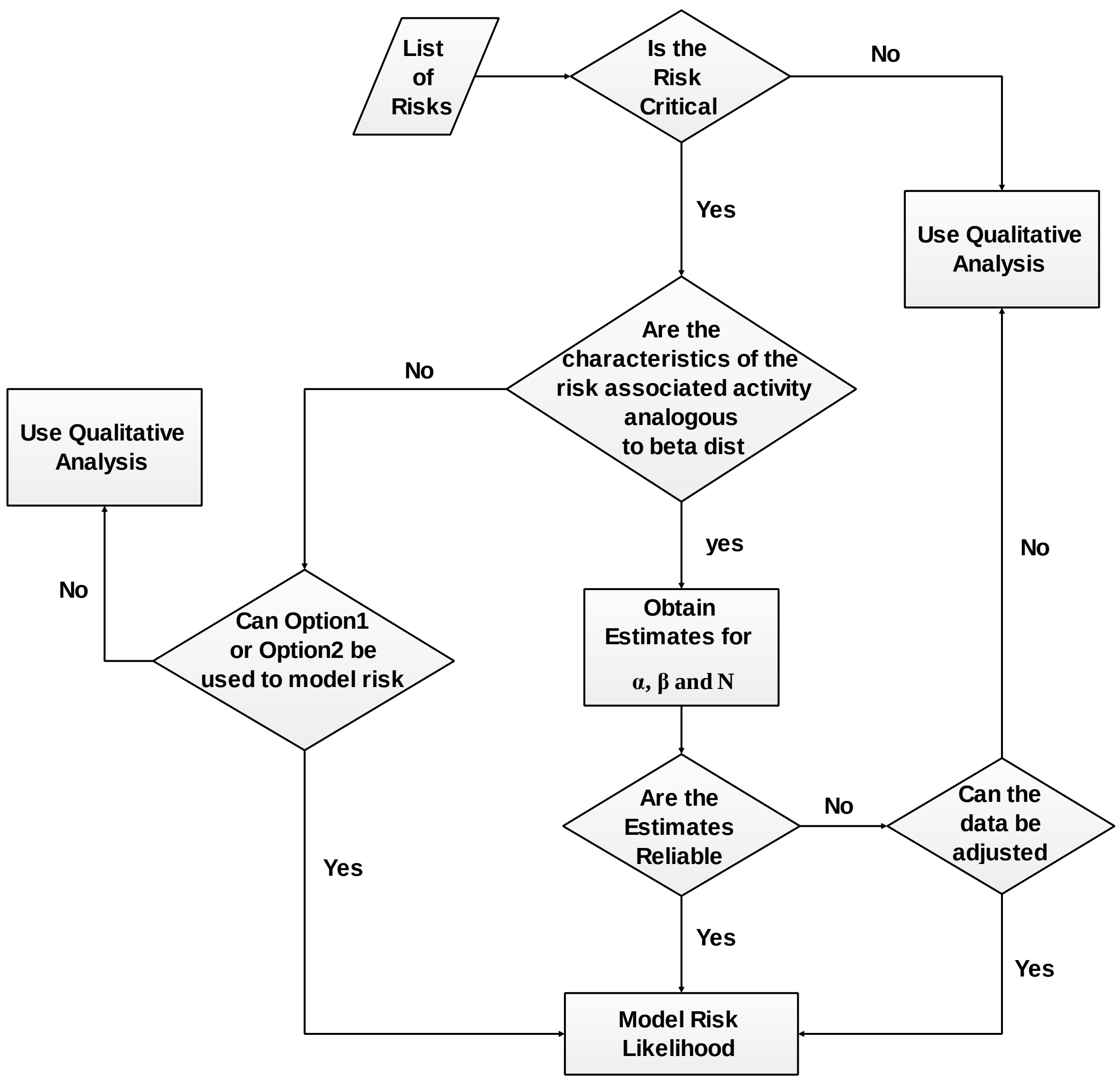

Figure 4-9: Procedure for risk likelihood estimation

4.1.3.7 Risk Expected loss

The expected loss of the risk is analogous to the threat level. The only difference is that threat level is referred to when using qualitative analysis and expected losses is referred to when using quantitative analysis. The threat/expected losses can be calculated using the following formula:

$$Expected\ loss = Impact \times Likelihood$$

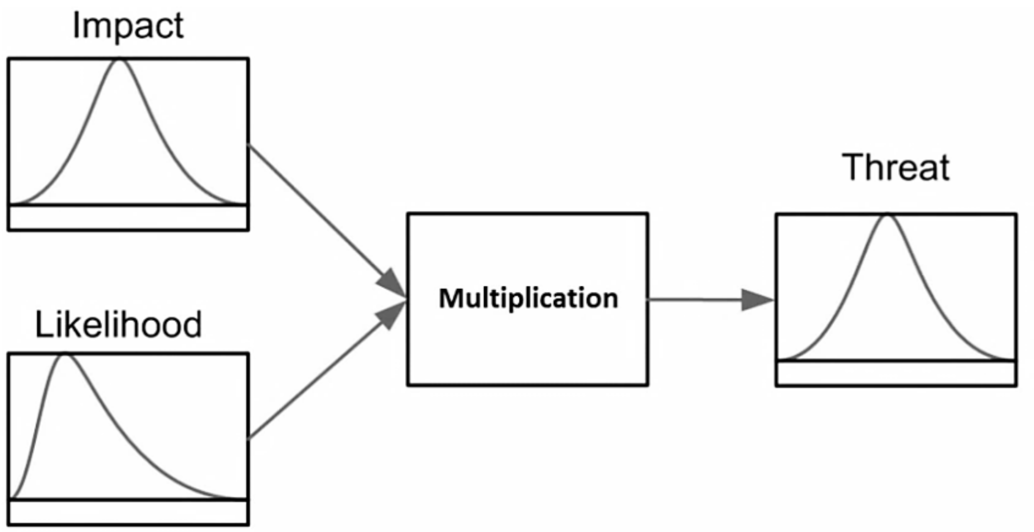

Figure 4-10: Determining the threat level empirical distribution

The probability density function of the likelihood and probability density of the impact is multiplied to yield an empirical distribution for the risk threat. The risk threat/expected loss distribution is then used to determine the risk response strategy according to the procedure in section 6.6.

4.1.3.8 Limitations of Quantitative Techniques

Probability models require detailed numerical information. In some cases, the requisite data may not exist.

Furthermore, risks can be vague and undefined, requiring subjective assessment. Classical probability models cannot handle subjectivity. Therefore, qualitative risk analysis should be used when the risks are poorly defined or understood. (Dey 2010).

(i) The PERT methodology limitations

(a) Expert judgement

The sensitivity of PERT to the expert judgement can be significant (MacCrimmon & Ryavec 1962). Thus, it is recommended that PERT only be used if reliable expert judgement is available. When no reliable judgements can be made, qualitative risk assessment should be used.

(b) The beta distribution assumption

This assumption states that a distribution with a three-point estimate for mean, and a standard deviation one-sixth of the range $[\boldsymbol{A}, \boldsymbol{B}]$ can be approximated by a beta probability model. Farnum & Stanton has shown that the error related to the beta distribution assumption depends on the mode. The mode is a measure of central tendency of the beta distribution can be calculated using:

$$mode = \frac{\alpha - 1}{\alpha + \beta - 2}$$

If the mode varies from $A + 0.13(B - A)\ to\ A + 0.87(B - A)$, the error in the mean and standard deviation estimates can be regarded insignificant (Farnum & Stanton 1987).

(ii) Monte Carlo simulation Limitations

While **MCS** is very flexible and has virtually no limits to the analysis that can be done, the solutions are not exact but estimates, and the accuracy of the solution depends the reliability of the data and the number of repeated simulations.

CHAPTER 5 SELECTING A RISK RESPONSE STRATEGY

5.1 Introduction

Chapter 4 introduced the method to determine whether a risk is critical or non-critical. The methods for evaluating critical risks quantitatively and non-critical risks using qualitative methods are also shown in the previous chapter. This chapter will show how risk assessment and risk response are interlinked.

The complexity in choosing a risk response will depend on whether the risk is critical or not. Using RDM and AHP, the criticality of the risk can be determined. However, risk response types are frequently chosen without considering the characteristics of the enterprise and the internal environment (Fan, Lin & Sheu 2008). This chapter will present qualitative and quantitative methods for selecting the response strategy

5.1.1 Qualitative Technique

Steinberg et al. have noted that risks which present a low threat level should be accepted as the cost of doing business and thus, it is not necessary to further address these risks. Moderate threat level risks may require strategies that reduce the impact and/or likelihood. If possible, the enterprise may seek to share the impact of moderate risks with stakeholders. High threat level risks must be avoided by the enterprise by the implementation of certain control measures (Steinberg et al. 2004).

These guidelines are based on intuitive knowledge and best practice principles. The preferred response may vary depending on the enterprise. In the case of non-critical risks, it may be appropriate for management to use this method as it expedites the risk management process. However, critical risks require a more in depth analysis. A simple technique that is widely employed to determine the response is a risk matrix (Nicholas & Steyn 2008).

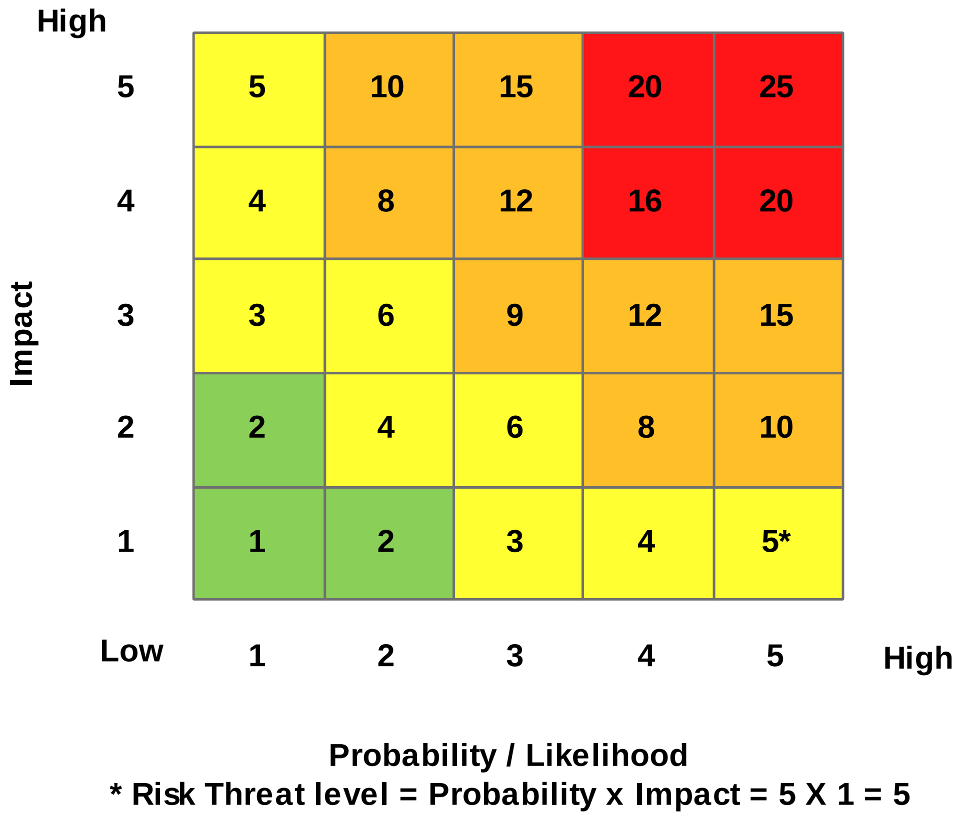

Figure 5-1: Risk matrix

Figure 5-1 shows the risk map that will be used to choose the risk response qualitatively. The X-axis represents the likelihood and the Y-axis represents the impact of risks. The product of risk impact and likelihood will yield a threat level value corresponding to one of four areas on the risk map:

- The Green area represents Low threat level risks (threat = 1 – 2)
- The Yellow area represents Medium threat level risks (threat = 3 – 6)
- The Orange area represents High threat level (threat = 8 – 16)
- The Red area represents Fatal Threat level risks (threat = 20 – 25)

The areas on the map correspond to the following risk response strategies:

- Red = Avoid
- Orange = Reduce/Share
- Yellow = Reduce/Share
- Green = Accept

By definition, non-critical risks should not pose a major threat to business objectives, thus, it is expected that all of the non-critical risks should fall into the green, yellow and the orange areas within the risk matrix. If non-critical risks fall within the red area within the risk matrix, the process of determining which risks are critical should be revisited.

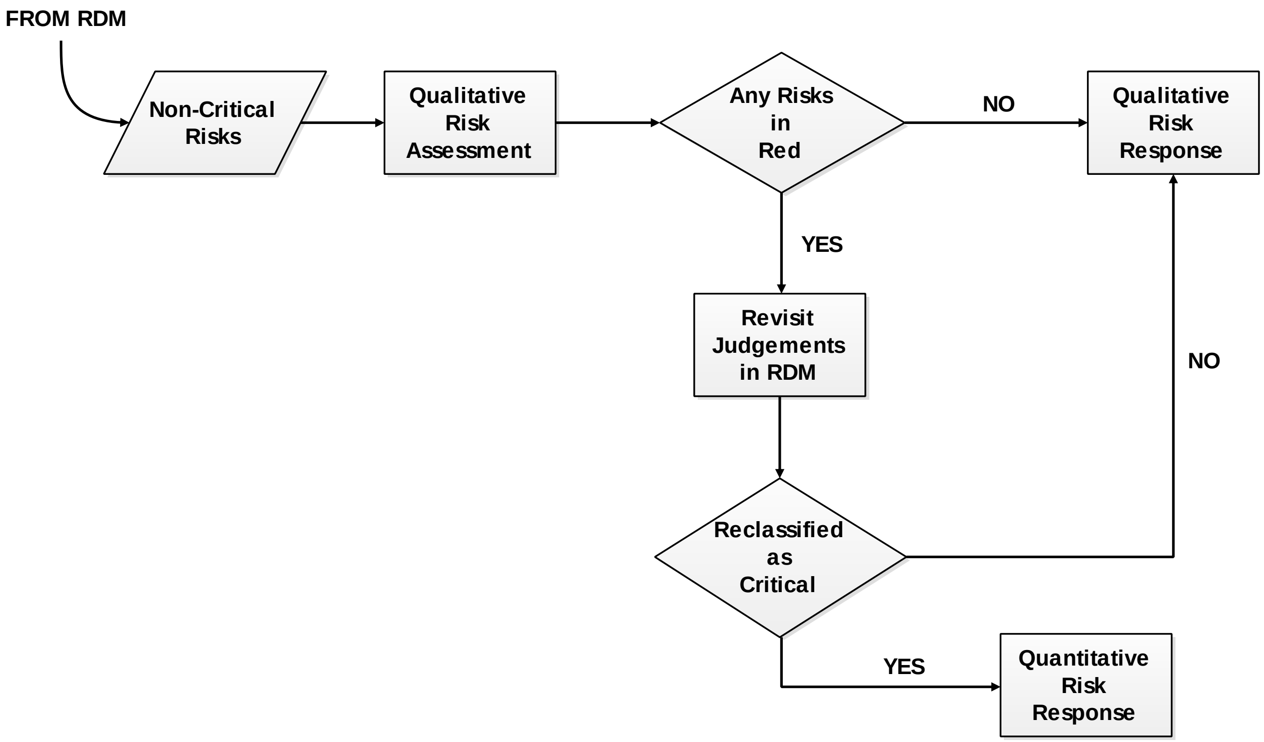

Figure 5-2: Procedure for Reclassification of risks

5.1.2 Quantitative Technique

The rationale behind the choice of a risk-response strategy is often missing or based on experience without proper consideration of enterprise characteristics and the properties of the risk. The method proposed by Fan, Lin & Sheu develops a mathematical relationship between the risk-handling cost, enterprise characteristics and risk properties.

The proposed model can, theoretically, be used for both critical and non-critical risks. However, it is time-consuming and impractical to evaluate all risks using this method. For this reason, the method will be applied to critical risks only.

According to this method, three risk handling strategies are observed. The first strategy is risk prevention and the second is risk adaptation. The final, risk handling strategy, is a combination of risk prevention and risk adaptation (Fan, Lin & Sheu 2008).

Risk prevention refers to the reduction of the risk probability. Risk adaptation is the implementation of plans that reduce the loss associated with risk events. In the combined risk handling strategy, the extent to which the risk is prevented and adapted to will depend on the characteristics of enterprise, respective risk handling costs of each option and the nature of the risk itself.

Risk response and risk handling are used interchangeably in this section.

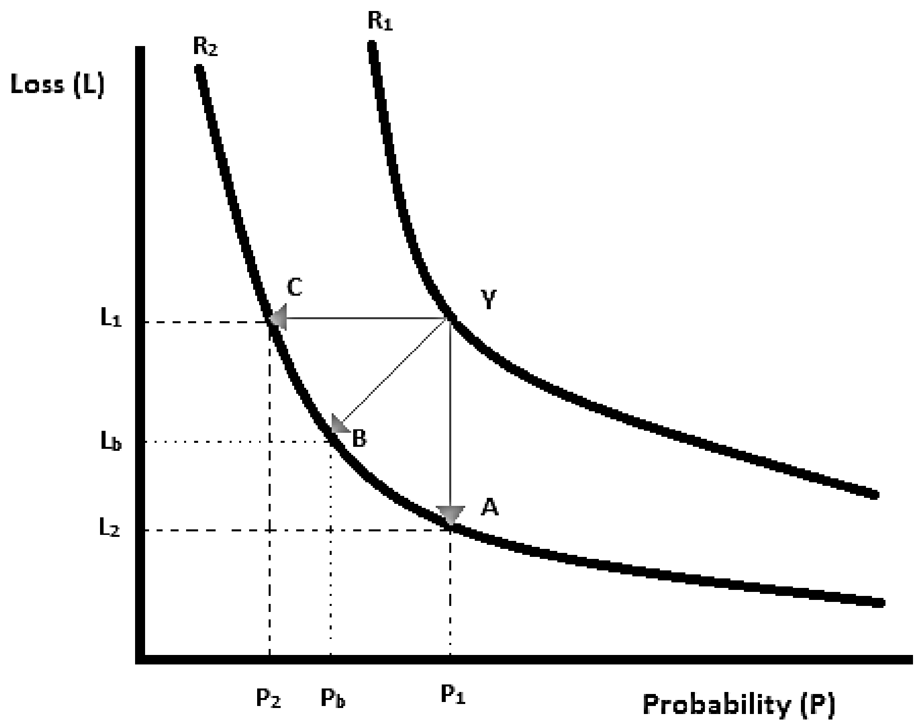

Figure 5-3: Graphical representation of risk handling strategies (Fan, Lin & Sheu 2008)

In Figure 5-3, the curve $\boldsymbol{R_1}$ represents the risk profile before a risk handling strategy is applied. The curve $\boldsymbol{R_2}$ represents the risk profile after the risk handling strategy has been applied.

It follows that $\boldsymbol{P_1}$ and $\boldsymbol{L_1}$ are the risk likelihood and risk impact before handling respectively. $\boldsymbol{P_2}$ and $\boldsymbol{L_2}$ are the risk likelihood and impact after risk handling has been applied such that:

$$\boldsymbol{L_2 \leq L_1}$$

$$\boldsymbol{P_2 \leq P_1}$$

The risk profile $\boldsymbol{R_1}$ represents the various combinations of $\boldsymbol{L_1}$ and $\boldsymbol{P_1}$. The values for $\boldsymbol{R_1}$ which forms the curve are calculated as $\boldsymbol{R_1 = P_1 \times L_1}$

The risk profile $\boldsymbol{R_2}$ is calculated as $\boldsymbol{R_2 = L_2 \times P_2}$**.** Any specific value on $\boldsymbol{R_1}$ or $\boldsymbol{R_2}$ is called the expected loss. However, a value on $\boldsymbol{R_1}$ is an unacceptable expected loss whereas a value on $\boldsymbol{R_2}$ is called an acceptable expected loss.

The purpose of risk handling is to reduce the expected loss from $\boldsymbol{R_1}$ to $\boldsymbol{R_2}$ where $\boldsymbol{R_2 < R_1}$.

5.1.2.1 Risk Prevention

In Figure 5-3, risk prevention is the pathway **YC**, thus the purpose of risk prevention is the reduction of the risk probability $\boldsymbol{P_1}$ (Fan, Lin & Sheu 2008). From Figure 5-3 it can be seen that for risk prevention:

$\boldsymbol{P_2} < \boldsymbol{P_1}$ and

$\boldsymbol{L_2} = \boldsymbol{L_1}$

Thus for risk prevention, the probability of occurrence is reduced while the magnitude of the impact remains the same.

5.1.2.2 Risk Adaptation

Risk adaptation follows the pathway **YA** in Figure 5-3. In adaptation, management has decided that the best method to deal with the risk is by lowering the impact $\boldsymbol{L_1}$. From this it can be seen that:

$\boldsymbol{L_2} < \boldsymbol{L_1}$ and

$\boldsymbol{P_2} = \boldsymbol{P_1}$

In risk adaptation, the probability of occurrence remains the same while the magnitude of the impact is reduced.

5.1.2.3 Risk Prevention-Adaptation

The third risk-handling strategy is a combination of both risk prevention and risk adaptation. Referring to Figure 5-3, the mixed methods approach follows the pathway **YB**. The use of this method results in:

$\boldsymbol{P_2} < \boldsymbol{P_b} < \boldsymbol{P_1}$ and

$\boldsymbol{L_2} < \boldsymbol{L_b} < \boldsymbol{L_1}$

For the prevention-adaptation combination any point of $\boldsymbol{R_2}$ between point **C** and **A** is a possible solution. However each point on $\boldsymbol{R_2}$ between **C** and **A** will have different cost associated with it. The lowest cost solution will be the most attractive one

5.1.2.4 Factors affecting the Risk Response Strategy Choice

Before a risk handling strategy is chosen, the factors affecting the strategy choice must be defined and understood. Fan, Lin & Sheu have developed a conceptual framework based on previous observations of construction projects. The framework revealed that the choice of a risk handling strategy is a function of the controllability of the risk, risk handling costs and the enterprise characteristics. (Fan, Lin & Sheu 2008)

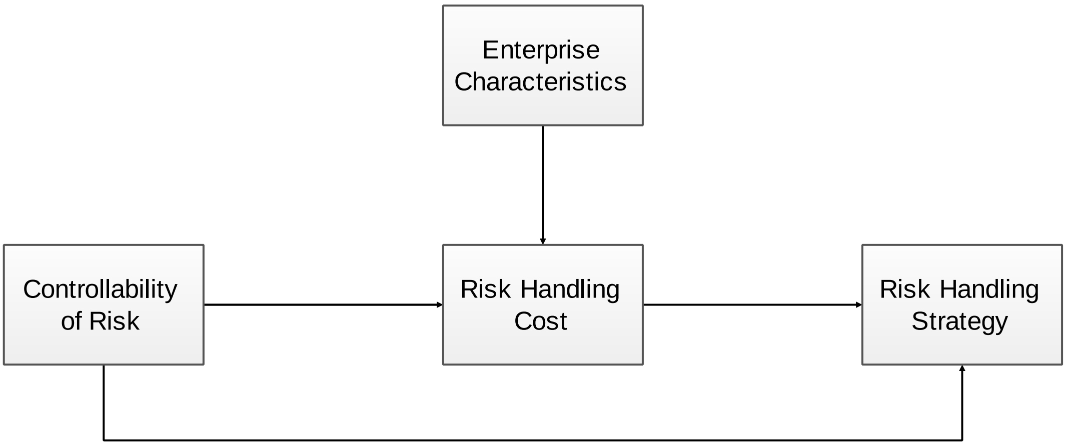

Figure 5-4: Conceptual framework of factors affecting choice of risk handling strategy adapted from (Fan, Lin & Sheu 2008)

(i) Controllability

The controllability refers to the ability of the enterprise to change the probability distribution of the risk (Miller & Lessard 2001). Low controllability is associated with events such as natural disasters, government legislation and external economic conditions. In these cases little or nothing can be done to change the risk likelihood distribution. In the case of high controllability, the likelihood distribution of the risk can be changed considerably.

Controllability can affect the choice of risk handling strategy in one of two ways. Low control usually implies higher cost of handling whereas high control typically involves lower costs. However, this may not necessarily be true for all risks. In some cases, it may be equally expensive to handle risks with high controllability.

Intuitively, a risk prevention strategy would be used for risks with high levels of control whereas a risk adaptation strategy would be used for risks with low levels of control. Note that the terms *"controllability"* and *"level of control"* are used interchangeably.

