

**Developing a tool for project contingency  
estimation in Eskom Distribution Western Cape  
Operating Unit**

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## Declaration

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## ABSTRACT

Construction projects are risky by nature, with many variables affecting their outcome. A contingency cost and duration are allocated to the budget and schedule of a project to provide for the possible impact of risks.

To enable the management of project-related risk on a portfolio level, contingency estimation must be performed consistently and objectively. The current project contingency estimation method used in the capital program management department of Eskom Distribution Western Cape Operating Unit is not standardised, and is based solely on expert opinion. The aim of the study was to develop a contingency estimation tool to decrease the influence of subjectivity on contingency estimation methods throughout the project lifecycle so as to enable consistent project risk reflection on a portfolio level.

From a review of contingency estimation approaches in literature, a hybrid method combining neural network analysis of systemic risks and expected value analysis of project-specific risks was chosen.

Interviews were conducted with project managers (regarding network asset construction projects completed in the last two financial years) to distinguish systemic and project-specific risk impact on cost and duration growth. Outputs from 22 interviews provided three data patterns for each of 89 projects. After interview data processing, 138 training patterns pertaining to 85 projects remained for neural network training, validation and testing.

Six possible neural network inputs (systemic risk drivers) were selected as project definition level, cost, duration, business category, voltage category and job category. A multilayer feedforward neural network was trained using a su-

pervised training approach combining a multi-objective simulated annealing algorithm with the standard backpropagation algorithm.

Neural network results were evaluated for different scenarios considering possible combinations of model input variables and number of hidden nodes. The best scenario (exclusion of business category input with nine hidden nodes) was chosen based on training and validation errors. Validation error levels are comparable to those of similar studies in the project management field. The chosen scenario was shown to outperform multiple linear regression, but calculated  $R^2$  values were lower than anticipated. It is expected that neural network performance will further improve as additional training patterns become available.

The trained neural network was combined with an expected value analysis tool (risk register format) to estimate contingency due to systemic risks alongside an estimation of contingency due to project-specific risks. The project-specific expected value method was modified by basing the contingency estimation on the expected number of realised risks according to a binomial scenario. A total cost distribution was included in tool outputs by assuming the contingency cost equal to the standard deviation of the cost estimate.

To aid business integration of the developed tool, study outputs included the points in the project lifecycle model at which the tool should be applied, and the process by which tool outputs become inputs to the enterprise risk management system.

By following this approach, systemic and project-specific risks are contained in a single tool providing contingency cost and duration output on project level, while enabling integration with reporting on program, portfolio and enterprise level.

## OPSOMMING

Konstruksieprojekte het van nature 'n hoë risiko omdat hulle uitsette deur baie veranderlikes geaffekteer word. Gebeurlikheidsreserwes vir koste en tyd word toegeken aan die begroting en skedule van 'n projek om voorsiening te maak vir die moontlike gevolge van risiko's.

Om die bestuur van projekverwante risiko op 'n portefeulje-vlak te vergemaklik, moet die beraming van gebeurlikheidsreserwes op 'n konsekwente en objektiewe manier uitgevoer word. Die huidige beramingsmetode vir projek gebeurlikheidsreserwes in die kapitaal programbestuur departement van Eskom Distribusie Wes-Kaap Bedryfseenheid is nie gestandaardiseer nie, en word slegs gebaseer op deskundige opinie. Die doel van hierdie studie was om 'n gebeurlikheidsreserwe beramingsinstrument te ontwikkel wat die invloed van subjektiwiteit op beramingsmetodes verminder deur die hele projeklewensiklus, en sodoende die konsekwente weerspieëling van projekrisiko op 'n portefeulje-vlak, te bewerkstellig.

Vanuit 'n studie van bestaande literatuur oor gebeurlikheidsreserwe-beraming, is 'n hibriede metode wat neurale netwerk analise van sistemiese risiko's en verwagte waarde analise van projek-spesifieke risiko's kombineer, gekies.

Onderhoude is gevoer met projekbestuurders (rakende netwerk batekonstruksieprojekte wat voltooi is in die afgelope twee finansiële jare) om te onderskei tussen die impak van sistemiese en projek-spesifieke risiko's op koste- en duurgroei. Uitsette van 22 onderhoude het drie datapatrone vir elk van 89 projekte verskaf. Na onderhouddata verwerk is, het 138 datapatrone vanuit 85 projekte oorgebly vir neurale netwerk opleiding, validasie en toetsing.

Ses moontlike neurale netwerk insette (sistemiese risikodrywers) is gekies as projek definisievlak, koste, duur, besigheidskategorie, spanningskategorie en werkskategorie. 'n Multi-laag vooruitvoerende neurale netwerk is deur 'n opleiding-onder-toesig benadering opgelei – 'n multi-doelwit gesimuleerde uitgloeïingsalgoritme gekombineer met die standaard agteruit-propagerende algoritme.