(ii) Enterprise Characteristics

Enterprise characteristics are factors that affect the way an enterprise operates; these factors can be internal or external. Factors that affect the choice of the risk handling strategy may include:

- Expertise
- Risk management infrastructure
- Size of the enterprise
- Enterprise complexity
- External economic factors
- Risk appetite

(iii)Risk Handling Costs

Risk handling costs refer to the expenses incurred when implementing a selected risk handling strategy. The method developed by Fan, Lin & Sheu and adapted for ERM assumes that risk handling costs are a function of the controllability and the enterprise characteristics (Fan, Lin & Sheu 2008).

5.1.2.5 Risk Handling Cost Model

The nomenclature used in this section is summarised in the table below.

Table 5-1: Variables in risk handling cost model

$\boldsymbol{P_1}$	Risk likelihood prior to risk handling
$\boldsymbol{L_1}$	Estimated monetary loss due to the risk event prior to risk handling
$\boldsymbol{R_1}$	Unacceptable expected monetary loss from the risk event $\boldsymbol{R_1 = P_1 \times L_1}$
$\boldsymbol{P_2}$	Risk likelihood after risk-handling
$\boldsymbol{L_2}$	Monetary loss from the risk event after risk-handling
$\boldsymbol{R_2}$	Acceptable expected monetary loss from the risk event $\boldsymbol{R_2 = P_2 \times L_2}$
$\boldsymbol{k}$	Unit risk prevention cost
$\boldsymbol{\omega}$	Proportion of uncertainty that cannot be reduced / controlled $\boldsymbol{0 \leq \omega \leq 1}$
$\boldsymbol{1 - \omega}$	Controllability of risk
$\boldsymbol{r}$	Opportunity cost or interest rate, $\boldsymbol{0 \leq r \leq 1}$

Risk handling involves the application of risk prevention and/or risk adaptation, thus, the total risk-handling cost is the sum of risk prevention and risk adaptation:

$$C_{TOT} = C_P + C_A$$

Where

$\boldsymbol{C_{TOT}}$ is the total risk handling cost

$\boldsymbol{C_P}$ is the cost of risk prevention

$\boldsymbol{C_A}$ is the cost of risk adaptation

(i) Risk Prevention

In the case of risk prevention, the resulting probability and impact after mitigation measures are:

$\boldsymbol{P_2 < P_1}$ and

$\boldsymbol{L_2 = L_1}$ respectively (See Figure 5-3).

Thus the prevention cost ($\boldsymbol{C_P}$) is a function of the risk probability. The equation for calculating the $\boldsymbol{C_P}$ value has been developed by applying the assumptions and properties:

- C_P and P_2 are inversely proportional. This means that as probability of a risk event is decreased, the cost of risk handling increases.
- When $P_2 = P_1, C_P = 0$. No risk handling cost is present as the post likelihood is equal to the prior likelihood.
- M_{CP} is slope of the C_P function. This is also referred to the marginal prevention cost. The slope of M_{CP} is negative due to the inverse relationship between C_P and P_2 (see Figure 5-5).
- As P_2 approaches 0 the marginal cost M_{CP} approaches infinity. In other words, it becomes unfeasibly expensive to reduce the probability when it is already a low.

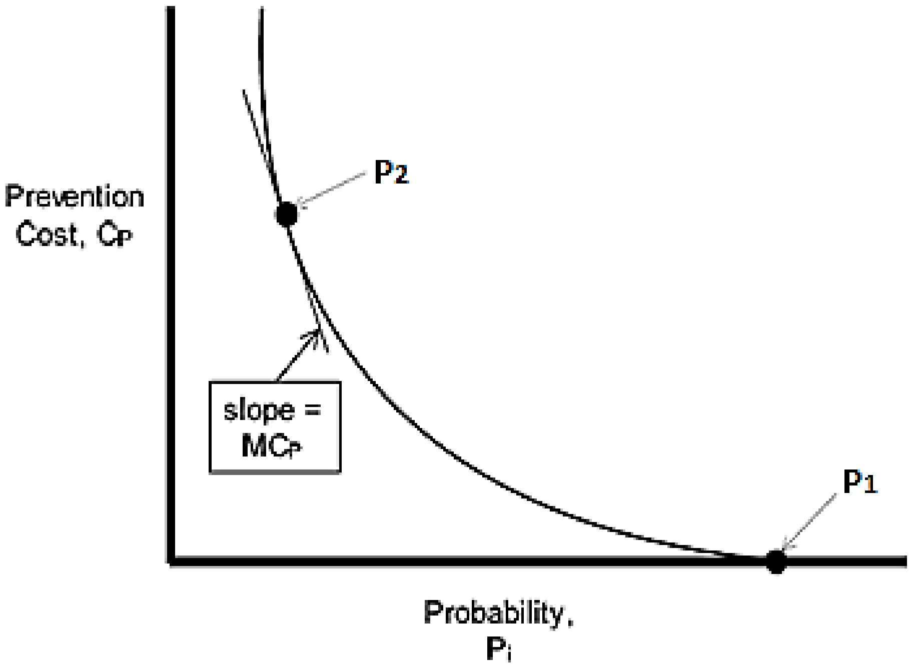

Figure 5-5: Graphical representation of risk prevention cost

(a) The Unit Prevention Cost, k

Uncertainty is partially due to a lack of information regarding the likelihood or impact of an event (ISO 31000:2009, Risk Management—Principles and Guidelines 2009). Thus, to reduce the value of P_1 more information is required although this may be difficult. The unit prevention cost k, is a measure of the difficulty in obtaining information to control the risk such that $P_2 < P_1$. Examples given in Fan, Lin & Sheu approximate k between 0 and 1000 (Fan, Lin & Sheu 2008).

The value of k is determined by the enterprise characteristics such as the technical complexity of the enterprise, internal environment, political factors and can be estimated by expert judgement.

(b) Uncontrollable Aspect of Risk, ω

Any risk has an uncontrollable proportion of uncertainty that cannot be removed feasibly. This uncontrollable aspect is called omega **(ω)**. From this, the level of control of a risk can be calculated as:

$$level\ of\ control = 1 - \omega$$

A visual representation of how the level of control and the probability of a specific risk can be seen in Figure 5-6:

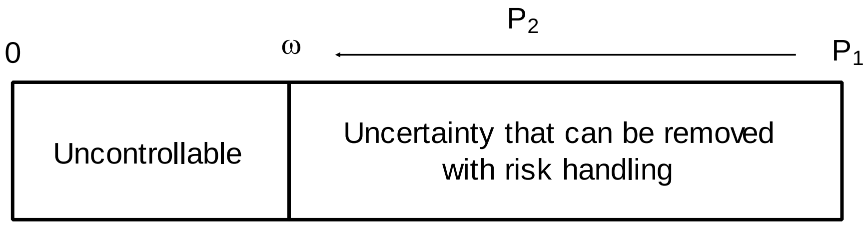

Figure 5-6: Illustration of the risk controllability concept adapted from (Fan, Lin & Sheu 2008)

The segments are:

- $\boldsymbol{P_1 - \omega}$ This represents the percentage of uncertainty that can be feasibly removed
- $\boldsymbol{P_2 - \omega}$ This represents the percentage of uncertainty that was not removed by applying a specific risk handling strategy, although technically it can be removed.

Where $\boldsymbol{\omega \leq P_2 \leq P_1}$

When the segment $[\mathbf{0}\ ;\ \boldsymbol{\omega}]$ is large, the implication is that there is a low degree of controllability associated with the risk.

Table 5-2: Assessing the Level of Control

ω	Implication for Risk controllability	Level of Control (1 - ω)
0	Essentially avoidable through application of risk control actions. Prevention advised	Total Control
0.2	Largely controllable. Prevention is possible	High Level of Control
0.4	Uncertainty can be reduced significantly.	Moderate Control
0.6	Uncertainty can be reduced but not significantly	Low Level of Control
0.8	Risk is largely uncontrollable. Adaptation should be considered.	Minimal Control
1	Risk is unavoidable. Adaptation advised	No Control

It has been noted that assessing the level of control is more natural than assessing the lack of control. Thus, participants in the risk management process should provide expert judgement on the level of control $(\mathbf{1} - \boldsymbol{\omega})$ as opposed to the amount of uncontrollability (Fan, Lin & Sheu 2008).

(c) Prevention Cost Model

The risk prevention cost equation can be derived using the following procedure:

The value of $\boldsymbol{M_{CP}}$, which is the slope of a tangent to the curve in Figure 5-5, can be defined as a function of $\boldsymbol{P_2}$, $\boldsymbol{\omega}$ and $\boldsymbol{k}$ by the following equation:

$$M_{CP} = \frac{-k}{(P_2 - \omega)}$$

Taking the integral from $\boldsymbol{P_1}$ to $\boldsymbol{P_2}$ of the slope function ($\boldsymbol{M_{CP}}$) will then yield the risk prevention cost function $\boldsymbol{C_P}$:

$$C_P = \int_{P1}^{P2} M_{CP}\, dP_2$$

$$C_P = \int_{P1}^{P2} \frac{-k}{(P_2 - \omega)} dP_2 = k \ln\left(\frac{P_1 - \omega}{P_2 - \omega}\right)$$

Thus, the cost prevention function is written as:

$$C_P = k \ln\left(\frac{P_1 - \omega}{P_2 - \omega}\right)$$

(ii) Risk Adaptation

The purpose of the risk adaptation is to reduce the loss associated with risk events. This study was restricted to monetary losses. Mitigation in risk adaptation is achieved by the addition of a buffer to absorb all or part of associated monetary loss.

Insurance is a commonly used method for a risk adaptation buffer. Alternatively, management may decide to establish contingency reserves to reduce the impact of the risks. In this study, we will limit ourselves to the use of an insurance policy to cover the loss associated with risk events when using the adaptation strategy. In the case of risk adaptation, the resulting posterior likelihood and impact are:

$\boldsymbol{P_2 = P_1}$ and

$\boldsymbol{L_2 < L_1}$

The rate of investment or insurance rate can be used in the estimation of the cost of adaptation $\boldsymbol{C_A}$ with the following assumptions and properties:

- $\boldsymbol{C_A}$ is inversely proportional to $\boldsymbol{L_2}$. This means that as the loss associated with the risk is decreased, the adaptation cost increases.
- When $\boldsymbol{L_1 = L_2}$, $\boldsymbol{C_A = 0}$, no risk handling cost is present as the post loss is equal to the prior loss.

- $\boldsymbol{M_{CA}}$ is the slope of the $\boldsymbol{C_A}$ function. This is also referred to as the marginal adaptation cost and the slope $\boldsymbol{M_{CA}}$ is constant.
- As the losses increase, the insurance cost increases in direct proportion. The marginal adaptation cost ($\boldsymbol{M_{CA}}$) when using the adaptation strategy is the insurance rate, $\boldsymbol{r}$ (See Figure 5-7).

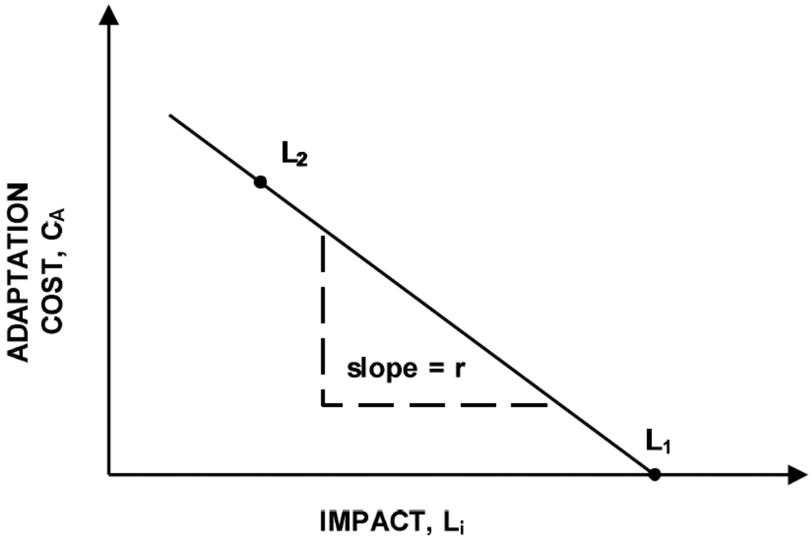

Figure 5-7: Graphical representation of adaptation cost

(a) Adaptation Cost Model

From Figure 5-7, the equation for the risk adaptation cost $\boldsymbol{C_A}$ can be derived using the following procedure:

$$r = \frac{\Delta C_A}{\Delta L_i} = \frac{C_{A1} - C_{A2}}{L_1 - L_2}$$

Since $\boldsymbol{C_{A1}}$ = 0 (see Figure 5-7) the resulting equation becomes:

$$r = \frac{-C_{A2}}{L_1 - L_2}$$

$$-C_A = r(L_1 - L_2)$$

The cost of adaptation is a scalar quantity which only requires the magnitude to fully describe it; thus, taking the absolute value of both sides of the equation yields:

$$|-C_A| = |r(L_1 - L_2)|$$

The right-hand side of the equation will always be larger than zero since $r > 0$ and$(L_1 - L_2) > 0$. Thus, the equation for the risk adaptation cost becomes:

$$C_A = r(L_1 - L_2)$$

(iii)Total Risk Handling Cost C_{TOT}

For any given risk event, the total cost of handling ($\boldsymbol{C_{TOT}}$) is the sum of both the adaptive and preventative methods as shown below:

$$C_{TOT} = C_P + C_A$$

$$C_{TOT} = k\ln\left(\frac{P_1 - \omega}{P_2 - \omega}\right) + r(L_1 - L_2)$$

5.1.2.6 Optimisation Analysis

The cost function is used to perform an optimisation analysis in order to identify the optimal strategy to reduce the risk from profile $\boldsymbol{R_1}$ to profile $\boldsymbol{R_2}$ at the lowest cost given a specific risk with known properties ($\boldsymbol{R_2}$, $\boldsymbol{\omega}$, $\boldsymbol{k}$, $\boldsymbol{r}$). The optimisation is as follows:

$Min \quad C_{TOT}(P_2, L_2)$

$s.t \qquad P_2 \times L_2 = R_2$

$\qquad 0 \le P_2 \le P_1$

$\qquad 0 \le L_2 \le L_1$

Now, it can be said that the ratio between $\boldsymbol{R_1}$ and $\boldsymbol{R_2}$ can be written as:

$$\varphi = \frac{R_2}{R_1} \; and \; 0 \le \varphi \le 1$$

Now, substitution of $\boldsymbol{R_2}$ in terms of $\boldsymbol{R_1}$ and $\boldsymbol{\varphi}$ can be performed, yielding:

$Min \quad C_{TOT}(P_2, L_2)$

$s.t \qquad P_2 \times L_2 = \varphi R_1$

$\qquad 0 \le P_2 \le P_1$

$\qquad 0 \le L_2 \le L_1$

$\qquad 0 \le \varphi \le 1$

The first constraint can be rearranged in order to find $\boldsymbol{L_2}$ in terms of $\boldsymbol{P_2}$:

$$L_2 = \frac{\varphi R_1}{P_2}$$

Now substituting $\boldsymbol{L_2}$ into the function $\boldsymbol{C_{TOT}}$, the total cost function $C_{TOT}(P_2, L_2)$ can be written as:

$$C_{TOT}\left(P_2, \frac{\varphi R_1}{P_2}\right)$$

Finally, the optimisation problem in terms of $\boldsymbol{P_2}$ is derived as:

$$Min \;\; C_{TOT}\left(P_2, \frac{\varphi R_1}{P_2}\right)$$

$$s.t \quad P_2 \times L_2 = \varphi R_1$$

$$\varphi P_1 \leq P_2 \leq P_1$$

$$0 \leq L_2 \leq L_1$$

$$0 \leq \varphi \leq 1$$

Notice that the domain of $\boldsymbol{P_2}$ has been restricted to a different value on the lower bound because $\boldsymbol{\varphi P_2}$ is the lowest feasible value of $\boldsymbol{P_2}$ (Fan, Lin & Sheu 2008). In other words, it would not be feasible to reduce the probability to a value of 0. Any attempt to decrease the risk probability to a very small value would result in a $\boldsymbol{C_{TOT}}$ that tends to infinity.

5.1.2.7 Results of the Optimisation Analysis

From the optimisation analysis, a graph of $\boldsymbol{\omega}$ **vs.** $\boldsymbol{\frac{rR_2}{k}}$ can be derived. The method for this is as follows (Fan, Lin & Sheu 2008):

First, it is assumed that the optimum probability $\boldsymbol{P^*}$ is located at the upper limit of the restricted domain $\boldsymbol{\varphi P_1 \leq P_2 \leq P_1}$. When the optimum probability is located at the upper limit, it implies an adaptation strategy is preferred (Fan, Lin & Sheu 2008) and thus:

$$P^* \cong P_1$$

The equation to calculate the optimum probability $\boldsymbol{(P^*)}$ obtained from the optimisation analysis in (Fan, Lin & Sheu 2008) is then equated to $\boldsymbol{P_1}$ and is shown below:

$$P^* = \frac{rR_2 - \sqrt{rR_2(rR_2 - 4k\omega)}}{2k} = P_1$$

Rearranging the equation yields:

$$\frac{rR_2}{k} = \frac{P_1^2}{P_1 - \omega}$$

Secondly, it is assumed that the optimum probability $\boldsymbol{P^*}$ is located at the lower limit of the restricted domain $\boldsymbol{\varphi P_1 \leq P_2 \leq P_1}$. When the optimum probability is located at the lower limit, it implies a prevention strategy is preferred and thus:

$$P^* = \varphi P_1$$

Following the same procedure as above, the equation to calculate $\boldsymbol{P^*}$ is equated to $\boldsymbol{\mu P_1}$ then rearranged:

$$P^* = \frac{rR_2 - \sqrt{rR_2(rR_2 - 4k\omega)}}{2k} = \varphi P_1$$

$$\frac{rR_2}{k} = \frac{\varphi^2 P_1^2}{\varphi P_1 - \omega}$$

The previous equations for calculating $\boldsymbol{P^*}$ are then used to generate Figure 5-8, which defines the zones in which a specific response strategy will be preferable. Various combinations of $\frac{\boldsymbol{rR_2}}{\boldsymbol{k}}$ and $\boldsymbol{\omega}$ for a given $\boldsymbol{P_1}$ value are generated to yield the asymptotes in Figure 5-8.

Figure 5-8 can then be used to determine the optimum risk handling strategy for a specific risk. Since Figure 5-8 must be generated whenever a risk is evaluated quantitatively, it can become time consuming and ultimately costly. Thus, it is advisable that this method only be used for critical risks.

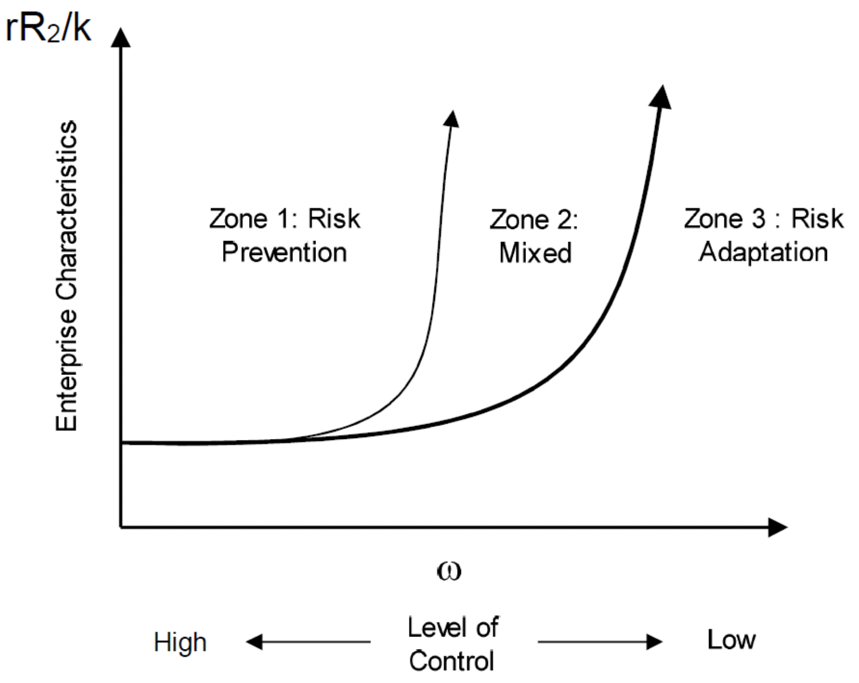

Figure 5-8: Risk Handling Strategy Choices redrawn from (Fan, Lin & Sheu 2008)

Risk prevention (zone 1) is preferred when $\boldsymbol{\omega}$ is small and the measure of the enterprise characteristics $\frac{\boldsymbol{rR_2}}{\boldsymbol{k}}$ is large. This combination represents a high level of control$(\boldsymbol{1 - \omega})$, high insurance rates (large $\boldsymbol{r}$), high–risk enterprise (large $\boldsymbol{R_2}$) and/or low prevention costs (small $\boldsymbol{k}$).

If the level of control tends toward low $(\boldsymbol{\omega \rightarrow 0.6})$, and the prevention costs are very high, a risk adaptation strategy (zone 3) could be preferred by management depending the characteristics of the enterprise, $\frac{\boldsymbol{rR_2}}{\boldsymbol{k}}$.

When control is almost non-existent ($\boldsymbol{\omega} \rightarrow \mathbf{1}$), the effects of the enterprise characteristics become insignificant, in which case, an adaptation strategy is always preferred.

When the level of control is not clear, the enterprise characteristic will determine the choice of a specific strategy. In this case, a mixed strategy (zone 2) could be used to minimise the risk handling costs.

(i) Effects of Controllability (ω) on the Model

When $\boldsymbol{\omega}$ has a large value, the controllability $(\mathbf{1} - \boldsymbol{\omega})$ is low. The effect of controllability dominates the enterprise characteristics $(\boldsymbol{r}, \boldsymbol{k}, \boldsymbol{R_2})$ and a risk adaptation strategy is preferred.

As $\boldsymbol{\omega}$ decreases, the level of risk control $(\mathbf{1} - \boldsymbol{\omega})$ increases. When this happens, risk prevention or a mixed strategy becomes more likely.

(ii) Effects of $\frac{rR_2}{k}$ on the Model

When $\boldsymbol{\omega}$ is not extremely large, the effects of $\frac{rR_2}{k}$ on $\boldsymbol{P}^*$ become significant.

The term $\frac{rR_2}{k}$ represents the enterprise characteristics such as enterprise complexity and size, risk appetite, leadership, insurance rates. In this discussion, each term in $\frac{rR_2}{k}$ will be explained and its respective effect on the choice of a risk handling strategy will be discussed.

The term $\boldsymbol{k}$ is the unit cost incurred to reduce the probability to the desired level. It is a measure of how difficult it is to obtain information to reduce the risk likelihood. A large $\boldsymbol{k}$ value results in a higher cost of prevention which prompts the consideration of a risk adaptation strategy.

The term $\boldsymbol{r}$ is the insurance rate that is paid to ensure a monetary buffer is maintained to absorb the impact of any potential risks. A small value for $\boldsymbol{r}$ indicates a low adaptation cost and thus, adaptation strategies are favoured when $\boldsymbol{r}$ is small.

The term $\boldsymbol{R_2}$ is the acceptable expected loss. This value is derived based on the risk appetite of the enterprise and intrinsically the size of enterprise. Enterprises with high – risk management styles would typically have large $\boldsymbol{R_2}$ values. Large enterprises usually have higher $\boldsymbol{R_2}$ values since they are able to absorb more losses than smaller enterprises. Small businesses and risk – averse management styles would typically desire a lower $\boldsymbol{R_2}$ value.

(iii)Combining the Effects of ω and $\frac{rR_2}{k}$

When $\frac{rR_2}{k}$ is large, the value of $\boldsymbol{P}^*$approaches the lower bound $\boldsymbol{\varphi P_1}$ in the domain $\boldsymbol{\varphi P_1} \leq \boldsymbol{P_2} \leq \boldsymbol{P_1}$and thus, a prevention strategy is preferred. Conversely, when $\frac{rR_2}{k}$ is small, the value of $\boldsymbol{P}^*$ approaches the upper bound $\boldsymbol{P_1}$ and thus, an adaptation strategy is preferred.

The position $\boldsymbol{P^*}$ in the domain $\boldsymbol{\varphi P_1 \leq P_2 \leq P_1}$ is also affected by the amount of uncontrollable uncertainty $\boldsymbol{\omega}$. When $\boldsymbol{\omega}$ is large (approaching 1), it means that controllability $(\mathbf{1}-\boldsymbol{\omega})$ of the risk is very low. In this case, $\boldsymbol{P^*}$ approaches the upper limit, $\boldsymbol{P_1}$, and the value of $\frac{\boldsymbol{rR_2}}{\boldsymbol{k}}$ has an insignificant effect on the optimum probability. Thus, $\boldsymbol{P^*} = \boldsymbol{P_1}$

Thus, it can be said that when the controllability $(\mathbf{1}-\boldsymbol{\omega})$ is very low, an adaptation strategy is always preferred.

As $\boldsymbol{\omega}$ decreases, the controllability $(\mathbf{1}-\boldsymbol{\omega})$ increases, $\boldsymbol{P^*}$ shifts away from the upper bound to the middle of the domain $\boldsymbol{\varphi P_1 < P^* < P_1}$ and the effect of enterprise characteristics $(\boldsymbol{r}, \boldsymbol{k}, \boldsymbol{R_2})$ on the choice of a risk handling strategy becomes more pronounced. A further decrease in $\boldsymbol{\omega}$ will see the $\boldsymbol{P^*}$ value approaching the lower bound of the domain $\boldsymbol{\varphi P_1}$.

(iv) Rules – of – Thumb for Quantitative Selection of Risk Handling Strategy

In order to accelerate the process of choosing a risk response strategy using this method, Fan, Lin & Sheu have developed rule-of-thumb techniques for choosing the risk response strategy. These rules are based on the findings of the optimisation analysis, which show how the terms $\frac{\boldsymbol{rR_2}}{\boldsymbol{k}}$ and $\boldsymbol{\omega}$ effect optimal value of $\boldsymbol{P_2}$ also referred to as the optimum likelihood $\boldsymbol{P^*}$ (Fan, Lin & Sheu 2008).

Table 5-3: The Rule-of-Thumb guidelines for choice of risk response strategy

1.	$\frac{\boldsymbol{rR_2}}{\boldsymbol{k}} \ll \boldsymbol{4\omega}$	***The effect of ω dominates choice of risk a handling strategy***
(a)	The optimum solution is located at the right extreme of the domain $(\boldsymbol{\varphi P_1}, \boldsymbol{P_1})$. This implies the selection of a risk adaptation strategy	
2.	***otherwise***	***Enterprise characteristics become more important as omega decreases***
(a)	ω is large ($\omega > 0.8$)	$\boldsymbol{P^*} = \boldsymbol{P_1}$ regardless of the value of $\frac{\boldsymbol{rR_2}}{\boldsymbol{k}}$ thus adaptation is needed
(b)	ω decreasing ($0.2 < \omega < 0.8$)	As $\boldsymbol{\omega}$ decreases, $\boldsymbol{P^*}$ found within the domain$(\boldsymbol{\varphi P_1}, \boldsymbol{P_1})$**.** The value of $\frac{\boldsymbol{rR_2}}{\boldsymbol{k}}$ determines the response strategy. Use Figure 5-8
(c)	ω small ($\omega < 0.2$)	$\frac{\boldsymbol{rR_2}}{\boldsymbol{k}}$ has a large impact on the value of $\boldsymbol{P^*}$**.** Thus prevention is needed
i	$\frac{rR_2}{\omega} >> 1$	Pushes $\boldsymbol{P^*}$ to toward left extreme of the domain $(\boldsymbol{\varphi P_1}, \boldsymbol{P_1})$ thus a prevention strategy
ii	$\frac{rR_2}{\omega} < 1$	Pushes $\boldsymbol{P^*}$ to right extreme of the domain $(\boldsymbol{\varphi P_1}, \boldsymbol{P_1})$ thus an adaptation strategy.

Using the rule-of-thumb guidelines, Figure 5-8 does not have to be generated for each risk, thus saving a considerable amount of time.

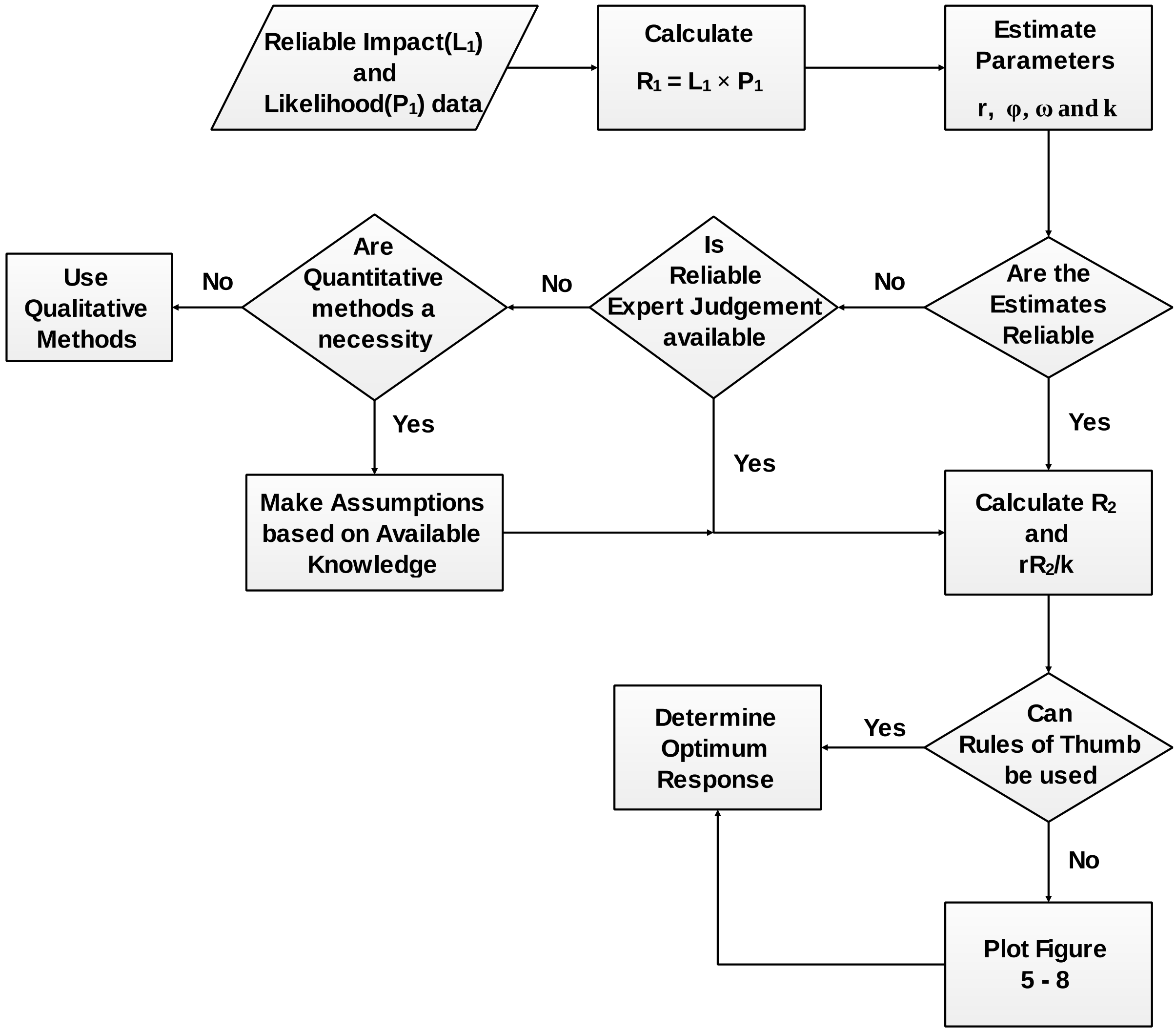

Figure 5-9: Procedure for selecting the optimum risk response

CHAPTER 6 CASE STUDY: DISCUSSION AND RESULTS

6.1 Introduction

The preceding chapter presented the research methodology employed in this study. The current chapter discusses case study and the results of implementation of the methodologies in the preceding chapters.

6.2 Case Study Review

A case study was used in order to test whether the proposed framework was practical and systematic. Due to the nature of the risks, stipulations by the company and the research ethics committee of Stellenbosch University, the names of participants and the company remain anonymous. Certain assets that are synonymous with the company will be referred to as vehicles, assets or tools.

Owing to the nature of the work undertaken at the company studied, risks are primarily operational. That is, they relate to the health and safety of individuals. It is also the case that the current risk management processes at the company are mostly qualitative although cost estimates were shown to be associated with specific qualitative ratings.

Several Questionnaires were provided to the key employees of the company (see Appendix A). Collection of the completed questionnaire was done anonymously.

6.3 Internal Environment

The evaluation of the internal environment was performed using a questionnaire. The participants were asked to provide ratings for various statements relating to the internal environment. Each statement was formulated to evaluate the state of specific attributes within the company, among them:

- Leadership and Strategy
- People and Communication
- Accountability and Reinforcement
- Risk Management and Infrastructure

The rating system for the internal environment is described in the following table.

Table 6-1: Rating system used for Internal Environment

Rating	Weighting
Strongly Agree	+2
Agree	+1
Neutral	0
Disagree	-1
Strongly disagree	-2

When the mean ratings were found to be $\mu \leq 0$, then action is required and if the mean ratings were $0 < \mu < 0.9$, then caution with respect to that attribute is noted and action is suggested. For $0.9 \leq \mu < 1.4$, a good correlation exists between the enterprise and the embodiment of an attribute in a positive way. For $\mu \geq 1.4$, participants feel strongly that the enterprise embodies the attribute in a positive way.

A standard deviation greater than 1.5 indicates that the participants were ambivalent. The median is also considered.

Table 6-2 contains the statements used to evaluate the internal environment at the company. Ten statements were used to evaluate 4 characteristics of the internal environment within the enterprise.

Table 6-2: Enterprise internal environment questionnaire results

#	Statement	Attribute	Mean	Median	Deviation	SD	D	N	A	SA
1	The leaders of my unit set a positive example for ethical conduct.	Leadership and Strategy	0.15	0	1.21	2	1	4	5	1
2	I am aware of what is expected of me with respect to professional conduct	Leadership and Strategy	-0.38	0	1.04	2	3	7	0	1
3	I understand the vision, mission and overall objectives of the enterprise / unit.	Leadership and Strategy	-0.92	-1	0.95	4	5	3	1	0
4	Teamwork and communication is promoted by the leaders of your unit.	People and Communication	0.08	0	1.44	2	3	3	2	3
5	Channels of communication to management are available.	People and Communication	-0.25	-0.5	1.22	1	5	4	0	2
6	Disciplinary action is taken against employees that engage in unethical conduct.	Accountability	0.18	0	1.40	1	3	3	1	3
7	Does risk management make the environment a better place to work in?	Risk Management	-0.46	-1	1.20	1	8	2	0	2
8	The risk management process is well structured.	Risk Management	-0.15	0	0.99	1	4	4	4	0
9	Whenever a decision is made or a new task is undertaken, the risks are explicitly addressed.	Risk Management	-0.08	0	1.38	2	4	2	3	2
10	Designated risk owners have the authority and ability to manage risk adequately.	Risk Management	0.27	1	1.19	1	2	2	5	1

SA(+2) = Strongly Agree **A(+1) =Agree;**
N(0) = Neutral **D(-1) = Disagree** **SD(-2) = Strongly Disagree**

6.3.1 Leadership and Strategy

Beasley, Clune & Hermanson demonstrate that the extent of ERM understanding and implementation is dependent on the attitude at a senior management level. Thus leadership and strategy is one of the most important attributes of the internal environment that affect the ERM (Beasley, Clune & Hermanson 2005).

It follows that, the embodiment of ethical values through the actions of management greatly influences the corporate culture and norms within the enterprise. According to Table 6-2, the mean suggests that participants of the study perceive the actions of management as ethically questionable.

Moreover, the standard deviation suggests that the participants are divided in their opinion with respect to their leaders acting ethically. This may indicate that some leaders are perceived as ethical while the ethics of others may be questionable.

Although the mean and median of statement 1 suggest that management is not perceived as wholly unethical, action in this regard is suggested since it has been shown that questionable ethical values by management influence employees to act in the same way. The same applies for good ethical values (Steinberg et al. 2004). Unethical leadership also affects the risk management process by either creating situations of risk through ethically questionable actions or through dishonest representation of the risks.

Statement 2 relates to participants knowledge of expected professional conduct. Table 6-2 indicates that the majority of participants are neutral. This may imply that the participants have either not read an existing code of conduct or the code of conduct is not made readily available.

Honesty and integrity should be embodied in any formal code of conduct (ISO 31000:2009, Risk Management—Principles and Guidelines). Employees should be familiar with this document as it provides benchmarks against which values such as integrity, honesty and professional conduct can be measured. The company was advised to ensure that all employees are familiar with ethical standards of conduct on a regular basis.

Table 6-2 shows that a large majority of the participants do not understand the mission, vision and overall objectives of the enterprise or unit within the enterprise. The definition of a risk is an event that affects the objectives of enterprise resulting in abnormal conditions. If the employees, and more specifically the risk owners, do not understand the objectives of the enterprise, then the entire risk management process can be called into question.

According to ISO 31 000, the first principle of risk management is that it should create and protect value (See Section 2.2.2). Fundamental to creating value is the achievement of objectives. The role of risk management is to ensure that objectives are achieved (ISO 31000:2009, Risk Management—Principles and Guidelines 2009).

If objectives are not understood, the role and importance of risk management in protecting value cannot be fully realised. For this reason, the company should ensure that employees are aware of the objectives of the enterprise or unit.

6.3.2 People and Communication

The results from Table 6-2 show that teamwork and communication is promoted by management but not to the extent that it should be. It is the responsibility of management to ensure that all employees work together, as far as possible, to achieve objectives. This can only be done if the concerned parties understand the objectives, co-operate and communicate effectively.

Furthermore, the sixth principle of risk management (see section 2.2.2) states that good risk management practice is to include information from all relevant sources. If information is not shared, the risk management process can become less effective. Also, risk management should be dynamic and responsive to change. To facilitate this dynamic behaviour, the newest information must be available at all times. Effective communication partly ensures the sharing of new information.

Communication channels to management are necessary to report any irregular activities and behaviour. The poor rating assigned to statement 5 could be due to the fact that participants felt the communication channels to management were either not adequate or that nothing is done after reporting irregular behaviour. Reporting irregular behaviour via communication channels to management partly ensures that ethical standards are upheld. Communication channels can also be used to obtain clarification on the expected behaviour in terms of the code of conduct.

6.3.3 Accountability

It was expected that disciplinary action against unethical conduct would be strictly enforced in the company. However the ratings show a distribution wider than expected (statement 6).

The participants were undecided as to whether unethical behaviour goes unpunished. One third of the participants agreed that disciplinary action is taken against unethical behaviour. The rest either stated that they had no opinion or that they disagreed. The indecision could be an indication that action is taken intermittently. The company was advised to investigate this indecision, since unethical behaviour, if left unchecked, gradually becomes part of an enterprise's normal operating conditions (Steinberg et al. 2004).

Statement 5, channels of communication, might have received a poor rating because participants felt that after reporting unethical conduct, no action was taken.

6.3.4 Risk Management

Four main principles (section 2.2.2) make up the foundation for effective risk management (ISO 31000:2009, Risk Management—Principles and Guidelines 2009):

- Facilitates continual improvement.
- Is well structured.
- Is considered in all decisions that expose an enterprise or its employees to risk.
- Provides risk owners with the resources and capability to mitigate risks.

The participants felt that caution should be noted with respect to designated risk owners having the capability or resources at their disposable to effectively mitigate risk.

Firstly, consider the case when the lack of capability impedes effective risk management. According to PriceWaterhouseCoopers, the commitment to competence is an important factor in ensuring effective risk management. While a trade-off between competence level and cost will always exist, the skills and knowledge required to complete a specific activity should not be lacking in the individual performing the activity (PriceWaterhouseCoopers 2011). The company should investigate whether the risk owners have the skills and knowledge required to perform their duties effectively.

Resource allocation is dependent on the attitude of the management towards risk management. This is further validated when analysing statement 9, which shows that participants did not believe that risk management makes the environment a better or safer place to work in. Owing to this fact, it is likely that management shares this philosophy to some extent. Most companies are required by law, to perform operational health and safety assessments. The company health and safety regulations as well as risk mitigation controls are then audited at the end of the financial year.

If the company is merely adhering to the minimum required standards, it would partly validate the conclusion that insufficient resources are allocated, resulting in poor risk management. Poor risk management leads to the perception that the environment is not made a safer or better place to work in.

From Table 6-2, it can be seen that the general perception is that risks are not explicitly addressed whenever a new task or decision is made (statement 9). Data provided and conversations with various personnel at the company, indicated that the company uses a predominantly reactive style of risk management. This meant that when undesirable events occur, it is recorded on an incident report.

While this style of risk management is partly necessary, the company should also develop proactive risk management processes further. Proactive risk management ensure that risk management is part of every decision or task. It must be noted that, while beneficial, is not possible to identify all possible risks in advance. Thus, a reactive risk management mechanism, such as incident reports are necessary.

6.4 Risk Identification

Various methods for risk identification have been offered in Chapter 3. These include working group techniques (Chapman 1998) and interview techniques (Spetzler & Holstein 1975). Each of these methods has advantages and disadvantages.

The interview technique would have been used to identify a comprehensive list of risks. The participants would have been key personnel in the company. Unfortunately, this was not possible due to prior commitments and work schedule of the key personnel at the company. Instead, a comprehensive list of risks identified in 2012 was provided by the company for analysis in this study. Incident reports containing events that have occurred but were not yet included in the formal risk management process was also provided. Several risks were identified at random for analysis from these documents. These risks are shown in Table 6-3:

Table 6-3: Risks identified from risk register and incident reports

Risk ID	Risk Description
1	Inhalation of chemicals during paint stripping of components
2	Staff member death/injury due to use of cell phones and media players
3	Incorrect stacking and storing practices results in item falling from height injuring staff member.
4	Shock, falling, lacerations during repairing of vehicle doors
5	Contractor control: contractor creates risk situation resulting in injury
6	Abuse of assets: vandalism and staff urinating in assets
7	Abuse / Improper use of lifting equipment resulting in injury
8	Essential equipment not working/malfunctioning leads to injury or downtime
9	Hazardous materials handling: improper handling of solvents causes chemical fire
10	Excessive noise and dust / debris in working area
11	Fire control: broken / malfunctioning fire extinguishers.
12	Recurring incidents of theft. Tools and other assets stolen
13	Staff not wearing personal protective equipment (PPE) results in injury
14	Staff injury due to poor procedures or procedures not being followed / enforced
15	Removing vehicle wheels : Staff member death/injury
16	Staff aggression towards supervisors: Supervisors abused verbally or physically.
17	Withdrawal of contract services due to non-payment: hazardous waste handling by staff

Each risk has been allocated a designated risk ID which will be referred to in the following sections. Appendix B shows the risks that Table 6-3 was constructed from.

6.4.1 Risk Classification

Classification of the risks gives an indication of how the risks affect the enterprise as opposed to which objectives are affected by specific risks. Figure 3-1 depicts the classification structure that was used to classify the risks. As stated previously, a comprehensive list of risks was provided by the company. The list of risks contained only operational risks. Each operational risk was then classified either as a health, safety, environmental or asset risk. Classification of the risks can be seen in Table 6-4 :

Table 6-4: Classification of risks

Risk ID	Risk	Classification
1	Inhalation of chemicals	H
2	Cell phones and media Players	S
3	Incorrect stacking and storing	S
4	Repairing vehicle doors	S
5	Contractor Control	S
6	Abuse of assets	H,A
7	Abuse of lifting equipment	S
8	Equipment not working	S, A
9	Materials handling	H
10	Noise and dust	H
11	Malfunctioning fire extinguishers	S
12	Theft	A
13	Staff not wearing PPE	H, S
14	Procedural issues	S
15	Removing vehicle wheels	S
16	Staff Aggression	S
17	Non-payment of services	H

Health risks are associated with the events that directly affect the efficiency of a functioning human body. Health risks may also manifest long after the risk event has occurred. For example, regular inhalation of chemicals may lead to long term pulmonary disease such as chemical pneumonia.

Safety risks refer to events that violates a safe state of being, that is, a condition where an employee is protected against physical, social or emotional harm. Safety risks usually bring about immediate effects if not dealt with properly

Environmental risks are associated with events that directly influence the environment such as chemical spills. Asset risks are events that directly affect company assets such abuse of equipment or are related to company assets such as the effects of non-functional machinery.

The abuse of assets has been classified as both an asset and health risk. This is due to the fact abuse of assets encompasses vandalism of assets as well as urination in the assets. Vandalism is an asset risk because it directly affects the company assets whereas urination in the assets poses a health threat.

Essential equipment not working has been listed as a safety risk and an asset risk. It was classified as an asset risk because non-functionality impedes work efficiency and progress. Furthermore, malfunctioning machinery can create safety risks such as cranes malfunctioning during lifting procedures.

Staff not wearing personal protective equipment (PPE) may lead to unsafe conditions thus, it is classified as a safety risk. However PPE also protects employees against health risks such as chemical contact with the skin etc.

Non-payment of contract services, such as waste disposal contracts, within the company meant that employees are forced to handle hazardous waste products. This can lead to health risks.

6.5 Risk Assessment

6.5.1 Risk Prioritisation

6.5.1.1 Hierarchy Structure

The Analytical Hierarchy Process was used to prioritise the risks in order of importance as perceived by key personnel at the company. The first part of the AHP technique is to structure the problem as a hierarchy:

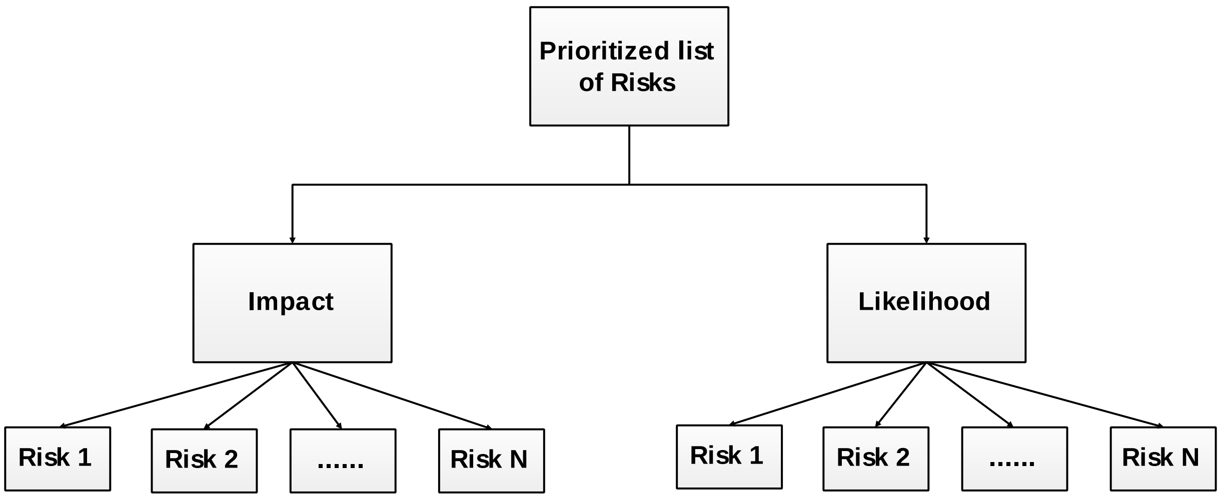

Figure 6-1: AHP hierarchy structure for prioritisation of risks

The hierarchy shows that two criteria were selected, namely the risk impact and likelihood. The goal of the AHP is to obtain a prioritised list of risks which are evaluated against these criteria.

6.5.1.2 Preference Encoding

The next procedure is preference encoding of risks in Table 6-4. The preferences were encoded by asking the participants to score the risks based on the impact and likelihood. Appendix A depicts the questionnaire used for preference encoding. The preference encoding of the risks are performed for both impact and likelihood, which then yields two sets of preference ratings. Table 6-5 and Table 6-6 show the various responses in terms of risk impact and likelihood respectively. The preference rating for a risk was determined by multiplying the score weight by number of responses and summing these values. The formula is shown below:

$$Preference = \sum_{1}^{5} i \cdot N_i$$

$i = score\ weight$

$N_i = number\ of\ repsonses\ in\ for\ score\ weight\ i$

An example for risk 1: the inhalation of chemicals is shown below:

$$Preference(Risk\ 1) = 1 \cdot (3) + 2 \cdot (1) + 3 \cdot (4) + 4 \cdot (5) + 5 \cdot (1) = 42$$

Table 6-5: Preference encoding for risk impact

ID	Risk	N.Resp	1	2	3	4	5	Preference Rating
1	Inhalation of chemicals	14	3	1	4	5	1	42
2	Cell phones and media Players	14	2	4	3	2	3	42
3	Stacking and storing	14	1	3	1	2	7	53
4	Repairing vehicle doors	11	0	4	3	3	1	34
5	Contractor Control	14	1	3	5	3	2	44
6	Abuse of assets	12	1	0	0	1	10	55
7	Abuse of lifting equipment	14	2	2	4	4	2	44
8	Equipment not working	14	0	0	5	4	5	56
9	Materials handling	14	2	2	5	3	2	43
10	Noise and dust	14	2	0	7	2	3	46
11	Malfunctioning fire extinguishers	14	3	4	1	2	4	42
12	Theft	14	0	2	0	4	8	6
13	Staff not wearing PPE	14	2	4	1	3	4	5
14	Procedural issues	14	2	1	4	5	2	46
15	Removing vehicle wheels	11	2	2	1	4	2	35

Table 6-6: Preference encoding for risk likelihood

ID	Risk	N.Resp	1	2	3	4	5	Preference Rating
1	Inhalation of chemicals	14	2	4	4	3	1	39
2	Cell phones and media Players	14	3	5	3	1	2	36
3	Stacking and storing	14	1	0	9	2	2	46
4	Repairing vehicle doors	11	1	6	3	1	0	26
5	Contractor Control	14	1	3	6	1	3	44
6	Abuse of assets	12	1	1	1	1	8	50
7	Abuse of lifting equipment	14	3	3	4	3	1	38
8	Equipment not working	14	0	1	6	4	3	51
9	Materials handling	14	3	2	7	1	1	37
10	Noise and dust	14	2	1	7	2	2	43
11	Malfunctioning fire extinguishers	14	3	3	6	2	0	35
12	Theft	14	0	4	1	4	5	52
13	Staff not wearing PPE	14	3	4	4	1	2	37
14	Procedural issues	14	0	7	4	2	1	39
15	Removing vehicle wheels	11	3	3	3	1	1	27

6.5.1.3 Priority Vectors and Consistency

Following the encoding, the pairwise comparison matrix is formed. This matrix was then normalised and the priority weight vector was calculated. The priority weight contains the relative importance of risks. As the priority increases, the risk becomes more important.

(i) Impact Priority Vector

Table 6-7 contains priorities for the risks evaluated based on the impact criterion. The initial priorities have a Consistency Ratio (CR) = 10.71%. This is slightly larger than the acceptable value of 10%. While this value is probably sufficient to ensure consistency, the revision of judgements using the method proposed in section 4.1.1.2 was investigated.

The adjusted priorities can be seen in the final column of Table 6-7 with CR = 8.01%, which is within the acceptable limits.

Table 6-7: Initial and adjusted priority vectors for risk impact

	Consistency Ratios (%)	CR = 10.71	CR = 8.01
ID	**Risk**	**Initial Priority (%)**	**Adjusted Priority (%)**
1	Inhalation of chemicals	4.36	4.44
2	Cell phones and media Players	2.81	2.89
3	Stacking and storing	8.23	8.79
4	Repairing vehicle doors	2.28	2.32
5	Contractor Control	7.78	7.01
6	Abuse of assets	16.07	16.14
7	Abuse of lifting equipment	3.91	3.99
8	Equipment not working	13.70	14.14
9	Materials handling	3.14	3.20
10	Noise and dust	5.52	5.39
11	Malfunctioning fire extinguishers	2.62	2.68
12	Theft	19.19	18.38
13	Staff not wearing PPE	4.20	4.29
14	Procedural issues	5.02	5.11
15	Removing vehicle wheels	1.18	1.22

Figure 6-2 depicts the risk priorities evaluated on the impact criterion. From this figure it can clearly be seen that risk 6, risk 8 and risk 12 dominate the impact criterion priorities. This meant that, from the list of evaluated risks, participants perceived the abuse of assets, essential equipment not working and theft of assets/tools as the events which had the most significant effect on the company in terms of the impact criterion.

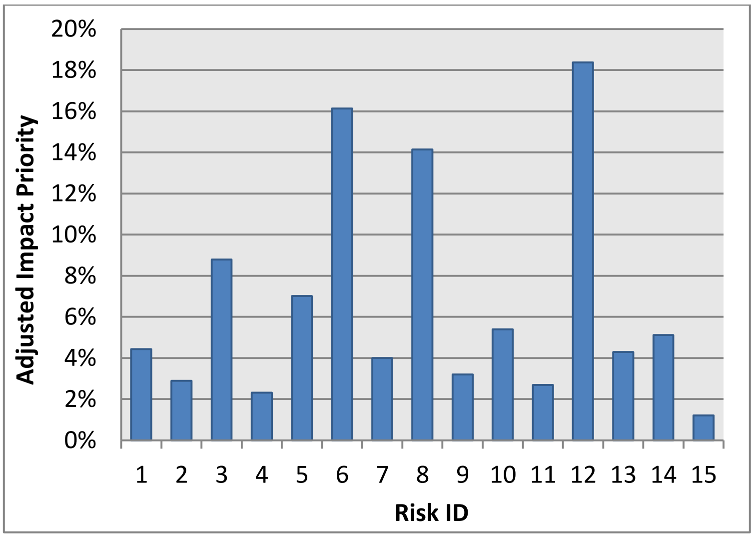

Figure 6-2: Adjusted priority values for risk impact

(ii) Likelihood Priority Vector

Next, the likelihood priorities are determined. The initial priorities show a CR = 10.44%. This is slightly larger than the acceptable value of 10%. The revision of judgements procedure is followed again resulting in adjusted priorities that can be seen in the final column of Table 6-8, with CR = 4.01% which is within the acceptable limits.

Table 6-8: Initial and adjusted priority vectors for risk likelihood

	Consistency Ratios (%)	**CR = 10.44**	**CR = 4.07**
ID	**Risk**	**Initial Priority (%)**	**Adjusted Priority (%)**
1	Inhalation of chemicals	3.35	3.36
2	Cell phones and media Players	2.61	2.61
3	Incorrect stacking and storing	8.98	9.55
4	Repairing vehicle doors	1.55	1.17
5	Contractor Control	8.51	8.63
6	Abuse of assets	15.31	15.80
7	Abuse of lifting equipment	7.87	4.14
8	Equipment not working	16.86	17.19
9	Materials handling	3.51	3.52
10	Noise and dust	6.75	6.69
11	Malfunctioning fire extinguishers	2.24	2.31
12	Theft	14.57	17.10
13	Staff not wearing PPE	3.05	3.09
14	Procedural issues	3.85	3.80
15	Removing vehicle wheels	0.99	1.04

Figure 6-3 depicts the priorities evaluated on the likelihood criterion. From this figure, it can clearly be seen that risk 6, risk 8 and risk 12 dominate the likelihood criterion priorities. This result is similar to the trend depicted in Figure 6-2. The priorities indicate that the abuse of assets, essential equipment not working and theft of assets/tools are the events that are most likely to occur.

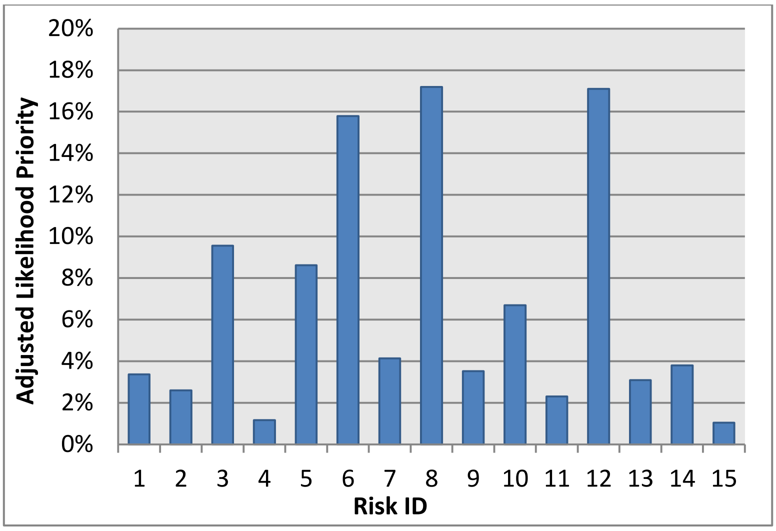

Figure 6-3: Adjusted priority vector for risk likelihood

Since risk 6, risk 8 and risk 12 exhibit the largest priorities with respect to both criteria, it can already be predicted that these risks will have the largest priorities with respect to the global priority vector, which 1.18takes into account the relative importance of the criteria with respect to the goal.

(iii)Global Priority

The global priority is calculated according to the procedure in section 4.1.1.2. First, the matrix $\boldsymbol{S}$ is formed with columns equal to the adjusted impact and likelihood priority vectors from Table 6-7 and Table 6-8 respectively.

$$S = \begin{Bmatrix} 4.36 & 3.36 \\ 2.81 & 2.61 \\ 8.23 & 9.55 \\ 2.28 & 1.17 \\ 7.78 & 8.63 \\ 16.07 & 15.80 \\ 3.91 & 4.14 \\ 13.70 & 17.19 \\ 3.14 & 3.52 \\ 5.52 & 6.69 \\ 2.62 & 2.31 \\ 19.19 & 17.10 \\ 4.20 & 3.09 \\ 5.02 & 3.08 \\ 1.22 & 1.04 \end{Bmatrix}$$

Next, the relative importance of criteria is arranged in a matrix $\boldsymbol{B}_{criteria}$. When several criteria exist, the analytical hierarchy process must be followed to determine the importance of the criteria with respect to the goal. However, only two criteria exist in this case, namely the risk impact and likelihood. These criteria were assumed to have equivalent weight of 50%.

Thus:

$$B_{criteria} = \begin{Bmatrix} 50 \\ 50 \end{Bmatrix}$$

The global priority is then calculated by matrix multiplication of $\boldsymbol{S}$ and $\boldsymbol{B_{criteria}}$. Table 6-9 shows the global priorities based on the adjusted priority vectors for impact, likelihood and $\boldsymbol{B_{criteria}}$.

Table 6-9: Global Priority Vector

ID	Risk	Global Priority
12	Theft	17.74
6	Abuse of assets	15.97
8	Equipment not working	15.67
3	Incorrect stacking and storing practices	9.17
5	Contractor control	7.82
10	Excessive noise and dust / debris	6.04
14	Procedural issues	4.45
7	Abuse of lifting equipment	4.07
1	Inhalation of chemicals	3.90
13	Staff not wearing PPE	3.69
9	Materials handling	3.36
2	Cell phones and media players	2.75
11	Malfunctioning fire extinguishers	2.50
4	Repairing vehicle doors	1.75
15	Removing vehicle wheels	1.13

Table 6-9 shows that the participants in the risk management study perceived the theft of tools and other assets as the most threatening risk. This was closely followed by the abuse of assets and essential equipment not working.

Considering the risks in Table 6-9, it was expected that risk 8, essential equipment not working, would have the largest priority since functional essential equipment is required to complete vital activities thereby achieving objectives. However, participants perceived theft of assets as a more threatening risk.

This could be due to the fact that participants may have experienced theft personally at the company resulting in a wholly negative predisposition toward theft. If this is the case, it can be construed as motivational biases, in that a predisposition toward theft influenced the ratings.

Since the questionnaire did not require the participants to specify the tools and/or assets that were stolen, it may happen that essential asset/tools were stolen, thus delaying work and reducing productivity. If essential equipment was being stolen, then the severity of risk is warranted.

One of the main functions of the company is the repair and maintenance and repair of said assets. Thus, the abuse of these assets by staff and contract workers negates this main function. For this reason, risk 6, the abuse of assets is the second most severe risk in Table 6-9.

The initial and adjusted global priorities are shown in Figure 6-4. From this figure it can be seen that there is no significant change in global priorities due to revision of judgements. It was stated that since the consistency ratio was only slightly larger than 10%, the original solution would be sufficient. Thus Figure 6-4 validates this claim.

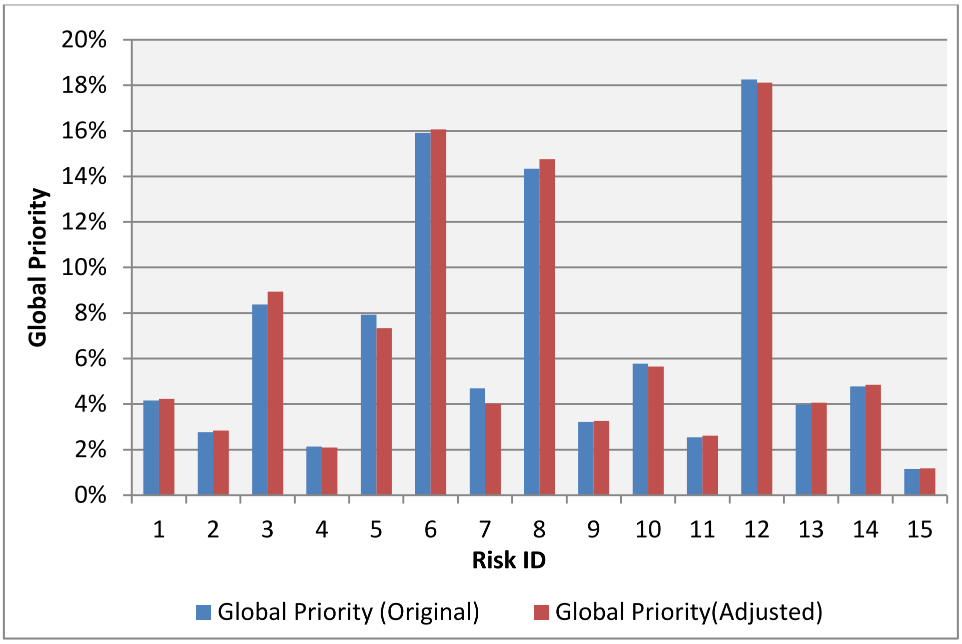

Figure 6-4: Initial and adjusted global priorities

6.5.1.4 Analytical Hierarchy Process Criteria Sensitivity Analysis

The final step in the AHP is to determine the robustness of the solution. This is done according the method in section 4.1.1.2. First, the criteria weights in $\boldsymbol{B_{criteria}}$ were adjusted after which the global priority was recalculated. This procedure was followed for several variations in the criteria weights. The results are shown in Table 6-10:

Table 6-10: Analytical hierarchy process sensitivity analysis

Prioritised list of Risks		(Impact Weight %, Likelihood Weight %)						
ID	**Risk**	**(50,50)**	**(60,40)**	**(70,30)**	**(80,20)**	**(40,60)**	**(30,70)**	**(20,80)**
		Global Priority %						
12	Theft	16.88	17.34	17.80	18.26	16.41	15.95	15.49
6	Abuse of assets	15.69	15.76	15.84	15.92	15.61	15.54	15.46
8	Equipment not working	15.28	14.96	14.65	14.33	15.60	15.91	16.23
3	stacking and storing	8.60	8.53	8.45	8.38	8.68	8.75	8.83
5	Contractor control	8.15	8.07	8.00	7.93	8.22	8.29	8.36
10	noise and dust	6.14	6.02	5.89	5.77	6.26	6.38	6.51
14	Procedural issues	4.43	4.55	4.67	4.78	4.31	4.20	4.08
7	Abuse of lifting equipment	5.89	5.49	5.09	4.70	6.28	6.68	7.08
1	Inhalation of chemicals	3.86	3.96	4.06	4.16	3.75	3.65	3.55
13	Staff not wearing PPE	3.63	3.74	3.86	3.97	3.51	3.40	3.28
9	Materials handling	3.33	3.29	3.25	3.22	3.36	3.40	3.44
2	Cell phones and media players	2.71	2.73	2.75	2.77	2.69	2.67	2.65
11	Malfunctioning fire extinguishers	2.43	2.47	2.50	2.54	2.39	2.35	2.32
4	Repairing vehicle doors	1.91	1.99	2.06	2.13	1.84	1.77	1.70
15	Removing vehicle wheels	1.09	1.11	1.12	1.14	1.07	1.05	1.03

The first column of global priorities represents the standard conditions, namely equivalent impact and priority criteria weight. Each successive column represents the risk priorities when the respective criteria have been altered to the percent values given in brackets.

Table 6-10 shows that the solution is robust to changes in criteria weights. The risk rankings only change in the last two columns, and only among the top 3 risks. The remainder of the risks are not significantly influenced by changes in the impact or likelihood weighting.

The robustness of the solution is due to the fact that participants scored, on average, the impact and likelihood of a specific risk with the same value, or only 1 point difference. For example, a risk given a 4 impact score would either receive a 3, 4 or 5 likelihood rating.

Further analysis revealed that, on average, the likelihood score would never be more than the impact score for a given risk (See Table 6-19 in section 6.5.4). This meant that if the impact was rated as 4, the likelihood would either be 4 or 3.

These results are a clear indication of bias (see section 3.2.2.2). Since questionnaires were completed anonymously, biases could not be detected beforehand and subsequently reduced. In order to continue with the analysis of the results, it is assumed that the data collected is acceptable.

In spite of the presence of possible biases, a sensitivity analysis is presented next.

In second to last column, which represents a 30% impact and 70% likelihood criteria weight, it can be seen that risk 8, essential equipment not working, becomes more important than risk 6, the abuse of assets. Thus, risk 6 moves down from the second to the third position in the priority rankings while risk 8, essential equipment not working moves from up from the third to the second position. Risk 12, the theft of tools and assets, remains the most important risk.

In the final column, which represents a 20% impact and 80% likelihood criteria weight, it can be seen that risk 8, essential equipment not working, becomes the most important risk, followed by theft and subsequently abuse of assets.

Figure 6-5 is a graphical representation of the sensitivity of the top 3 risk events to changes in impact and likelihood criteria weight. The X-axis represents specific criteria weighting sets (See Table 6-11); the Y-axis represents the deviation from the standard value.

Table 6-11: Criteria Weight set corresponding to Figure 6-5

Criteria Weight set	Impact, Likelihood
1	**(0.8,0.2)**
2	**(0.7,03)**
3	**(0.6,0.4)**
4 (standard)	**(0.5,0.5)**
5	**(0.4,0.6)**
6	**(0.3,0.7)**
7	**(0.2,0.8)**

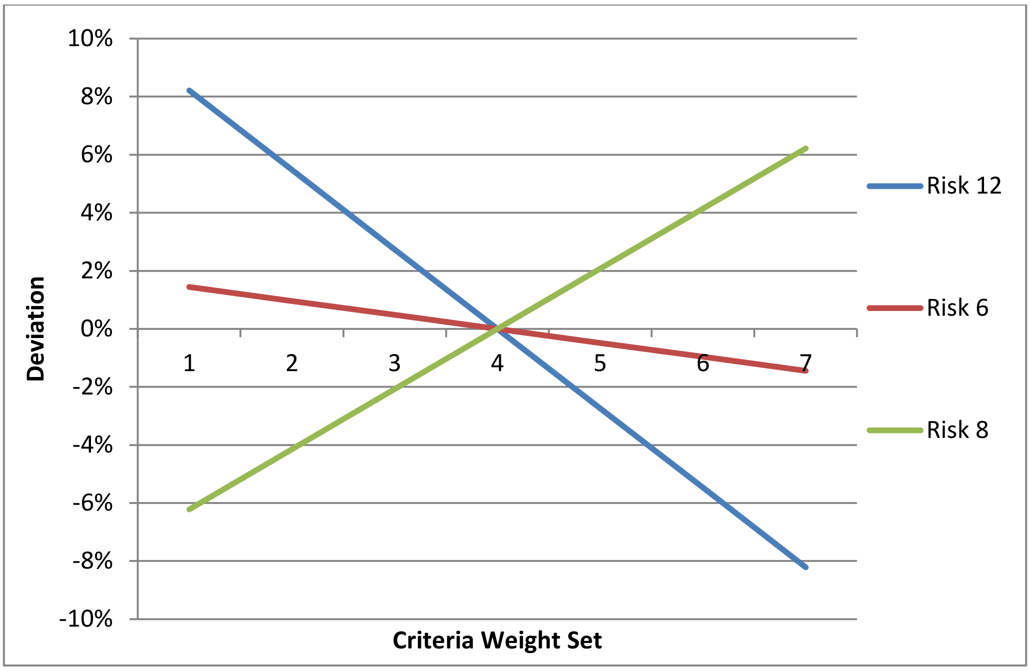

Figure 6-5: Graphical representation of top 3 risks sensitivity

The graph also shows that risk 6 is very stable with respect to deviation in any direction. Risk 8 and 12 are more susceptible to change.

Figure 6-5 shows more clearly that as the likelihood is increased (moving from set 4 to set 7), risk 6 and risk 12 deviate in the negative direction, that is, they become less important while risk 8 deviates in the positive direction, that is, becomes more important. This implies that risk 8 is more sensitive to changes in likelihood than risk 12 or risk 6.

The susceptibility to changes in likelihood shows that the frequency with which essential equipment malfunctions is more important than the resulting impact it has on the company. This is intuitive because as the frequency of malfunctioning equipment increase, downtime increases and productivity decreases. It is also the case that frequently malfunctioning machinery are sources of frustration for individuals who cannot perform their duties as result.

As the impact is increased, (moving from set 4 to set 1), risk 12 and risk 6 deviate in the positive direction, that is, becomes more important. The percentage deviation of risk 12 is larger than that of risk 6, which demonstrates that it is more sensitive to an increase in the impact. Risk 8 deviates in the negative direction, becoming less important.

From the sensitivity analysis, it can be said that losses associated with theft are more important than the frequency. The same conclusion can be applied to abuse of assets. In the case of essential equipment not working, the sensitivity analysis shows that the frequency is more important the impact.

6.5.2 Identifying Critical Risks

6.5.2.1 RDM Questions

The next procedure is the Risk Diagnosing Methodology or RDM. In this technique, the risks are designated as either critical or non-critical based on a series of questions relating to each risk (See section 4.1.2.1.).

Twelve of the 17 risks identified in Table 6-3 were randomly chosen to perform the RDM methodology. It must be noted that while the AHP and RDM are usually performed sequentially, the methods are independent and can be completed separately. Thus, 12 risks were chosen at random for the RDM analysis. Some of the risks chosen for RDM appear in the AHP, so, these shared risks will be compared based on ranking to criticality.

Table 6-12 gives the chosen list of risks as they appear in the RDM questionnaire. The risk ID corresponds to those indicated in Table 6-3. The completed risk profile can be seen in Table B-5 and Table B-6 in Appendix B.

Risks were deliberately chosen at random, placed in a different order as well as worded differently when compared to the AHP questionnaire. This was done to reduce anchoring bias to the AHP questionnaire answers given, since the data requested by the AHP and RDM are similar.

Table 6-12: Risk used in the RDM

ID	Risk
7	Abuse / Improper use of lifting equipment resulting in injury
6	Abuse of assets: vandalism and staff urinating in assets
16	Staff aggression towards supervisors: Supervisors abused verbally or physically.
9	Hazardous materials handling: improper handling of solvents causes chemical fire
1	Inhalation of chemicals during paint stripping of components
2	Staff member death/injury due to use of cell phones and media players
3	Incorrect stacking and storing practices results in item falling from height injuring staff member.
17	Withdrawal of contract services due to non-payment: hazardous waste handling by staff
13	Staff not wearing PPE results in injury
15	Staff Injury: Removing and replacing vehicle wheels
5	Contractor control: contractor creates risk situation resulting in injury
4	Shock, falling, lacerations during repairing of vehicle doors

Table 6-13: Scores by participants for RDM Question 1

RDM Question 1				
ID	**Risk**	**Mean**	**Deviation**	**Median**
7	Abuse of lifting equipment	2.21	1.05	2.5
6	Abuse of assets	3.92	1.16	4
16	Staff aggression towards supervisors	3.21	1.31	3
9	Materials handling	1.79	1.12	1.5
1	Inhalation of chemicals	3.00	1.54	3.5
2	Cell phones and media players	1.86	1.03	1.5
3	stacking and storage	2.57	1.28	2
17	Withdrawal of contract services	4.21	1.12	5
13	staff not wearing PPE	2.36	1.28	2
15	Removing vehicle wheels	1.91	0.83	2
5	Contractor control	2.38	1.19	2
4	Repairing vehicle doors	1.73	0.79	2

Table 6-13 displays the mean and standard deviation of risks measured on the number of occurrences dimension. In Table 6-13 above, the higher the mean rating, the higher the risk. Table 6-13 also shows the standard deviation and the median. In cases where the mean is significantly greater than the median or where the standard deviation is greater than 1.5, a wide distribution of opinions exists. From Table 6-13, it can be seen that no such cases occur thus yielding reliable results.

Table 6-14: Scores by participants for RDM Question 2

RDM Question 2				
ID	**Risk**	**Mean**	**Deviation**	**Median**
7	Abuse of lifting equipment	1.62	0.96	1
6	Abuse of assets	2.18	1.25	2
16	Staff aggression towards supervisors	2.08	1.04	2
9	Materials handling	2.54	0.97	3
1	Inhalation of chemicals	1.55	0.93	1
2	Cell phones and media players	2.31	1.25	2
3	Stacking and storage	1.85	1.21	1
17	Withdrawal of contract services	1.54	0.88	1
13	Staff not wearing PPE	2.15	1.28	2
15	Removing vehicle wheels	2.45	1.44	2
5	Contractor control	2.77	1.48	2
4	Repairing vehicle doors	2.45	1.29	2

Table 6-14 shows the risk measured on the level of control dimension. The risk events which participants perceived as difficult to control have a higher rating. A low mean rating implies that the risk can be controlled. The findings from Table 6-14 indicate all of the risks can be controlled to varying degrees. No mean values significantly greater than the median or standard deviations greater than 1.5 was observed in Table 6-14 thus, the results are considered as reliable.

Table 6-15: Scores by participants for RDM Question 3

RDM Question 3				
ID	**Risk**	**Mean**	**Deviation**	**Median**
7	Abuse of lifting equipment	4.23	1.01	5
6	Abuse of assets	4.27	0.65	4
16	Staff aggression towards supervisors	4.62	0.65	5
9	Materials handling	3.77	1.09	3
1	Inhalation of chemicals	4.55	0.69	5
2	Cell phones and media players	4.23	1.01	5
3	Stacking and storage	4.15	1.14	5
17	Withdrawal of contract services	4.69	0.63	5
13	Staff not wearing PPE	4.00	0.91	4
15	Removing vehicle wheels	4.00	1.00	4
5	Contractor control	3.77	1.24	4
4	Repairing vehicle doors	4.00	1.10	4

Table 6-15 presents the risks rated on the impact on objectives dimension. The results give the impression that the majority of the risks pose significant threat to the objectives of the company. If the objectives cannot be achieved, the enterprise cannot create value. However, results from Table 6-2 indicated that the majority of the participants were not aware of the objectives of the enterprise or unit. If a participant is not aware of the objectives of the enterprise, then their ability to score the impact of risks on the objectives is questionable.

The data, although slightly unreliable due the results in Table 6-2, is accepted as reliable in order to continue with the analysis.

6.5.2.2 Risk Criticality

Once the ratings for the risks are obtained, the risk profile is built, Table B-5 and Table B-6 in Appendix B presents the risk profile. Following the rules for risk diagnosing in section 4.1.2.1, risk criticality is determined from the risk profile. Table 6-16 shows the criticality of the risks assessed using RDM.

Table 6-16: Risk Criticality based on the risk diagnosing methodology

ID	Risk	Category	Criticality
7	Abuse of lifting equipment	L	Non-Critical
6	Abuse of assets	H – F	Critical
16	Staff aggression towards supervisors	L – H	Critical
9	Materials handling	S – H	Critical
1	Inhalation of chemicals	L – H	Critical
2	Cell phones and media players	L	Non-Critical
3	Stacking and storage	L – H	Critical
17	Withdrawal of contract services	M	Non-Critical
13	Staff not wearing PPE	L – F	Critical
15	Removing vehicle wheels	L – M	Non-Critical
5	Contractor control	S – F	Critical
4	Repairing vehicle doors	L – M	Non-Critical

In the Table 6-16, S = safe, L = low, H = high and F = fatal.

A risk categorised higher than medium is considered to be critical. When a risk is categorised with a distribution such as L – H, the company should plan for the undesirable case. Thus, L – H becomes H and the associated risk is considered to be critical.

Moreover, distributions give an indication of the level of agreement. For wide distributions, the level of agreement is very low. This has an implication on the cost of risk controls. Since the company is advised to plan for the undesirable case, a risk categorised as S – F would have to be controlled based on the F category. It is cost effective to investigate the lack of consensus and reduce the spread of opinions such that the risk can be categorised using a single category.

6.5.2.3 Overall Enterprise Risk

The RDM was also used to determine overall enterprise risk. Following the procedure in section 4.1.2.2, the overall risk for the pessimistic case (when distributions are assumed to be in the undesirable category), and the optimistic case (distributions are assumed to be in the desirable category) can be calculated. Table 6-17 below shows the weighting assigned to the various risk categories.

Table 6-17: RDM risk category weighting

Risk Category	Category Weighting
F (Fatal Risk)	4
H (High Risk)	3
M (Medium Risk)	2
L (Low Risk)	1
S (Safe Risk)	0

Figure 6-6 below, is the overall enterprise risk based on a 0 to 100% scale. In this figure, 100% represents the case when all the risks are fatal and 0% indicates that all the risks are safe.

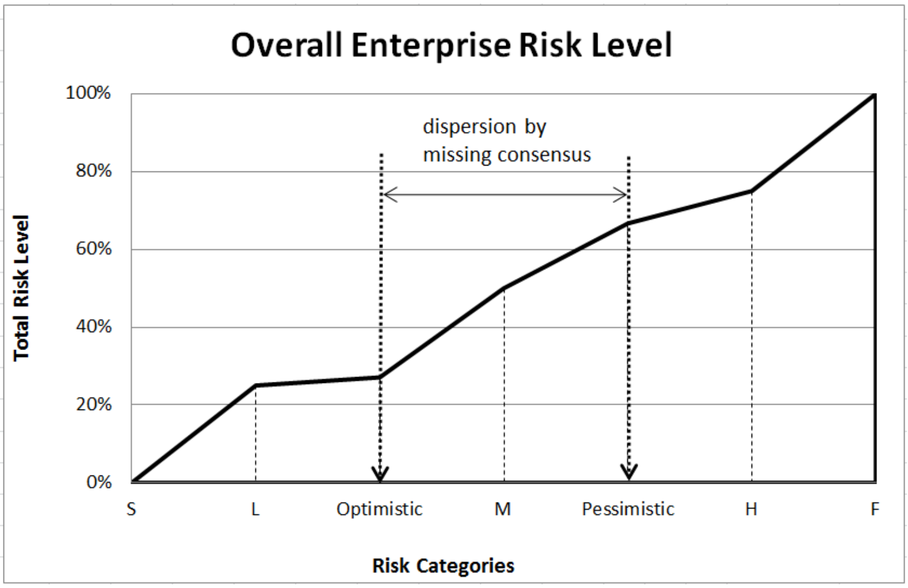

Figure 6-6: Overall Enterprise Risk

Figure 6-6 shows that the optimistic case is situated at approximately 27% of the total risk, between low and medium risk. The pessimistic case lies between the medium and high at approximately 65%. The dispersion by lack of consensus is the vertical distance between these points, which is approximately 38%.

The dispersion indicates that every evaluation of risk is at least 62% reliable. While this is acceptable, the company should strive towards a minimum reliability of at least 80%. This can be achieved by increasing awareness about the risks in the company.

Interpreted differently, it can be said that any evaluation of risk may have a deviation of at most 38%. Figure 6-6 also shows that on average, risks will be found within the pessimistic and optimistic region.

6.5.3 Risk Diagnoses Compared to Risk Priority

Table 6-18 shows the risks that were common to both the RDM and AHP. The risks are arranged in order of importance as determined by the AHP methodology. The risk category and resultant criticality are listed.

Table 6-18: Risk criticality compared to risk priority.

Risk ID	AHP ranked list	RDM Category	Criticality
6	Abuse of Assets	H-F	Critical
3	Stacking and Storing Practices	L-H	Critical
5	Contractor Control	S-F	Critical
7	Abuse of Lifting Equipment	L	Non-Critical
1	Inhalation of Chemicals	L-H	Critical
13	Staff Not Wearing PPE	L-F	Critical
9	Materials handling	S-H	Critical
2	Cell phones and Media Players	L	Non-Critical
4	Repairing Vehicle Doors	L-M	Non-Critical
15	Removing Vehicle Wheels	L-M	Non-Critical

The results show that, the risk priority is not sufficient to establish whether qualitative or quantitative analysis is required. Table 6-18 shows the list of risks in order of importance based on AHP results. The list shows that the top three risks are all critical. However, the fourth risk is non-critical even though it has been ranked as more important than other critical risks.

This is due to the fact that RDM takes into account the level of control over the risk. Well understood risks are usually easier to control and thus non-critical. This is the case with the fourth highest risk in Table 6-18.

6.5.4 Risk Impact and Likelihood: Qualitative Technique

The qualitative assessment of the risks was performed using the risk impact and likelihood questionnaire in Appendix A. Since qualitative analysis is performed quickly and with little difficulty, the risks shown in Table 6-19 were evaluated regardless of criticality. This will also serve to emphasise the amount of time and effort required for qualitative assessment as opposed to quantitative. The average impact and likelihood as well as the standard deviation were calculated as shown in Table 6-19. A standard deviation greater than 1.5 indicates a lack of consensus.

Table 6-19: Qualitative assessment of risk impact and likelihood

ID	Risk	Impact	Likelihood	St. Dev (Impact)	St. Dev. (likelihood)
1	Inhalation of chemicals	3	3	1.30	1.19
2	Cell phones and media Players	3	3	1.41	1.34
3	Incorrect stacking and storing practices	4	4	1.48	0.99
4	Repairing vehicle doors	4	3	1.04	0.81
5	Contractor control	4	4	1.17	1.23
6	Abuse of assets	5	5	1.16	1.40
7	Abuse of lifting equipment	4	3	1.29	1.27
8	Equipment not working	4	4	0.88	0.93
9	Materials handling	4	3	1.27	1.15
10	Noise and dust	4	4	1.27	1.21
11	Malfunctioning fire extinguishers	3	3	1.62	1.02
12	Theft	5	4	1.07	1.27
13	Staff not wearing PPE	4	3	1.53	1.34
14	Procedural issues	4	3	1.27	0.97
15	Removing vehicle wheels	4	3	1.47	1.29

The following risks were identified as having an impact with a standard deviation larger than 1.5:

- Risk 13: Staff not wearing PPE
- Risk 11: Malfunctioning fire extinguishers

Broken fire extinguishers was a risk event obtained from the incidents reports and thus had not yet been included in the formal risk management processes at the company. Thus, all the participants might not have been aware of this risk event prior to the evaluation process.

Staff not wearing PPE was not associated with a specific activity in the risk questionnaire. It was meant to be a general question as it was noticed that many of the risk events arise due to staff not wearing PPE. This may have been a vague question as the impact of not wearing PPE can vary depending on the task. None of the risks evaluated on the likelihood dimension displayed a standard deviation greater than 1.5.

6.5.5 Risk Impact and Likelihood: Quantitative Technique

3 critical risks were chosen from Table 6-18. These were:

- Inhalation of chemicals
- Stacking and storing practices
- Contractor control

6.5.5.1 Risk Ratings and information from the company data

The data provided in this section will be used in subsequent quantitative assessment procedures. The risk register provided by the company gave the following ratings for the critical risks:

Table 6-20: Company risk ratings before mitigation

ID	Risk	Impact	Likelihood	Exposure
1	Inhalation of chemicals	2	4	6
3	Stacking and storage practices	3	3	6
5	Contractor control	5	5	5

From the Table 6-20, it can be seen that the company evaluated the risk based on a third parameter, exposure. Exposure is how often the employees perform the task that exposes them to the risk. The tasks associated with each risk can be seen in Table 6-3. An interpretation of the exposure values is shown in Table 6-21.

Table 6-21: Exposure values interpretation from company data

Weight	Interpretation
1	Remotely possible
2	Sometimes
3	Once per month
4	Once per week
5	Once per day
6	Continuous; daily

The company impact ratings in Table 6-20 are associated with specific costs. These costs are summarised in Table 6-22:

Table 6-22: Impact weight description and associated cost from company data

Weight	description	Cost (R)
1	Minor injury	> 1000
2	Temporary injury	> 10 000
3	Serious injury	> 100 000
4	One fatality	> 500 000
5	Several fatalities	> 1 000 000
6	Many fatalities	> 10 000 000

The company also provide a list of risk control strategies as well as the risk rating after the controls were implemented.

Table 6-23: Company risk controls and ratings after mitigation

ID	Risk Controls	Impact	Likelihood	Exposure
1	Layer of water to cover the stripping chemicals	1	1	5
3	Training of staff; supervision by warehouse supervisor	1	2	6
5	Project meetings; Service Level Agreements	2	3	5

Table 6-3 shows that each risk is associated with an activity. For the inhalation of chemicals, the activity is cleaning of components with solvent. The risks event and control thereof associated with the activities are as follows:

The residue from the solvent used, drips onto the ground during the cleaning process. This residue is volatile and evaporates readily. The fumes are then inhaled by the worker. The chosen risk control is to cover the residue with a layer of water drastically reducing the evaporation rate.

For stacking and storing practices, the activity is improper stacking and storing of materials which then fall from height and injure personnel. The mitigation strategy is the training of personnel in proper stacking and storing practices as well supervision by a storage manager.

For contractor control, the activity is contractors engaging in unsafe and hazardous behaviour due to lack of knowledge about risks or disregard for safety procedures. The resulting mitigation is to conduct meetings with the contractors to establish service level agreements. Service level agreement sets the standard to which contractors will be held.

6.5.5.2 Risk Impact based on Quantitative Techniques

Quantifying the risk impact using the method in section 4.1.3.4 requires a sufficient amount data that is reliable. The company was unable to provide the data, thus the expert opinion methodology for estimating the risk impact distribution was used (See section 4.1.3.5).

Using expert opinion, an optimistic, pessimistic and most likely cost of the risk is required to perform the analysis. These values were obtained from the data provided by the company in section 6.5.5.1. First, the optimistic cost was obtained by looking at the impact weighting assigned to the risks after mitigation in Table 6-23. This impact rating was then used to find the corresponding cost in Table 6-22. The pessimistic value was obtained by looking at the risk impact before mitigation in Table 6-20 and finding the corresponding cost in Table 6-22.

Accurate values for the most likely cost could not be obtained from the company. Thus it was assumed to be approximately 15% to 40% of the pessimistic cost. This assumption is only made due to a lack of data. The main research goal of this study is not to perform a risk assessment for company but partly, to show that quantitative risk management can be performed without being overly complex.

Table 6-24 was set up based on the company data and assumptions. Here, $\boldsymbol{A}$ represents the optimistic cost, $\boldsymbol{B}$ is the pessimistic cost and $\boldsymbol{m}$ is the most likely cost. The mean and standard deviation were calculated using the formulas in section 4.1.3.5. The beta distribution shape parameters, $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$, are then calculated using the equations in section 4.1.3.4.

Table 6-24: Beta and PERT parameters for the impact of critical risks

Parameters	Inhalation of chemicals	Stacking and storing	Contractor Control
$\boldsymbol{A}$	R 1 000	R 10 000	R 10 000
$\boldsymbol{m}$	R 4 000	R 35 000	R 150 000
$\boldsymbol{B}$	R 10 000	R 100 000	R 1 000 000
mean	R 4 500	R 41 667	R 268 333
St. Dev.	R 1 500	R 15 000	R 165 000
$\boldsymbol{\alpha}$	3.951	3.749	3.229
$\boldsymbol{\beta}$	4.938	5.053	5.257

Monte Carlo Simulation was used to generate the beta distribution estimation for the risk impact. Ten thousand simulations were conducted for each of critical risk in Table 6-24 using BETA.INV function in EXCEL.

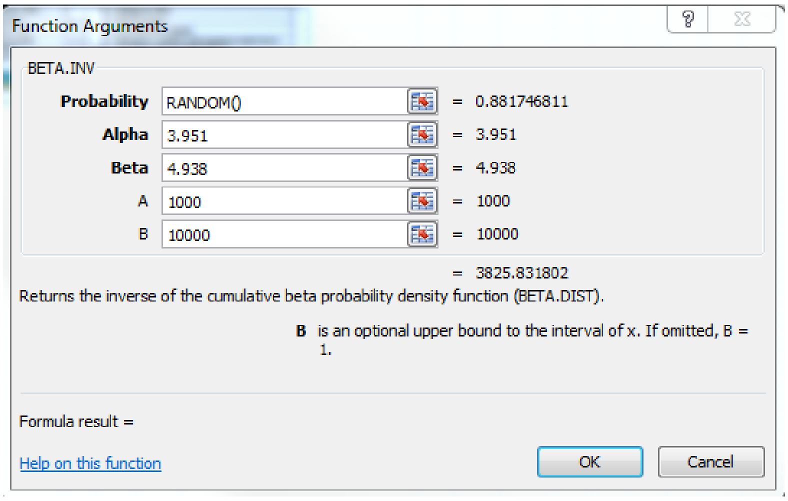

Figure 6-7: BETA.INV function in Microsoft Excel for impact distribution

- The probability box is a random probability value generated at each simulation run using the Monte Carlo Software.
- The alpha and beta are the respective distribution shape parameters.
- A and B are the upper and lower bounds, which correspond to the pessimistic and optimistic cost estimation respectively.

Following the estimation of impact values, the frequency plots are generated using the procedure in section 4.1.3.4. Table 6-25 shows the bins and frequency for the estimated risk impact values with respect to the inhalation of chemicals. Figure 6-8 is a histogram of the frequency data.

Table 6-25: Frequency for impact distribution of inhalation of chemicals

class	bins	Frequency
1	1074 – 1617	1
2	1618 – 2161	12
3	2162 – 2705	147
4	2706 – 3249	377
5	3250 – 3793	706
6	3794 – 4337	1001
7	4338 – 4881	1258
8	4882 – 5425	1343
9	5426 – 5969	1373
10	5970 – 6513	1287
11	6514 – 7057	973
12	7058 – 7601	701
13	7602 – 8145	440
14	8146 – 8689	256
15	8690 – 9233	103
16	9234 +	22

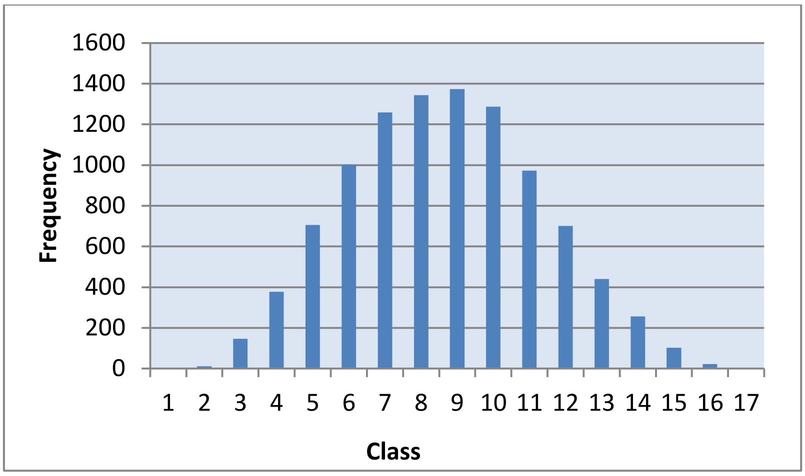

Figure 6-8: Frequency Plot for inhalation of chemicals impact

Figure 6-8 indicates that the most probable impact will occur at either class 8 or class 9. This corresponds to the bins 4882 – 5424 and 5426 – 5969 respectively. Considering the lower limit of class 8 and the upper limit of class 9, it can be deduced that whenever the risk event inhalation of chemicals occurs, it will cost the company approximately R 4 880 to R 5 969. Injury due to incorrect stacking and storing may cost the company anywhere between R 44 081 and R 54 676. Unsafe behaviour by contractors can potentially cost the company between R 387 962 and R 509 805 per incident.

6.5.5.3 Risk Likelihood based on Quantitative Techniques

Each of the critical risks chosen for quantitative analysis exhibit the characteristics of an activity described in section 4.1.3.6. Thus, the quantitative method for estimating risk likelihood can be used. This method requires an estimate of the number of times an activity is completed in given time period, the number of allowable successes and the number of allowable failures. Here, success is completing the activity without the risk occurring and a failure is noted when the risk occurs while performing the activity.

The company was unable to provide reliable estimates for the required parameters. Thus, the number of repetitions is assumed based on the exposure rating prior to mitigation (See Table 6-20), and the number of failures are assumed based on the nature of the activity. The assumptions are as follows:

The inhalation of chemicals is associated with paint stripping of components. The exposure for this risk is continuous, daily. It was assumed that on any given day, the number of times the activity is completed is 60. The tolerance for health risk such as the inhalation of chemicals should be very low thus, it was assumed that number of failures is 10. The number of successes is then 50.

Stacking and Storing is associated with improper storage of components. The exposure for this risk was continuous, daily. It was assumed that on any given day 100 components are stored in designated storage areas. The number of tolerable failures was assumed to be 25. The number of successes is then 75.

Contractor control is associated with contract workers performing various activities at the company. The exposure for this risk was once per day. It was assumed that collectively, contractors perform approximately 50 different tasks per day. Since the contractors are not directly under the control of the company, the tolerable failures is assumed to be 20. The number of successes is then 30.

Table 6-26: Beta distribution parameters for the likelihood of critical risks

Beta distribution Parameters	Inhalation of chemicals	Stacking and storing	Contractor Control
Number of Repetitions	60	100	50
Successes	50	75	30
Failures	10	25	20
Probability of observing the given number of failures and successes		Randomly generated value	

For risk likelihood, the probability of observing the given number of successes and failures is required. This parameter is inherently unknown and thus will be generated at each Monte Carlo Simulation run. Ten thousand Monte Carlo simulations were conducted to estimate the likelihood distribution of the critical risks.

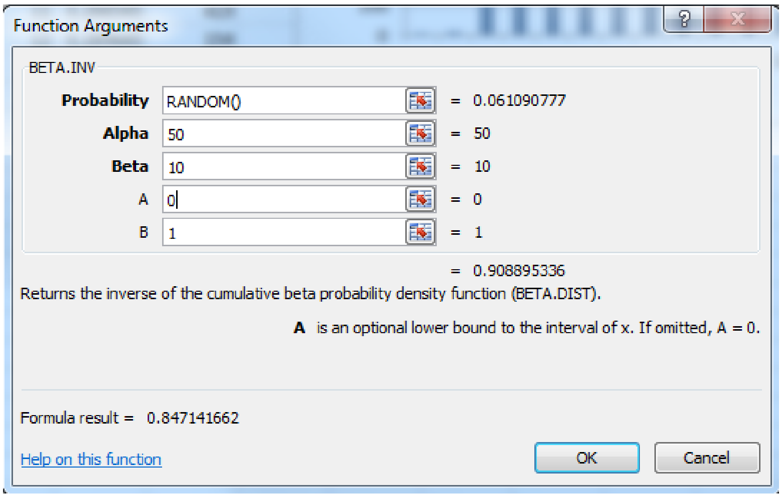

Figure 6-9: BETA.INV function in Microsoft Excel for likelihood distribution

- The probability box is a random probability value generated at each simulation run using the Monte Carlo Software. In this case, the random value is the probability of observing the assumed number of successes and failures for the activity.
- The alpha and beta are distribution shape parameters. The alpha value is the number of successes and the beta value is the number of failures.
- The risk likelihood is bounded by the domain [0 ; 1]. Thus, A and B values are 0 and 1 respectively.

Based on these values, a probability of success (p_s) is calculated for each simulation. The risk likelihood is then $1 - p_s$. At the end of the process, 10 000 risk likelihood values are estimated. Following the estimation of risk likelihood values, the frequency plots are generated. Table 6-27 shows the frequency values for the inhalation of chemicals risk.

Table 6-27: Frequency for likelihood distribution of inhalation of chemicals

class	bins	Frequency
1	0.0355 – 0.0585	1
2	0.0586 – 0.0816	19
3	0.0817 – 0.1047	217
4	0.1048 – 0.1278	657
5	0.1279 – 0.1509	1334
6	0.1510 – 0.1740	1728
7	0.1741 – 0.1971	1898
8	0.1972 – 0.2202	1641
9	0.2203 – 0.2433	1133
10	0.2434 – 0.2664	683
11	0.2665 – 0.2895	419
12	0.2896 – 0.3126	154
13	0.3127 – 0.3357	76
14	0.3358 – 0.3588	32
15	0.3589 – 0.3819	4
16	0.3820 +	4

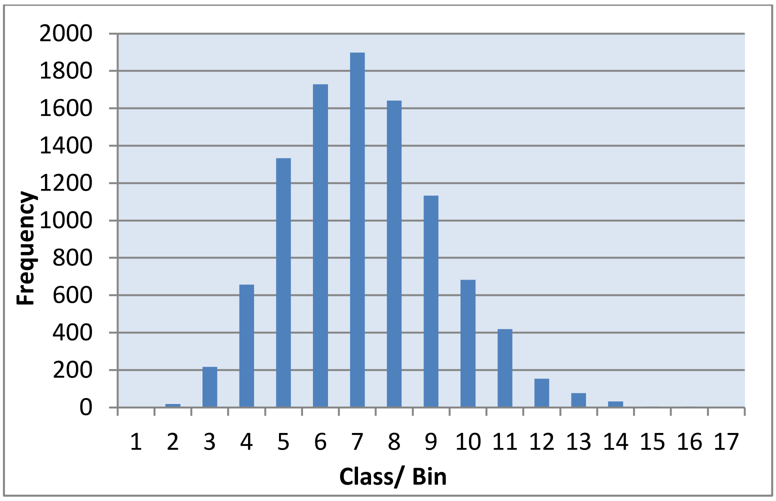

Figure 6-10: Frequency Plot for inhalation of chemicals likelihood

Figure 6-10 indicates that the most probable likelihood will occur at either class 6 or class 7. This corresponds to the bins 0.1510 – 0.1740 and 0.1741 – 0.1971 respectively. Consider the lower limit of class 6 and the upper limit of class 7. Thus, each time paint stripping of components is performed, the likelihood of inhaling chemicals is approximately 15.1 to 19.71%.

Figure C-3 showed that each time an item is stacked incorrectly, the likelihood of injury when it falls can range between 24.5 and 28.9%. Figure C-4 showed that each time a contractor performs an activity, the likelihood of a risk situation being created is approximately 40.7 to 47.6%.

It was stated that if an activity cannot be classified using the guidelines in section 4.1.3.6, the following options are available.

- Option 1: Use the impact distribution to obtain a point estimate for likelihood.
- Option 2: Use expert judgement to obtain a point estimate for the probability.
- Option 3: Use qualitative analysis for the impact and likelihood.

Assuming that the activities could not be classified using the guidelines, option 1 is demonstrated. From Table 6-25, it can be seen that each class is associated with a frequency or number of observations for risk impact. It is then proposed that the most probable impact is located within the range of the top 2 classes. The probability of observing an impact, or risk likelihood in that range of the bins, can be calculated as:

$$Risk\ likelihood = \frac{\sum Frequency(top\ 2\ classes)}{Total\ number\ of\ observation\ for\ all\ classes}$$

The values in Table 6-28 are the number of observations in the top 2 classes for the inhalation of chemicals risk.

Table 6-28: Top 2 classes for inhalation of chemicals

class	bins	Frequency
8	4882 – 5425	1343
9	5426 – 5969	1373

The total number of impact observations generated using Monte Carlo simulation was 10 000. Thus, risk likelihood can be calculated as:

$$risk\ likelihood = \frac{1343 + 1373}{10\ 000} = 0.2716$$

Thus, for inhalation of chemicals, a risk likelihood of 27.16% is observed for an impact occurring in the range R 4 882 to R 5 969. Following the same procedure for the other risks, stacking and storing showed a likelihood of 26.6% with an impact range of R 44 081 to R 54 676. Contractor control showed a likelihood of 27.9% with impact ranging from R 387 962 to R 509 805.

The likelihood values calculated are almost identical. This is due the fact that the PERT method was used to determine impact distribution mean and standard deviation. The PERT method will always result in a near symmetrical beta distribution yielding similar estimations for the risk likelihood. If empirical data was used to model risk impact, the probability distribution would depend on the spread of the data, yielding variable likelihood estimations.

Table 6-29 shows the comparison of the beta distribution likelihood estimation against the likelihood estimation using option 1 alternative.

Table 6-29: Comparison of likelihood estimates

Risk	Beta Distribution likelihood estimate	Option 1 likelihood estimate
Inhalation of Chemicals	15.1 – 19.71 %	27.16%
Stacking and storing	24.5 – 28.9%	26.6%
Contractor control	40.7 – 47.6%	27.9%

6.5.6 Expected Losses

The impact and likelihood distributions were then used to calculate the expected losses. The expected loss is analogous to the risk threat level used in qualitative analysis. Expected losses are calculated as:

$$Expected\ Loss = Impact\ \times Likelihood$$

Section 5.1.2 defines the different expected losses. The unacceptable expected loss $\boldsymbol{R_1}$ is the expected loss before mitigation. The acceptable expected loss $\boldsymbol{R_2}$ is the expected loss after risk mitigation controls have been applied. The unacceptable expected losses were calculated for the critical risk. Since 10 000 impact and likelihood values were estimated using Monte Carlo simulation, 10 000 $\boldsymbol{R_1}$ values were calculated. Next, the $\boldsymbol{R_1}$ frequency plot was generated for each of the critical risks evaluated.

6.5.6.1 Inhalation of Chemicals

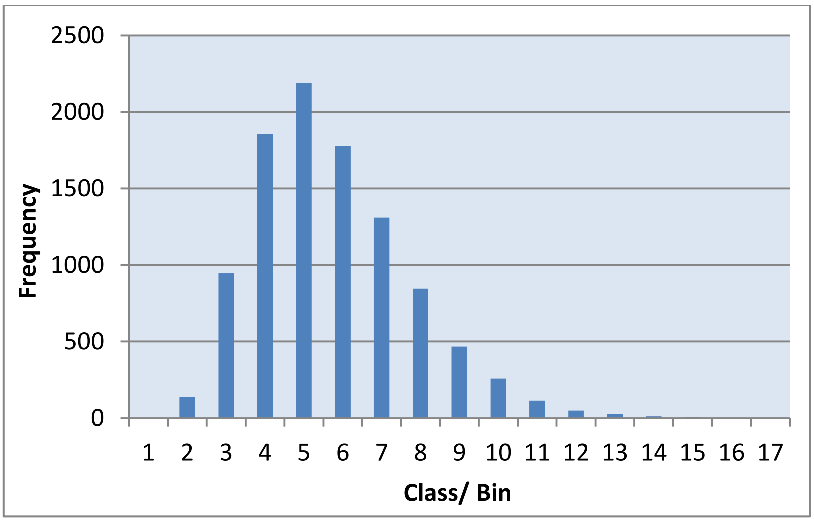

Figure 6-11: Inhalation of chemicals frequency distribution for R_1

Figure 6-11 shows the frequency plot for expected losses with respect to inhalation of chemicals. The bins corresponding to the classes can be found in Table C-1 in Appendix C. The graph shows that the most probable $\boldsymbol{R_1}$ value will be found in either class 4 or 5. This corresponds to an unacceptable expected loss of approximately R 612.7 to R 964.6.

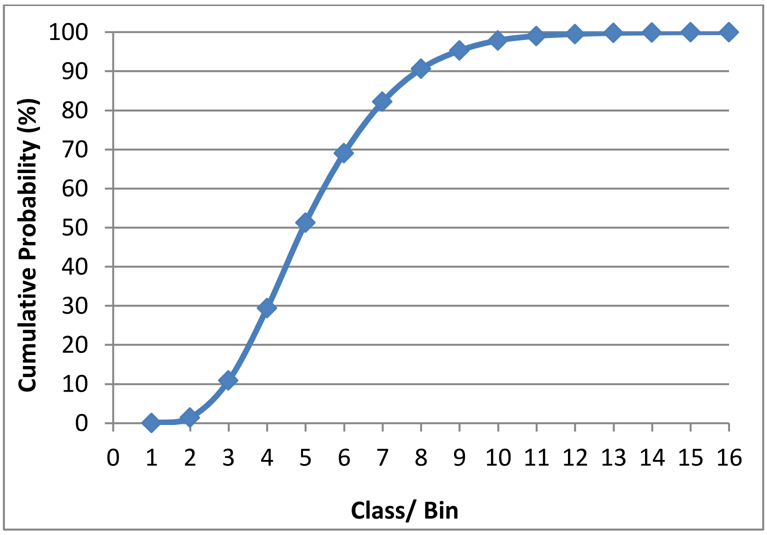

Figure 6-12: Inhalation of chemicals cumulative probability distribution

The cumulative probability distribution was obtained from the frequency which was used in section 6.6 to determine risk response strategy. Appendix C gives the cumulative plots for the other critical risks.

6.5.6.2 Stacking and Storing Practices

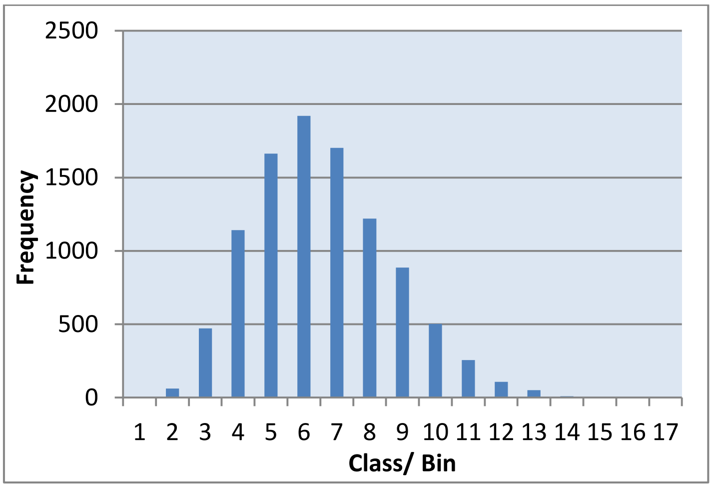

Figure 6-13: Stacking and storing frequency distribution for R_1

Figure 6-13 shows the frequency plot for expected losses with respect to stack and storing practices. The bins corresponding to the classes can be found in Table C-1 in Appendix C. The graph shows the most probable $\boldsymbol{R_1}$ value will be found in either class 6 or 7. This corresponds to an unacceptable expected loss of approximately R 11 949 to R 15 900.

6.5.6.3 Contractor Control

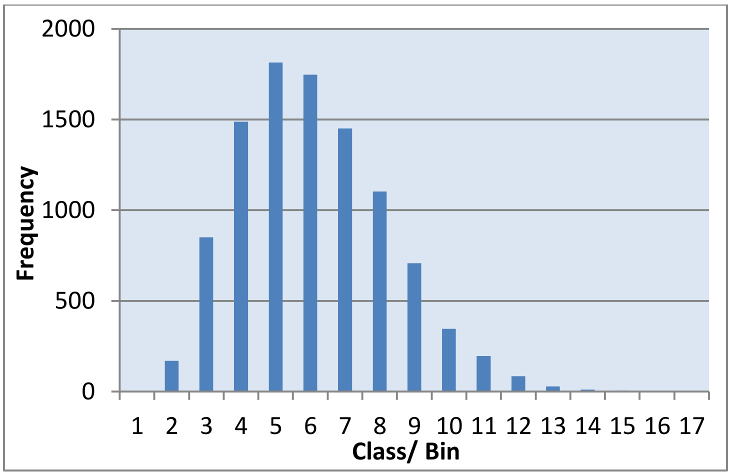

Figure 6-14: Contractor control frequency distribution for R_1

Figure 6-14 shows the frequency plot for expected losses with respect to contractor control. The bins corresponding to the classes can be found in Table C-1 in Appendix C. The graph shows the most probable $\boldsymbol{R_1}$ value will be found in either class 5 or 6. This corresponds to an unacceptable expected loss of approximately R 134 852 to R 198 894.

6.6 Risk Response Choices

6.6.1 Risk Response Choice: Qualitative Technique

Section 6.5.4 presented the risk impact and likelihood evaluated using qualitative techniques. The results of the qualitative impact and probability estimation are then arranged in a risk matrix shown in Figure 6-15 below. The numbers within the matrix represent the risk ID from Table 6-19

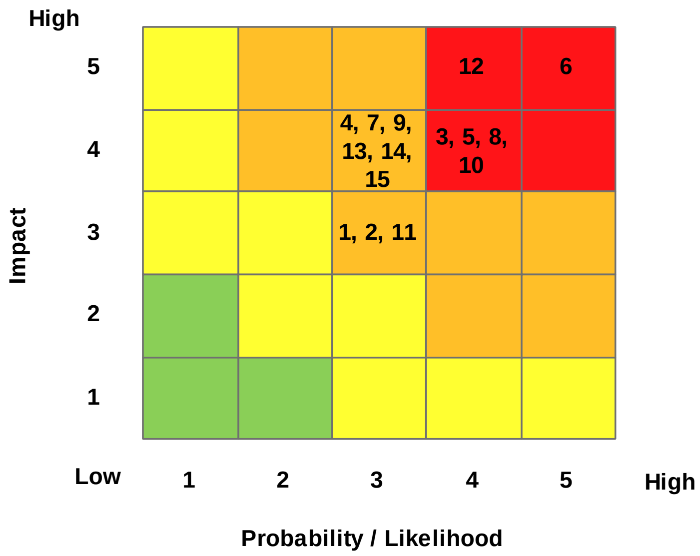

Figure 6-15: Completed Risk matrix

The description of the various colour coded regions can be seen in Table 6-30 below.

Table 6-30: Description of regions in the risk matrix

Classification	Response action
Safe	ACCEPT
Low	REDUCE/SHARE
Medium	REDUCE/SHARE
High	AVOID

It follows that; any risks in the green area should be accepted as the cost of doing business. Risks in the yellow area and orange area should be reduced or shared. Risks in the red area should be avoided.

Sharing and reducing the risk are not mutually exclusive. This means that the company can take both actions simultaneously if that option is available. Table 6-31 shows the suggested response actions for risks based on qualitative assessment techniques.

Table 6-31: Suggested risk response actions based on Figure 6-15

ID	Risk	Severity	Response
1	Inhalation of chemicals	9	reduce/share
2	Cell phones and media Players	9	reduce/share
3	Incorrect stacking and storing practices	16	avoid
4	Repairing vehicle doors	12	reduce/share
5	Contractor control	16	avoid
6	Abuse of assets	25	avoid
7	Abuse of lifting equipment	12	reduce/share
8	Equipment not working	16	avoid
9	Materials handling	12	reduce/share
10	Noise and dust	16	avoid
11	Malfunctioning fire extinguishers	9	reduce/share
12	Theft	20	avoid
13	Staff not wearing PPE	12	reduce/share
14	Procedural issues	12	reduce/share
15	Removing vehicle wheels	12	reduce/share

Qualitative risk response methods are typically used when the risks are non-critical. However, all the risks shown in Table 6-19 were evaluated regardless of the criticality. This was done to demonstrate the simplicity of selecting a risk response using qualitative as opposed to quantitative techniques.

6.6.2 Risk Response Choice: Quantitative Technique

The risk response strategy choice based on quantitative techniques is shown in this section. This methodology requires the following variables:

- A point estimate for $\boldsymbol{R_1}$, the unacceptable expected loss.
- $\boldsymbol{\varphi}$, the ratio of $\boldsymbol{R_2}$ to $\boldsymbol{R_1}$
- A point estimate for $\boldsymbol{R_2}$, the acceptable expected loss
- $\boldsymbol{\omega}$, the irremovable uncertainty
- $\boldsymbol{k}$, the unit prevention cost
- $\boldsymbol{r}$, the insurance rate

6.6.2.1 A Point Estimate for R_1, the Unacceptable Expected Loss

It is noted that reducing the probability distribution of $\boldsymbol{R_1}$ to a point estimate significantly reduces the information regarding parameter and how it affects the company. Unfortunately, it is a necessity when using this methodology.

The point estimate for $\boldsymbol{R_1}$ is chosen using the cumulative probability distribution in Figure 6-12, Figure C-5 and Figure C-6. When the cumulative probability reaches 50%, the associated class number is read from the graph. Each class number corresponds to a specific cost range in the $\boldsymbol{R_1}$ frequency tables (see Table C-1 in Appendix C). The middle value in this range is chosen as the point estimate for $\boldsymbol{R_1}$.

It must be noted that companies can increase the effectiveness of risk mitigation by selecting a higher cumulative probability as this will cover more of expected losses. However, this will yield a higher value for $\boldsymbol{R_1}$ and a consequentially higher mitigation cost.

For the inhalation of chemicals, class number 5 is associated with a cumulative probability of 50%. This corresponds to an unacceptable expected loss in the range R 788.7 to R 963.7. The middle of this range yields the $\boldsymbol{R_1}$ point estimate of R 876.

Following the same procedure the other risks, it was noted that stacking and storing had an unacceptable loss of R 12 937 and contractor control had an unacceptable loss of R 150 862.

6.6.2.2 The R_1 to R_2 Ratio

The ratio can be calculated using qualitative impact and likelihood judgements provided by the company in Table 6-20 and Table 6-23. Any expected loss is a product of impact and probability. Thus, for inhalation of chemicals:

$$R_1 \ = \ 2 \ \times 4 = 8$$

$$R_2 \ = \ 1 \ \times 1 = 1$$

Here, $\boldsymbol{R_2}$ is considered to be the product of the impact and probability ratings after mitigation (See Table 6-23). $\boldsymbol{R_1}$ is the product of the impact and probability ratings before mitigation (See Table 6-20). Thus,

$$\varphi \ = \frac{R_2}{R_1} \ = \frac{1}{8} = 0.125$$

Following the same procedure for the risks, it was found that φ = 0.22 for stacking and storing and φ = 0.24 for contractor control.

6.6.2.3 A Point Estimate for R_2, the Acceptable Expected Loss

It is assumed that the calculated ratio, φ, applies to quantitative data. Therefore, $\boldsymbol{R_2}$ for inhalation of chemicals is:

$$R_2 = \ \varphi \, R_1 = \ 0.125 \times \ R\ 876$$

Thus $R_2 = R\ 110$

Following this procedure for stacking and storing and contactor control, we find that $R_2 = R\ 2\ 875$ and $R_2 = R\ 36\ 207$ respectively.

6.6.2.4 The Unit Prevention Cost, k

The unit prevention cost is a measure of the difficulty to control the risk, and is usually estimated by expert opinion. However, the company was unable to provide a value for $\boldsymbol{k}$. Based on the risk controls in Table 6-23, values for $\boldsymbol{k}$ were assumed.

Consider the inhalation of chemicals. Table 6-23 shows that the risk control is simply adding a layer of water over the chemical residue to prevent evaporation. Due to the simplicity of this solution, $\boldsymbol{k}$ was chosen as R 50.

For the stacking and storing procedures, the controls are training staff and employing warehouse manager. This is slightly more difficult, thus, $\boldsymbol{k}$ was allocated a value of R 150.

Contractor control mitigation involves project meetings with the contracting company wherein negotiation of new contracts and service level agreements are made. Since the contractors are not explicitly within the control of the company, and that difficulties can often arise in contract negotiation and service levels agreements, a value of R 350 was chosen for $\boldsymbol{k}$.

6.6.2.5 The Irremovable Uncertainty, ω

Question 2 of the risk diagnosing methodology required participants to score the risk based on a controllability dimension. A score of 1 indicated total control whereas a score of 5 indicated no control. The values for the irremovable uncertainty $\boldsymbol{\omega}$ are analogous to the RDM score for question 2.

Table 6-32 RDM Score compared to irremovable uncertainty

RDM Score	ω
1	0
2	0.25
3	0.5
4	0.75
5	1

Using regression analysis the following formula was obtained for $\boldsymbol{\omega}$:

$$\omega = 0.25 \times (RDM\ mean\ score) - 0.25$$

Table 6-33 shows the calculated values for $\boldsymbol{\omega}$.

6.6.2.6 The Interest Rate, r

The company was unable to provide information in this regard. Thus the interest rate was assumed to be 5% for all risks.

Table 6-33: Quantitative risk response methodology requirements

Variable	Description	Inhalation of chemicals	Stacking and storing	Contractor Control
$\boldsymbol{\omega}$	Irremovable uncertainty	0.14	0.21	0.44
$\boldsymbol{\mu}$	R_2 to R_1 ratio	0.125	0.22	0.24
$\boldsymbol{R_1}$	Unacceptable expected loss	R 877	R 12 937	R 150 863
$\boldsymbol{R_2}$	Acceptable expected loss	R 110	R 2 875	R 36 207
$\boldsymbol{k}$	Unit prevention cost	R 50	R 150	R 300
$\boldsymbol{r}$	Interest rate	5%	5%	5%
$\boldsymbol{\frac{rR_2}{k}}$	Enterprise characteristics	0.11	0.958	6.035

6.6.2.7 Risk Responses

The rule of thumb in guidelines in Table 5-3 is used to determine the risk responses based on the enterprise and level of control.

Table 6-34: Risk Responses based on rules of thumb

Risk	$\boldsymbol{\frac{rR_2}{k}}$	$\boldsymbol{4\omega}$	Response
Inhalation of Chemicals	0.110	0.54	Adaptation
Stacking and Storing Practices	0.958	0.84	Unclear, use Figure 6-16
Contactor Control	6.035	2.215	Unclear, use Figure 6-17

Table 6-34 shows that the response strategy for the inhalation of chemicals can be chosen using the rules of thumb. The graph of $\boldsymbol{\frac{rR_2}{k}}$ $\boldsymbol{vs\ \omega}$ must be plotted in order to determine the response strategy for the other risks.

(i) Inhalation of Chemicals Risk Response

Table 6-34 shows that the company should adapt to the inhalation of chemicals risk rather than trying to prevent it. This result is counter-intuitive because a company should always attempt to prevent health risks first.

Since the model evaluates the cost of preventing the risk against the cost of adapting to the risk, a low adaptation cost increases the preference towards adaptation. In the case of inhalation of chemicals, the small $\boldsymbol{R_2}$ value resulted in very low adaptation costs. Thus, adaptation became the preferred strategy. This result was foreseeable as the model development does not account for ethical considerations in risk response. Prevention should always be considered when the health and safety of workers are at risk.

(ii) Stacking and Storing Risk Response

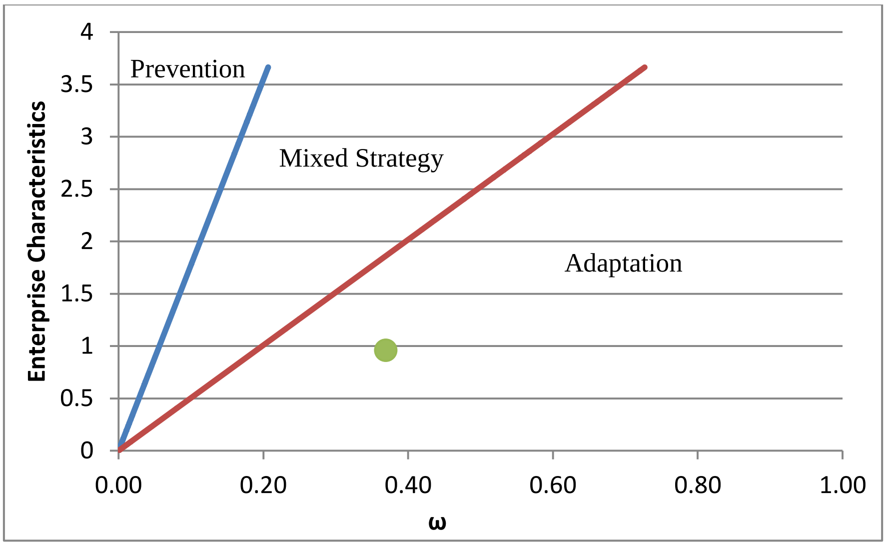

Figure 6-16: Risk Response Strategy for Stacking and Storing

Figure 6-16 was used to determine the preferred risk response strategy for stacking and storing. From Table 6-33 , it can be seen that $\frac{rR_2}{k} = 0.958$ and $\omega = 0.21$. Thus, the optimum response (the green dot) is located in the adaptation region.

This meant that the company should rather implement insurance to cover possible losses instead of training and supervising employees with respect to correct stacking and storing procedures.

Since stacking and storing is a safety risk, ethical considerations must be taken into account when selecting a risk response strategy. These ethical considerations should always outweigh the monetary costs involved. Thus, a preventative or a mixed strategy should be used to mitigate effects of incorrect staking and storing practices.

(iii)Contractor Control

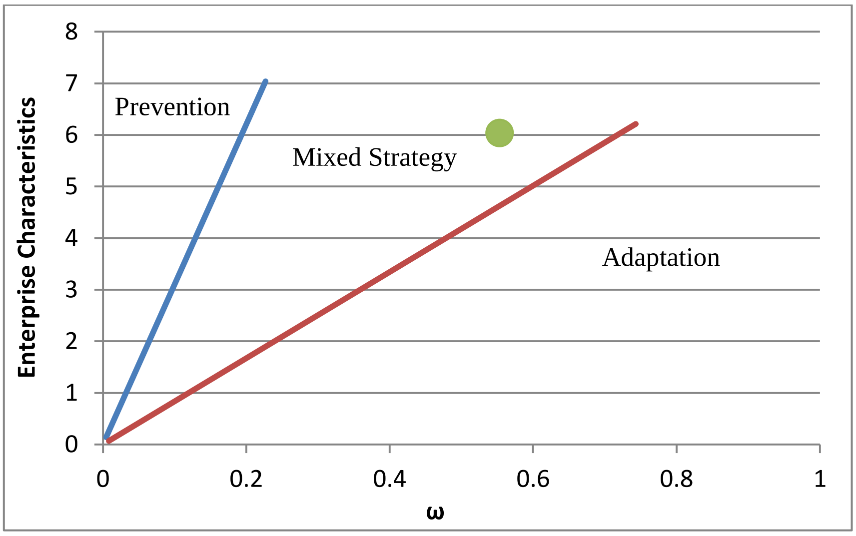

Figure 6-17: Risk Response Strategy for contractor control

Figure 6-17 shows the graph of $\boldsymbol{\frac{rR_2}{k}}$ $\boldsymbol{vs\ \omega}$ for the contractor control risk. From Table 6-33, it can be seen that $\frac{rR_2}{k} = 6.035$ and $\omega = 0.44$. Thus, the optimum response (the green dot) is located in the mixed strategy region.

This result indicated that the company should implement preventative measures such as re-negotiation of service level agreements but also insure for any losses that may occur. Such a strategy agrees with ethical considerations since prevention is included in the response strategy.

The contingency plan is to insure for any losses that may occur. This is necessary because the company does not have direct control over the contract workers. The company relies on service levels agreed upon in negotiations with contractors to mitigate the risk. The partial lack of control is validated by the large irremovable uncertainty $\omega = 0.44$.

6.6.3 Responses Accounting for Ethical Considerations

The final risk response strategies taking into account the model prediction and ethical considerations is shown in Table 6-35.

Table 6-35: Risk response strategies accounting for ethical considerations

Risk	Response
Inhalation of Chemicals	Prevention
Stacking and Storing Practices	Prevention
Contactor Control	Mixed Strategy

The model was unable to account for ethical considerations in risk response. For this reason, the prediction of the model should not be regarded as the best possible solution. When ethical considerations are not a factor, the model produces reliable results.

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

The previous chapter discussed the results arising from implementation of the framework in case study. This chapter presents the general overview of the proposed framework and the achievement of the research goal. Lastly, recommendations are made for future studies.

7.2 Conclusions

- The case study has shown that the core risk management functions, which are necessary in any ERM process, have been successfully encompassed in this framework. These are risk identification, response and assessment.
- Typical risk management literature presents qualitative or quantitative methods in isolation. This study has shown that both quantitative and qualitative techniques can be successfully incorporated into a single, comprehensive risk management framework.
- The methods presented have shown that such a framework can be largely practical. Furthermore, each process in the framework has been integrated in a logical and systematic nature.
- All Calculations, including the Monte Carlo Simulation were performed using Microsoft EXCEL, making implementation of the framework computationally possible without the use of complex programs.
- The proposed framework was able to identify when quantitative analysis is necessary and when qualitative analysis is sufficient. Since quantitative analysis can become complex and time consuming, this distinction is essential to maintaining the practicality of the framework.
- The results show that expert judgement can be used effectively when empirical data is sparse. Alternatives to empirical data are essential in risk management as data is seldom readily available.
- The results of the case study has shown that the framework is able to identify the level of understanding of risk management, the perception of risk management and cultural attributes within an enterprise which affect the risk management process.
- This study has shown that risk management does not have to overly simple to be implemented, or overly complex to be effective.

7.3 Achievement of Research Goal

The main research goal of the study was to develop a practical, systematic enterprise risk management framework that incorporates both qualitative and quantitative risk management techniques. An analysis of practicality and systematic structure of the proposed risk management framework follows.

- The risk identification process, although not studied, lists various techniques and approaches to obtain a comprehensive list of risks.
- The computations in risk prioritisation using AHP can become complex. Thus, such computation requires some prior learning before it can be used effectively.
- It was noted that the time spent on the AHP can become significant as the number of risks increases. Limiting the number of risks evaluated to approximately 25 with a maximum of three criteria will reduce the time spent on comparisons to approximately four to six hours. If more than one individual performs comparisons and computations, the time spent can be significantly reduced.
- Qualitative analysis of risk has been shown to be easily implemented. The simple rating systems associated with qualitative are widely implemented in industry have been shown to be practical, albeit not very descriptive, when assessing risks.
- By contrast, quantitative methods have been shown to provide in-depth analyses of critical risks. However, this naturally increases the complexity of the analysis. Three concerns relating to the practicality of proposed quantitative methods have been noted.
- The first is the availability of data. The framework has accommodated for a lack of data by incorporating expert judgement methods. These methods allow the estimation certain parameters in the absence of data. However reliable expert judgement is required to produce acceptable results.
- The second concern is the complexity of methods. While the methods can become complex, the information that is provided from quantitative analysis vastly surpasses the information from qualitative analysis. This advantage validates the increased complexity of quantitative methods. The only method among the quantitative techniques that proved too complex to be practical was the optimum risk response strategy using the quantitative method.
- The final concern is the time needed to complete a quantitative analysis of the risks. Quantitative analysis will always take longer to complete when compared to qualitative analysis. However, quantitative analysis provides information and an understanding of critical risks that qualitative analysis simply cannot. Thus the time taken to complete such analyses is validated.

This discussion has shown that it is possible to incorporate both qualitative and quantitative risk management techniques in a systematic and practical framework. Thus the goal of the study was achieved.

7.4 Recommendations

- The risk identification process could not be performed due to the time schedule and prior commitments of the employees at the company. Due to this limitation, the effectiveness and practically of the proposed methods could not be properly established. Further studies are required that incorporate the methods proposed in Chapter 3.
- Grouping of opinions applies an importance weighting to an individual's opinion based on their knowledge and expertise of topic to be discussed. Since the questionnaires were completed anonymously, grouping of individual opinions could not be performed. The effect of grouping opinions should be investigated in future studies.
- Another concern that arose due to the anonymous nature of the data collection had to do with the presence of biases in the impact and likelihood rating. The ratings showed that participants exhibited a form of bias. If the ratings were obtained in one-on-one meeting with participants, biases could be detected and managed. Mitigation of biases should be investigated in further studies.
- Several assumptions had to be made when the optimum risk response was determined using quantitative methods. These assumptions were made because the company was unable to provide reliable estimates for the required parameters. It was noted that the assumptions result in errors. However, these do not negate the main research objective of the study, which was to develop a systematic risk management framework that can be applied practically. Accurate estimates of the required parameters should be obtained to ascertain the effect on the results.
- Objective setting has been excluded from this study for reasons presented in Chapter 1. The effect of objective setting processes should be investigated in future studies.
- The complexity and dubious results produced by the quantitative method to determine the optimum risk response is an inherent attribute of the method. Consequently, this method is impractical. Future studies should consider a methodology that is less complex and can account for ethical considerations.
- Non-Probabilistic impact modelling should be investigated to determine whether these methods can be incorporated into the proposed risk management framework.

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APPENDIX A Questionnaires

A.1 Risk Impact and likelihood evaluation questionnaire

1) **Inhalation of Chemicals** –consider tasks involving chemical solvents/dangerous chemicals. Rate how often inhalation of these chemicals occur and how severe the health impact is

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

2) **Using Cell phones and Media Players –** Please rate how often staff members are injured or perform tasks in an unsafe manner due to the use the above mentioned devices. Also rate how bad the impact is.

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

3) **Incorrect Stacking and storing practices –** when parts or tools are stored incorrectly, can this result in an injury? If so, please state how often injuries occurs due to this and how serious the impact is.

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

4) **Injury: Repairing Vehicle Doors –** how often is someone injured (shock, cuts, falls etc.) when performing the task? and on average how bad is the impact of the injuries.

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

5) **Contractor control –** Do the contractors create situations of risk and if so, state how often it occurs how serious the impact is (injuries, damage to property etc.?)

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

6) **Abuse of assets –** how often are the assets vandalised? This includes urinating in the assets. Also, state how bad the impact of this abuse is with respect to cost.

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

7) **Abuse/ improper use of lifting equipment –** when lifting equipment is used, is it always done correctly? If not, please state the likelihood of improper use and the impact thereof (injury/death or equipment damages)

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

8) **Essential Equipment not working –** how often does this occur and in terms of the cost to company, how severe is the impact?

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

9) **Material supply control –** do chemical spills occur due improper handling or mistakes? If so rate it based on the following risks such as chemical fires, chemical solvent burns on skin etc.

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

10) **Excessive noise and dust/debris –** non-operational tasks such as replacing floors, cutting grass, general maintenance and repairs result in dust, workplace distraction or very loud noise. Can this be a hazard? Please rate the following

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

11) **Broken/ Malfunctioning Fire extinguishers –** can this be hazard? If so, please rate how often it occurs and how bad the possible consequences are.

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

12) **Theft of tools and other property –** How often does theft occur on site, and when it does how severe are the consequences with respect to the cost to company or individuals?

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

13) **Staff not wearing PPE –** how often do injuries occur due to staff not wearing PPE and how severe are the consequences?

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

14) **Procedural issues –** How often do risk situations occur if proper procedure are not followed when performing various activities, also state how severe impact is on average.

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

15) **Injuries removing Vehicle wheels –** have there been injuries while performing this task (Back injuries, cuts, falls etc.) in the past? If yes, how often do they occur and how severe is the impact?

	1	2	3	4	5
IMPACT	☐	☐	☐	☐	☐
LIKELIHOOD	☐	☐	☐	☐	☐

A.2 Risk Diagnosing Questionnaire

Risk Statements	How often does the risk occur? very low 1	2	3	4	very high 5	Assume the risk does occur. Do you think anything could be done to reduce/prevent number of occurrences? Yes 1	2	3	4	no 5	If the risk should occur how severely do they affect the enterprise/departmental objectives very low 1	2	3	4	very high 5
(7) The Improper use of Equipment(lifting or other) causes damage to persons or equipment															
(6) Urinating in the coaches/sets/machine rooms etc. poses threat to health, respect for workplace etc															
(16) Staff Aggression towards Supervisors: Supervisor abused verbally or physically															
(9) Fires caused by use of Chemicals in cleaning, stripping of parts/trains etc.															
(1) Inhalation of Chemical Fumes can lead to injury or death															
(2) Injury/Death due use of Cellphones and/or Electronic Devices															
(3) Incorrect Stacking of components in warehouse leads to injury															
(17) Withdrawal of Contract services due to Non-Payment(Interwaste etc.)															
(13) Injury due to staff not wearing PPE															
(15) Staff Injury: Removing and replace train wheels															
(5) Improper safety by contractors causes Injury of Staff/Contractor															
(4) Injuries during Repairing of Train Doors															

Figure A-1: Risk Diagnosing Methodology Questionnaire

A.3 Internal Environment Questionnaire

1) **Leadership and Strategy** – The leaders of my unit set a positive example for ethical conduct.

Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

2) **Leadership and Strategy** – I am aware of what is expected of me in terms of the code of conduct.

Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

3) **Leadership and Strategy –** I understand the vision, mission and overall objectives of the enterprise/unit.

Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

4) **People and Communication –** Teamwork and Communication between employees is promoted by the leaders of your unit.

Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

5) **People and Communication –** Channels of communication to management are available

Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

6) **Accountability –** Disciplinary action is taken against employees that engage in unethical conduct.

Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

7) **Risk Management –**.Does risk management make the environment a better place to work in?

Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

8) **Risk Management –** The risk management process is well structured

Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

9) **Risk management –** Risks are explicitly addressed whenever a decision is made or new task is undertaken

Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

10) **Risk management –**Designated risk owners have the authority and ability to manage risk adequately.

Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

APPENDIX B Raw Data and Preliminary Analysis

B.1 Company Data

Table B-1 Company risk assessment data prior to risk handling

#	Activity	Hazard	Risk Description	Impact	Exposure	Likelihood	Risk level
50	Paint stripping of components	Chemicals	Inhalation of chemicals	2	6	4	M
28	Using cell phones and media players	Vehicle movement	Staff member death/injury	4	6	5	H
15	Stacking and storage practices in warehouse	Items falling from height	Staff member death/injury	3	6	3	M
6	Lifting assets (60t) with cranes	Crane	Malfunction of machine	5	6	5	H
33	Repairing vehicle doors in Yards	3kV	Electrical shock, falling, cuts, lacerations	4	5	5	H
11	Interaction between staff and supervisor	Staff aggression	Supervisor being attacked by staff	4	6	5	H
9	Material supply control (solvent)	Chemical (fire)	Vehicle can be set alight	6	6	6	H
42	Remove and replace wheels	Heavy weight falling	Staff member death/injury	4	6	2	M
4	Contractor control	No risk assessments	Depot/contractor staff injury	5	5	5	H
7	Lifting assets (60t) with cranes	Operator error	Abuse/incorrect use of lifting equipment	5	6	3	H
45	Cleaning components in the Steam Genny	Chemicals	Eye, skin, lung injury	2	6	2	M
26	Sandblasting of components	Dust	Inhalation of dust by operator	3	6	2	M
32	Chemical plating of components	Chemicals	Non-compliance to council effluent limits	5	6	3	H
46	Main field coil remove and replace	Heavy weight while bending	Back injury	3	4	3	M
12	Floor replacement and repairs	Noise and dust	congested bronchial tubes	4	5	5	H
n/a	Staff Control	Hazardous waste	Staff urinating in assets	These risks had not yet been included in risk management processes			
n/a	Inter waste account not settled	Hazardous waste	Staff exposed to hazardous waste during handling				
n/a	Staff/contractor Control	Theft	Lack of assets/tools due to theft				
n/a	Fire extinguishing	Broken fire extinguishers	Cannot put out fire				

Table B-2 Company risk assessment data after risk handling

#	Mitigation	Impact	Exposure	Likelihood	Risk level
50	Layer of water to cover the stripping chemicals	1	5	1	L
28	Cell phone and media player ban in operational and maintenance	3	3	2	M
15	Training of staff; supervision by warehouse supervisor	1	6	2	M
6	Scheduled plant maintenance.	2	6	2	M
33	HT regulation training; written procedure; briefing system	1	5	2	M
11	Management warning to staff; briefing system; discipline	1	6	3	M
9	Supplier to supply certificate of conformance with delivery of orders	2	6	2	M
42	Lifting procedure; training; maintenance schedule	1	5	1	L
4	Contractor file; Project meetings; Service Level Agreements	2	5	3	M
7	Crane licensing procedure; refreshers; PJO	2	6	2	M
45	Operator is issued with PPE; PJO.	1	5	1	L
26	PPE and training of operator; DOP	1	6	1	M
32	Operator training; DOP; PJO: water sampling	1	6	1	M
46	Rotating machine; DOP	1	4	2	L
12	PPE; PJO; DOP	2	5	2	M

B.2 AHP comparison matrices

Table B-3 Comparison Matrix for risk impact

Risk ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1/3	3	1	1/4	1	1/5	1	2	1	1/5	2	1	4
2	1	1	1/3	3	1/2	1/6	1/2	1/4	1	1/3	1	1/8	1/2	1/3	4
3	3	3	1	4	1	1/2	3	1/3	5	2	3	1/2	2	2	8
4	1/3	1/3	1/4	1	1/2	1/8	1/4	1/6	3	1/5	1	1/8	1	1/3	1
5	1	2	1	2	1	1/4	1	4	1	1/2	2	1/4	1	1	4
6	4	6	2	8	4	1	5	1	5	5	8	1/2	4	4	9
7	1	2	1/3	4	1	1/5	1	1/4	1	1/2	2	1/6	1	1/2	4
8	5	4	3	6	1/4	1	4	1	5	3	5	1	4	4	7
9	1	1	1/5	1/3	1	1/5	1	1/5	1	2	1	1/6	1/2	1/3	3
10	1/2	3	1/2	5	2	1/5	2	1/3	1/2	1	3	1/4	1	1	4
11	1	1	1/3	1	1/2	1/8	1/2	1/5	1	1/3	1	1/7	1/2	1	3
12	5	8	2	8	4	2	6	1	6	4	7	1	4	4	9
13	1/2	2	1/2	1	1	1/4	1	1/4	2	1	2	1/4	1	1	5
14	1	3	1/2	3	1	1/4	2	1/4	3	1	1	1/4	1	1	5
15	1/4	1/4	1/8	1	1/4	1/9	1/4	1/7	1/3	1/4	1/3	1/9	1/5	1/5	1

Table B-4 Comparison Matrix for risk likelihood

Risk ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	2	1/3	2	1/3	1/6	1	1/6	1	1/2	2	1/6	1	1	5
2	1/2	1	1/4	2	1/4	1/7	1	1/7	1	1/3	1	1/7	1	1/2	5
3	3	4	1	8	1	1/2	3	1/3	3	2	6	1/3	5	3	8
4	1/2	1/2	1/8	1	1/8	1/8	1/6	1/9	1/5	1/8	1/3	1/8	1/4	1/5	1
5	3	4	1	8	1	1/2	2	1/2	2	1	5	1/2	3	3	8
6	6	7	2	8	2	1	3	1	6	3	7	1	5	6	9
7	1	1	1/3	6	1/2	1/3	1	1/4	1	1/2	2	1/8	2	1	6
8	6	7	3	9	2	1	4	1	6	4	7	1	6	6	9
9	1	1	1/3	5	1/2	1/6	1	1/6	1	1/2	1	1/5	1	1	6
10	2	3	1/2	8	1	1/3	2	1/4	2	1	4	1/4	3	2	6
11	1/2	1	1/6	3	1/5	1/7	1/2	1/7	1	1/4	1	1/5	1	1/2	2
12	6	7	3	8	2	1	8	1	5	4	5	1	6	4	9
13	1	1	1/5	4	1/3	1/5	1/2	1/6	1	1/3	1	1/6	1	1	6
14	1	2	1/3	5	1/3	1/6	1	1/6	1	1/2	2	1/4	1	1	6
15	1/5	1/5	1/8	1	1/8	1/9	1/6	1/9	1/6	1/6	1/2	1/9	1/6	1/6	1

B.3 Completed Risk profiles (next page)

Table B-5 Risk Diagnosing Methodology completed profile

Risk Statements		How often does the risk occur					Assume the risk does occur. Do you think anything can be done to reduce/prevent the number of occurrences					Should the risk occur, how severely does it affect the enterprise/ departmental objectives					Question Class			Category
		rare	unlikely	possible	likely	Certain	definitely	yes	possibly	difficult	nothing	insignificant	minimal	caution	significant	severe				
		1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**				
The improper use of equipment (lifting or other) causes damage to persons or equipment.	N. Resp	5	2	6	1	0	8	3	1	1	0	0	1	2	3	7				
	cum%	36	50	93	100	100	62	85	92	100	100	0	8	23	46	100	**0**	**0**	*****	**L**
	+50%		●				●								●					
Urinating in the assets poses a threat to health and respect for the workplace.	N. Resp	0	2	2	3	5	4	3	3	0	1	0	0	1	6	4				
	cum%	0	17	33	58	100	36	64	91	91	100	0	0	9	64	100	*****	**?**	*****	**H – F**
	+50%				●			●							●					
Staff aggression towards supervisors: Supervisors abused verbally or physically.	N. Resp	0	6	3	1	4	5	3	4	1	0	0	0	1	3	9				
	cum%	0	43	64	71	100	38	62	92	100	100	0	0	8	31	100	**?**	**0**	*****	**L – H**
	+50%			●				●								●				
Fire caused by use of chemicals in cleaning or stripping of parts / vehicles etc.	N. Resp	7	5	1	0	1	2	4	5	2	0	0	1	6	1	5				
	cum%	50	86	93	93	100	15	46	85	100	100	0	8	54	62	100	**?**	**0**	**?**	**S – H**
	+50%	●						●						●						
Inhalation of chemical fumes can lead to injury or death.	N. Resp	3	2	1	4	2	7	3	0	1	0	0	0	1	3	7				
	cum%	25	42	50	83	100	64	91	91	100	100	0	0	9	36	100	**?**	**0**	*****	**L – H**
	+50%			●			●									●				
Injury / death due to the use of cell phones and/or other electronic devices	N. Resp	7	3	3	1	0	5	2	3	3	0	0	1	2	3	7				
	cum%	50	71	93	100	100	38	54	77	100	100	0	8	23	46	100	**0**	**0**	*****	**L**
	+50%	●						●							●					

Table B-6 Risk Diagnosing Methodology completed profile (continued)

Risk Statements		How often does the risk occur					Assume the risk does occur. Do you think anything can be done to reduce/prevent the number of occurrences					Should the risk occur, how severely does it affect the enterprise/ departmental objectives					Question Class			Category
		rare	**unlikely**	**possible**	**likely**	**Certain**	**definitely**	**yes**	**possibly**	**difficult**	**nothing**	**insignificant**	**minimal**	**caution**	**significant**	**severe**				
		1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**				
Incorrect stacking of components in warehouse leads to injury.	N. Resp	2	7	2	1	2	8	1	2	2	0	0	1	4	0	8				
	cum%	14	64	79	86	100	62	69	85	100	100	0	8	38	38	100	**?**	**0**	*****	**L-H**
	+50%		●				●									●				
Withdrawal of contract services due to non-payment (Interwaste, etc.)	N. Resp	0	2	1	3	8	9	1	3	0	0	0	0	1	2	10				
	cum%	0	14	21	43	100	69	77	100	100	100	0	0	8	23	100	*****	**0**	*****	**M**
	+50%					●	●									●				
Injury due to staff not wearing PPE	N. Resp	4	5	2	2	1	5	4	2	1	1	0	1	2	6	4				
	cum%	29	64	79	93	100	38	69	85	92	100	0	8	23	69	100	**?**	**?**	*****	**L-F**
	+50%		●					●							●					
Staff Injury while removing and replacing vehicle wheels	N. Resp	4	4	3	0	0	3	4	2	0	2	0	1	2	4	4				
	cum%	36	73	100	100	100	27	64	82	82	100	0	9	27	64	100	**0**	**?**	*****	**L-M**
	+50%		●					●							●					
Contractor Control: Contractors cause injury of staff / contractor due to poor safety behaviour	N. Resp	3	5	3	1	1	2	6	1	1	3	1	1	2	5	4				
	cum%	23	62	85	92	100	15	62	69	77	100	8	15	31	69	100	**?**	**?**	**?**	**S-F**
	+50%		●					●							●					
Injuries while repairing vehicle doors	N. Resp	5	4	2	0	0	3	3	3	1	1	0	1	3	2	5				
	cum%	45	82	100	100	100	27	55	82	91	100	0	9	36	55	100	**0**	**?**	*****	**L-M**
	+50%	●						●							●					

APPENDIX C Calculated Data and Auxiliary Figures

C.1 Stacking and Storing Impact Frequency Data

class	Bins(rands)	Frequency
1	12293-17590	1
2	17591-22888	61
3	22889-28186	196
4	28187-33484	522
5	33485-38783	835
6	38783-44080	1121
7	44081-49378	1306
8	49379-54676	1358
9	54677-59974	1300
10	59975-65272	1152
11	65273-70570	846
12	70571-75868	682
13	75869-81166	359
14	81167-86464	174
15	86465-91762	70
16	91763+	17

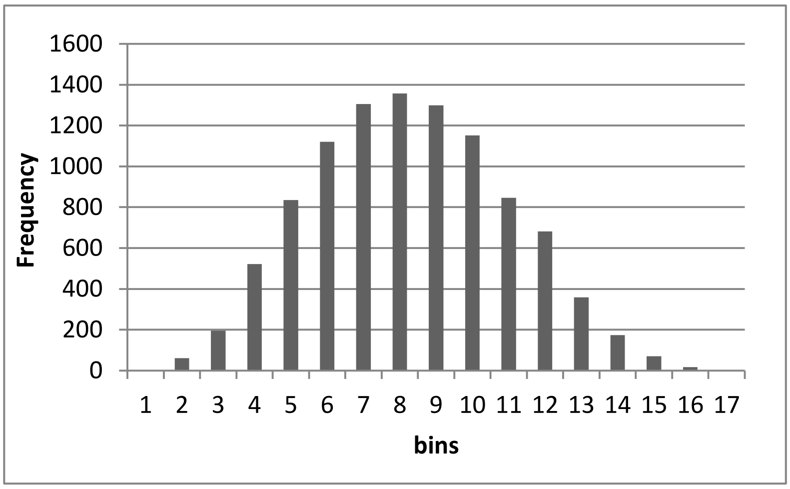

Figure C-1: Stacking and storing impact frequency

C.2 Contractor Control Impact Frequency Data

class	Bins(rands)	Frequency
1	22430-83351	1
2	83352-144273	75
3	144274-205195	377
4	205196-266117	853
5	266118-327039	1183
6	327040-387961	1378
7	387962-448883	1377
8	448884-509805	1415
9	509806-570727	1156
10	570728-631649	891
11	631650-692572	634
12	692572-753493	338
13	753494-814415	202
14	814416-875337	87
15	875338-936259	28
16	936260+	5

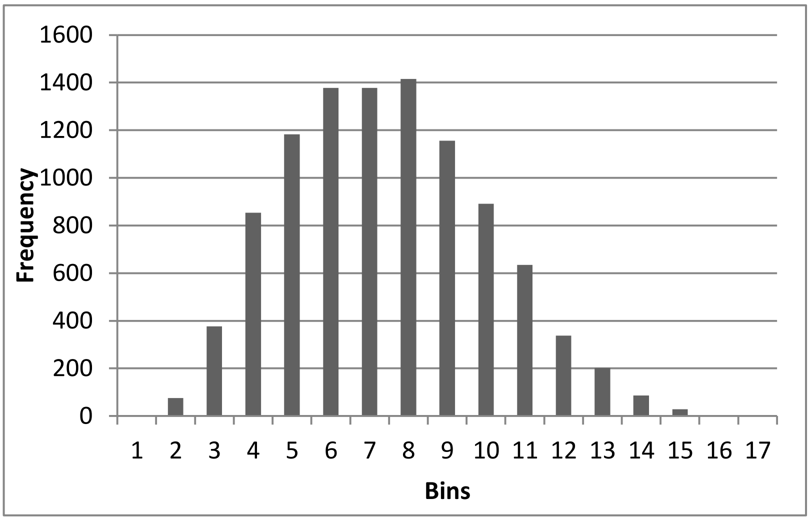

Figure C-2: Contractor control impact frequency

C.3 Stacking and storing Likelihood Frequency data

class	bins	Frequency
1	0.109-0.131	1
2	0.132-0.154	6
3	0.155-0.176	64
4	0.177-0.199	269
5	0.200-0.221	813
6	0.222-0.244	1518
7	0.245-0.267	1963
8	0.268-0.289	2033
9	0.290-0.312	1578
10	0.313-0.334	983
11	0.335-0.357	491
12	0.358-0.380	183
13	0.381-0.402	79
14	0.403-0.425	15
15	0.426-0.447	3
16	0.448+	1

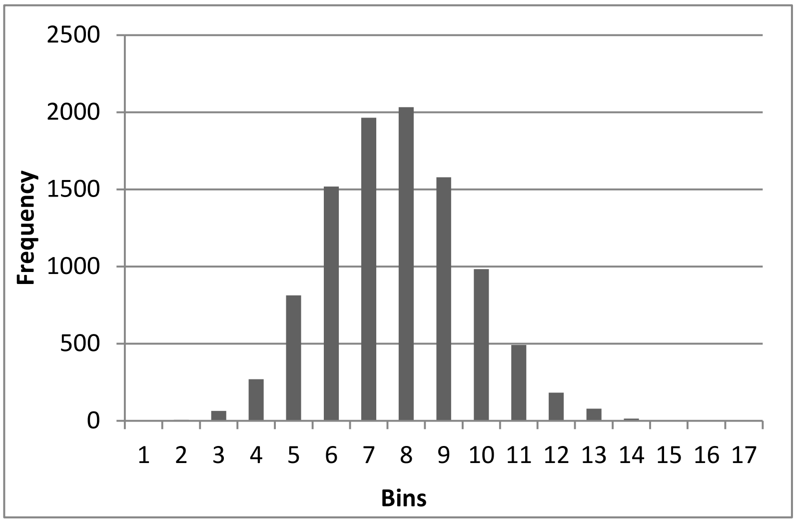

Figure C-3: Stacking and storing likelihood frequency

C.4 Contractor Control Likelihood Frequency data

class	bins	Frequency
1	0.163-0.197	1
2	0.198-0.232	3
3	0.233-0.267	42
4	0.268-0.301	179
5	0.302-0.336	536
6	0.337-0.371	1073
7	0.372-0.406	1671
8	0.407-0.441	1950
9	0.442-0.475	1828
10	0.476-0.510	1360
11	0.511-0.545	756
12	0.546-0.580	415
13	0.581-0.615	139
14	0.616-0.649	41
15	0.650-0.684	4
16	0.685+	2

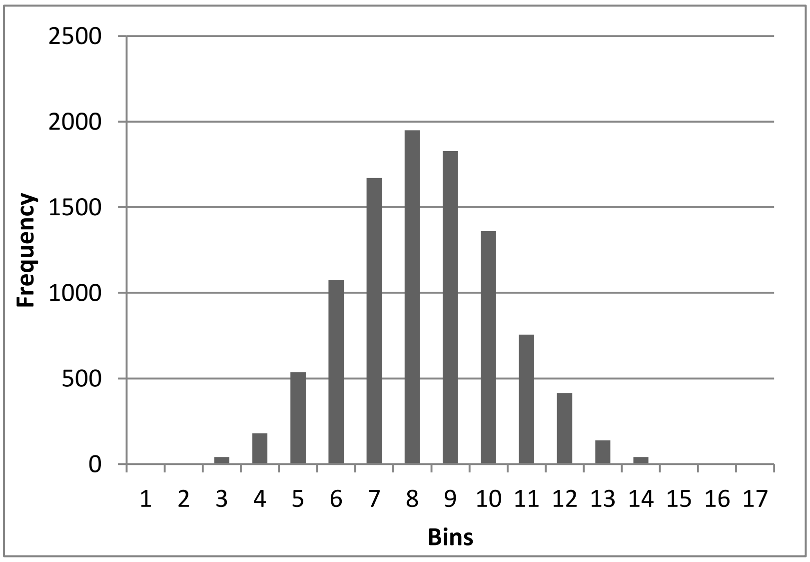

Figure C-4: Contractor control likelihood frequency

C.5 Expected Losses

Table C-1: Expected losses frequency data

Inhalation of chemicals			Stacking and Storing			Contractor Control		
class	**bins**	**Freq**	**class**	**bins**	**Freq**	**class**	**bins**	**Freq**
1	85-260	1	**1**	2069-4044	1	**1**	6768-38788	1
2	261-436	140	**2**	4045-6020	62	**2**	38789-70809	169
3	437-612	946	**3**	6021-7996	473	**3**	70810-10830	850
4	613-788	1855	**4**	7997-9972	1141	**4**	102831-134851	1487
5	789-964	2189	**5**	9973-11948	1663	**5**	134852-166872	1814
6	965-1140	1776	**6**	11949-13924	1919	**6**	166873-198893	1747
7	1141-1316	1311	**7**	13925-15900	1702	**7**	198894-230914	1451
8	1317-1492	845	**8**	15901-17876	1221	**8**	230915-262935	1103
9	1493-1668	467	**9**	17877-19852	886	**9**	262936-294956	707
10	1669-1844	259	**10**	19853-21828	502	**10**	294957-326978	345
11	1845-2020	114	**11**	21829-23804	256	**11**	326978-358998	195
12	2021-2196	50	**12**	23805-25780	107	**12**	358999-391019	85
13	2197-2372	27	**13**	25781-27756	51	**13**	391020-423040	28
14	2373-2548	12	**14**	27757-29732	9	**14**	423041-455061	11
15	2549-2724	6	**15**	29733-31708	3	**15**	455062-487082	5
16	2725+	2	**16**	31709+	4	**16**	487083	2

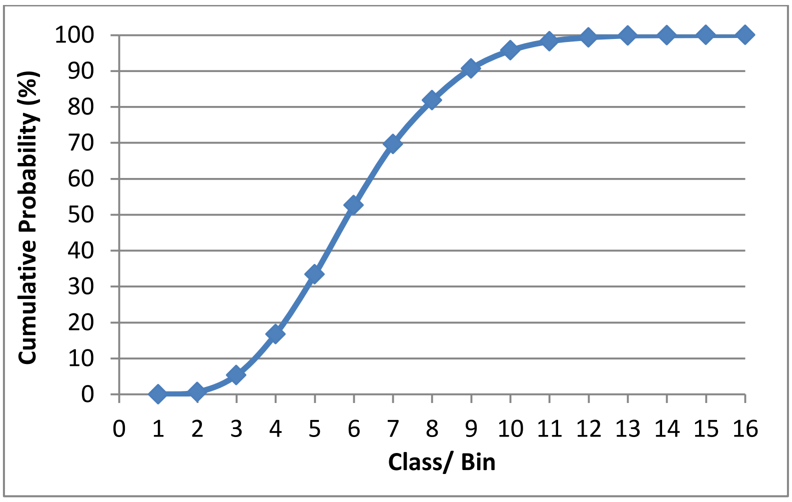

Figure C-5: Stacking and storing cumulative probability distribution

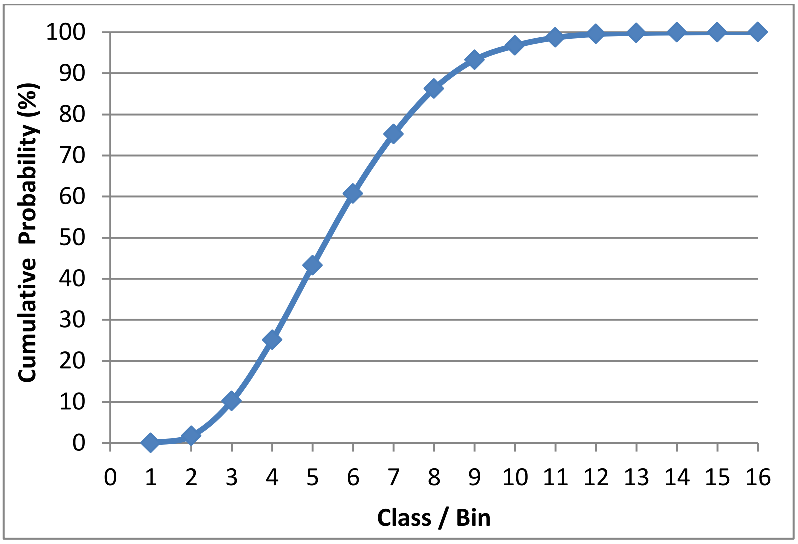

Figure C-6 : Contractor control cumulative probability distribution

C.6 Process analysis tool

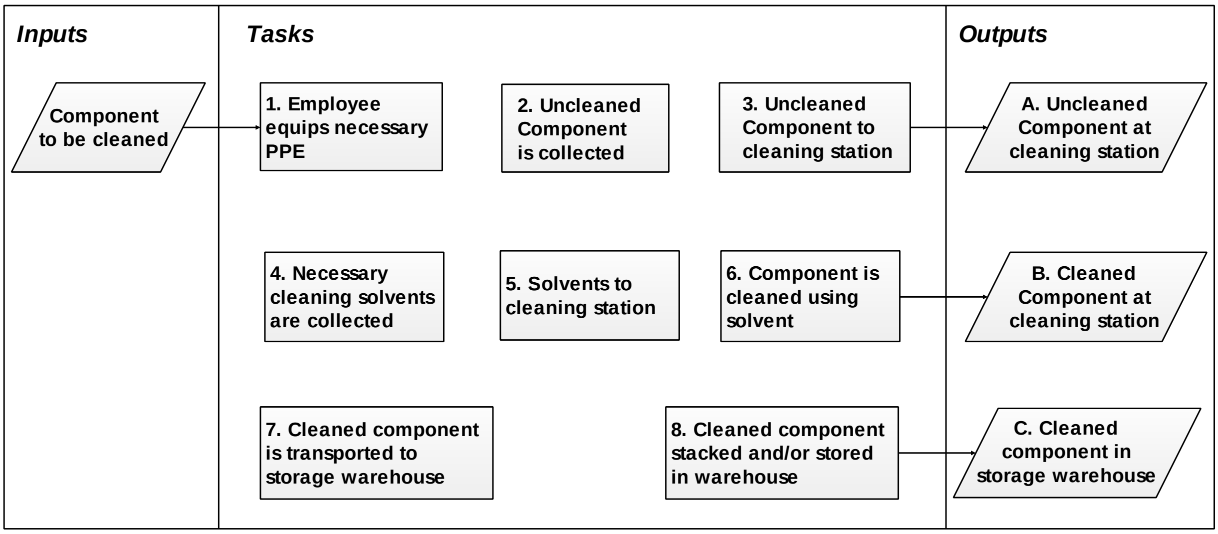

Figure C-7: Example Process analysis tool

C.7 Trigger list

1. Describe the Problem
    a. What is the problem?
    b. When can it happen?
2. Categorise the problem
    a. is the problem related to:
        i. finances
        ii. operations
        iii. enterprise structure
        iv. reputation
        v. legal and compliance factors
3. How often does the problem occur
4. How can the impact be measured
5. Is there anything that can be done to prevent this problem

APPENDIX D Probability Distributions

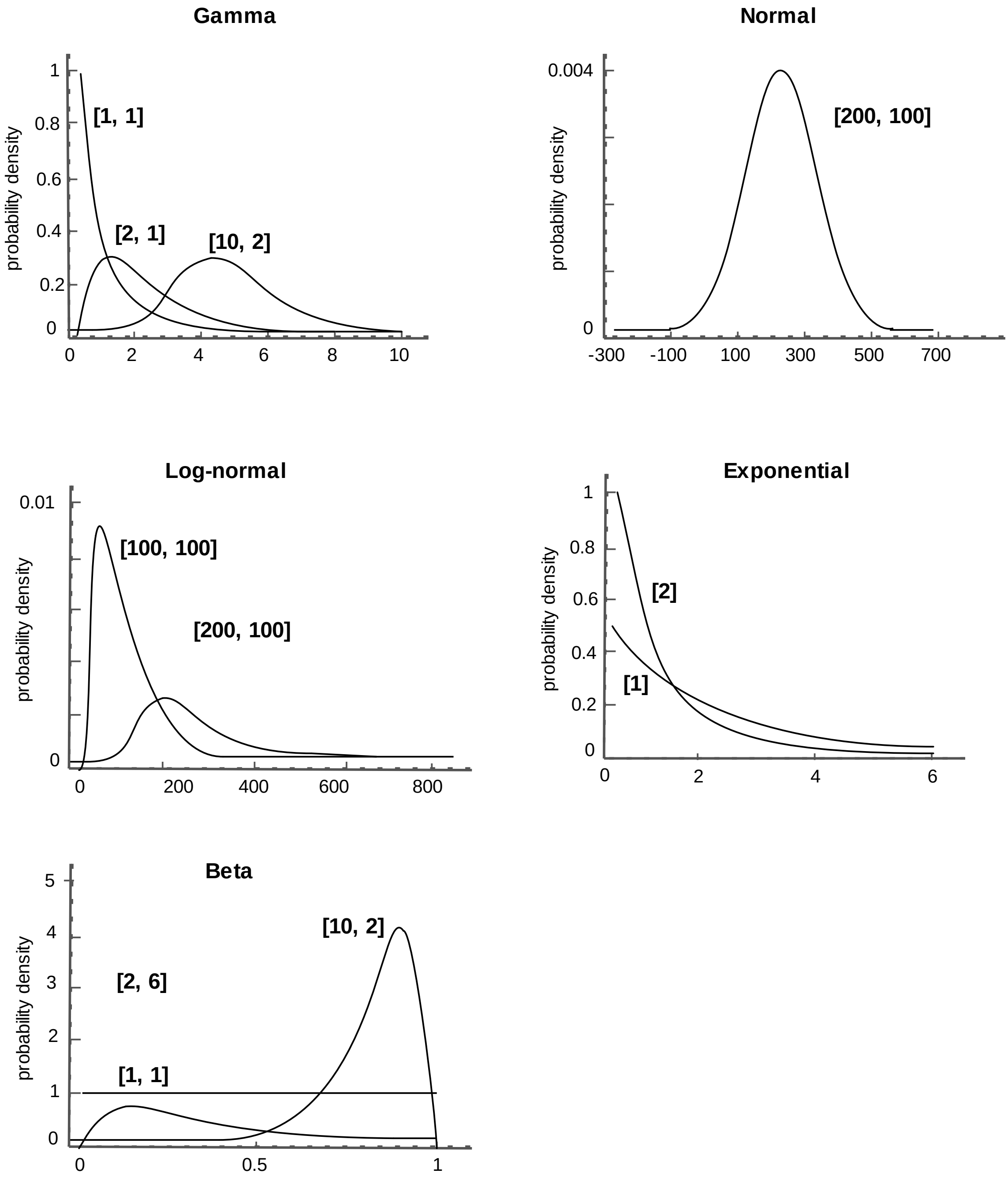

Figure D-1: Common Probability Density Functions

Table D-1 Mechanistic considerations of probability density functions

PDF	Mechanistic Considerations	Typical Examples
Beta	Estimates a continuous random variable with finite lower and upper limits. This distribution can take on very flexible shapes.	Mass fraction of an impurity in a metal sample bounded by 0 and 100%.
Binomial	Estimates a discrete random variable with the properties: (1) occurs in a fixed number of identical repetitions; (2) each repetition yields one of two elementary outcomes (e.g., "success" or "failure") and (3) has constant probability of success.	The number die tosses before a given number of successes are observed. A success is tossing a certain value
Poisson	Models occurrence of random, independent discrete events. Approximates the binomial distribution when number of repetitions is large and probability of success is small.	Determining the probably that 1 product is defective in a sample of 1000. Given that the manufacturing process of the product is strictly controlled.
Exponential	The measured quantity is the time/distance between successive events.	For a strict manufacturing process, the time between defective products produced.
Gamma	Analogous to exponential, except that the measured quantity is distance/time until the k^{th} success is observed instead of the time between successive events.	Time until the k^{th} defect is found for a given number of products produced.
Exponential	Determining the number of sample until "k" successes is observed in a given population.	For a strict manufacturing process, the probability that "k" defective products will be found for a given number of samples.
Log-Normal	Multiplication of random variables, or addition of logarithmic variables, will tend to yield a lognormal distribution.	The risk threat severity equation is multiplicative, and thus will generally produce a log-normal distribution.
Triangular	The PDF has a triangular shape. This is a rudimentary probability model that describes a random variable based on limited information.	Variability in a project cost given limited information.
Uniform	The PDF has rectangular shape. This is a simple probability model that generally describes a random variable based on limited information.	Used when all values have the same probability to be observed. Rolling a fair die.
Weibull	A model to estimate for time to failure of a product when the failure rate varies with time.	Examples for exponential and gamma would also be appropriate for Weibull.

APPENDIX E Detailed Interview Processes

E.1 Introduction

The introduction phase has two purposes. The first is to introduce the task, which involves clarifying the objectives of the interview, stating the importance of the data and the purpose of the results. The second purpose of the introduction is to determine whether the responses of the participant are influenced by motivational biases.

The interviewer and participant should discuss any benefits that the participant might acquire from the interview results. The interviewer should also point out that the aim of the interview process is to obtain results that clearly represent the judgement of the participant. Misrepresenting the data will be detrimental to the entire risk management process. The participant should also be informed that performance will not be judged during or after the process.

E.2 Structuring

The purpose of the structuring phase is to explain the procedures that will be followed in the interview and to define the uncertain data. In this study, the uncertain data will be risk events. The interviewer should then provide a definition for risk and ascertain whether the participant has received the background material in advance.

The participant is asked to analyse any processes presented in the background material carefully before presenting scenarios that lead to risk event. If the participant struggles to visualise scenarios later in the interview, the interviewer can lead him/her in a specific direction.

E.3 Opening Phase

The aim of the opening phase is to address any cognitive biases that may surface during the event identification and to condition the participant to think carefully about judgements. This phase should be directed towards determining the basis of the participant's judgements. The basis for judgement provides information regarding the presence of anchors, the unstated assumptions, the most available information and so forth.

The following questions have been adapted from (Spetzler & Holstein 1975). These questions can be used to determine the bases for judgement and detecting the subsequent biases:

- How do you judge whether a risk is probable or not? In other words, what are your bases for judgement?

It has been found that the bases for event identification will often be associated, either directly or indirectly, to risks that have been identified previously. These prior events could become anchors.

- What information do you consider when presenting a scenario or identifying a risk?

This will be indicative of the information that is readily available to the participant. If the interviewer suspects that the participant is relying on recently obtained information, the participant can be asked to think about extreme or unlikely scenarios.

- If you would like to revise any judgements, please specify the reason for doing so, and mention how revision affects your previous judgement?

Representativeness can occur when the participant requests to revise a previous judgement based on new knowledge, thoughts or ideas obtained during the interview process. The best way to handle this situation is to ask the participant to specify the reason for revision of the judgement and state how revision affects the previous judgement. The interviewer does not disregard the previous judgement.

- Are there any risk events you feel are not your responsibility to identify? For example, acts of God

This questions requests that the participant specify all assumptions that are made when making judgements. It also helps the interviewer to understand and document the range of uncertainties the participant is willing to discuss.

- Do you visualise scenarios that lead to risk events? If so, why do you do this?

This will indicate if a participant is identifying risk events based on whether he/she can construct plausible scenarios leading to a risk event. Coherence of a scenario can influence the judgements of an individual.

- What do you consider to be extreme or unlikely risk events with respect to the process in question?

This is a deliberate use of availability that is intended to reduce the effects of anchoring that is likely to occur. The interviewer then asks the participant to consider extreme scenarios that may lead to risk events. Asking the participant to consider extremes has the effect of increasing the variability of judgements. Variability in risk identification is good as it results in a diverse range of risk events.

E.4 Risk Identification

The attention of the participant is drawn to the process diagram (See Appendix C). The interviewer should not begin by asking the participant to identify the most likely risks. This may result in anchoring and adjustment. The participant likely to identify risks that are common or that have occurred recently. To increase the variability of results, the interviewer can ask the participant to consider extreme cases.

If the participant uses constructed scenarios to identify potential risk events, the interviewer should be attentive and check if the participant is struggling to construct plausible scenarios. In some cases, the coherence of a scenario leading to a risk event takes precedence over probability risk event. If the interviewer detects equally coherent scenarios that imply the risk event is improbable can be formulated by the interviewer. This may change the judgement of the participant in favour of the relevant risks.

The order in which risks are identified is determined by the situation. If the participant is more familiar with a specific area of the process or type of risk, then the interviewer should start there and gradually move towards less familiar areas. The length of the identification phase will depend on the ability of the participant to identify risk events. The interviewer should note any changes in the participant's attention and spend enough time with each of the participants in order to obtain the large number risks (Keizer, Halman & Song 2002).

E.5 Verification

The last stage of the interview process is verification of the results. The interviewer and participant analyse the list of risks. If the participant is not satisfied with the data then some of the steps in the interview process can be repeated.

APPENDIX F Glossary of terms

Table F-1: Frequently used terms

Terms	Description
Risk	An uncertain event that, should it occur, will have an effect on the achievement of the enterprise objectives
Appetite, Risk	The level of risk the enterprise is willing to accept in order to achieve its objectives
Assessment, Risk	Process that includes estimation of risk impact and likelihood, prioritisation of risks and risk criticality
Category, Risk	Indication of the risk threat level
Classification, Risk	Indication of how the risk affects the enterprise
Controllability, Risk	Measure of the ability to reduce the expected loss
Controls, Risk	Specific activities implemented to mitigate risks.
Corporate culture	Operational norms within the enterprise
Critical Risks	Risks that are not well understood or cannot be controlled.
Criticality, Risk	Indicates whether a risk is critical or not
Expected Loss	Product of the risk impact and likelihood.
Expert Judgement	Opinion of an individual that is knowledgeable within a given area of expertise
Frequency	Number of observations of a given quantity
Impact, Risk	The actual loss associated with a risk. Usually expressed in monetary terms
Internal Environment	Encompasses, the corporate culture as well as ethics, honesty and integrity of individuals within the enterprise
Likelihood, Risk	Probability of occurrence of the risk event
Management, Risk	Defined as the systematic process of identifying, assessing and responding to risk events
Non-Critical Risks	Risks that are well understood or can be controlled
Owner, Risk	An individual responsible for implementation of risk controls
Participant	An individual at The Company that took part in this study
Prioritisation, Risk	Rank ordering or risks in terms of perceived importance
Probability Density Function	A predictive model that is used to describe to a data set
Qualitative Methods	Methods that rely on subjective judgement to form conclusions
Quantitative Methods	Methods that rely on numerical data to form conclusions
Response/handling strategy, Risk	The type of approach taken when responding to a risk
The Company	The enterprise that provided data for the case study.
Threat Level, Risk	Analogous to expected loss. Except that the terminology threat level used when using qualitative methods