Die resultate van die neurale netwerk is oorweeg vir verskillende scenario's rakende moontlike kombinasies van die aantal versteekte nodes en model insetveranderlikes. Die beste scenario (uitsluiting van besigheidskategorie inset met nege versteekte nodes) is gekies op grond van opleidings- en validasiefoute. Validasie foutvlakke is vergelykbaar met dié van soortgelyke studies in die projekbestuur veld. Daar is gewys dat die gekose scenario meervoudige lineêre regressie klop, maar met laer  $R^2$  waardes as wat verwag is. Dit word verwag dat die neurale netwerk beter sal presteer soos bykomende opleidingsdatapatrone beskikbaar word.

Die opgeleide neurale netwerk is gekombineer met 'n verwagte waarde analise instrument (risiko-register formaat) om gebeurlikheidsreserwes as gevolg van sistemiese risiko's hand-aan-hand met gebeurlikheidsreserwes as gevolg van projek-spesifieke risiko's, te beraam. Die projek-spesifieke verwagte waarde metode is aangepas deur gebeurlikheidsreserwe-beraming te baseer op die aantal verwagte gerealiseerde risiko's volgens 'n binomiaal scenario. 'n Totale koste-verdeling is ingesluit in modeluitsette deur aan te neem dat die gebeurlikheidsreserwe vir koste gelyk is aan die standaardafwyking van die kosteberaming.

Om die besigheidsintegrasie van die ontwikkelde instrument te vergemaklik, het studie uitsette die punte in die projek lewensiklus waarby die instrument toegepas moet word, en die proses waardeur instrument uitsette omgesit word na insette vir die risikobestuur sisteem op ondernemingsvlak, ingesluit.

Deur hierdie benadering te volg, word sistemiese en projek-spesifieke risiko's omvat in een instrument wat gebeurlikheidsreserwes vir koste en tyd op projekvlak verskaf. Die integrasie met verslagdoening op program-, portefeulje- en ondernemingsvlak word ook bewerkstellig.

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## NOMENCLATURE

### Roman Symbols

$A$	Activation function
$a$	Number of anticipated realised project risks
$B$	Binomial random variable
$E$	Random vector / time-dependent stochastic process
$F$	Approximated nonlinear input-output mapping function
$f$	Unknown nonlinear input-output mapping function
$G$	Required level of accuracy of the project cost estimate at a certain project stage
$H$	Real-valued performance function
$h$	Number of bins or class intervals in a frequency histogram
$i$	Counter
$j$	Counter
$K$	Number of objective functions in a multi-objective problem

**Nomenclature**

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$k$	Number of decision variables in a multi-objective problem
$L$	Number of neural network hidden nodes
$m$	Number of independent Bernoulli trials
$n$	Sample size
$Q$	Number of neural network training patterns
$R$	Number of neural network input nodes
$T$	Number of neural network output nodes
$U$	Uniform distribution
$V$	Variance function
$x$	Regressor/predictor/decision variable
$Y$	Response/dependent variable

**Greek Symbols**

$\alpha$	Level of significance
$\beta_k, \beta_{kk}$	Regression coefficients
$\chi^2$	Chi-squared distribution
$\chi_0^2$	Chi-squared goodness-of-fit test statistic
$\delta_l$	Local gradient for hidden node $l$ in neural network
$\delta_t$	Local gradient for output node $t$ in neural network
$\gamma$	Probability of sufficiency of total portfolio budget
$\lambda$	Neural network regularisation parameter
$\mu$	Mean
$\nu$	Average historical rate of project cost overruns

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$\Phi^{-1}$	Quantile function of standard normal distribution
$\psi$	Neural network learning rate
$\rho_{ij}$	Correlation amongst project budget cost items $i$ and $j$
$\sigma^2$	Variance
$\sigma$	Standard deviation
$\nu$	Neural network momentum term
$\varepsilon$	Random error term
$\zeta$	Simulated annealing constant cooling factor
$\tau$	Probability that an individual project has sufficient initial budget

**Other Symbols**

$A'$	Derivative of the activation function
BF	The number of observations in a random data set
$BC_i$	Cost of item $i$ in the project budget
CE	Evaluation factor of each cost element in the project budget
$D_t$	Desired response of output node $t$
$E_c$	Neural network complexity penalty error term
$E_t$	Total error of output node $t$
$e_t$	Error signal at output node $t$
$e^x$	Exponential function
$FE_i$	Expected frequency of the $i^{th}$ class interval
$FO_i$	Observed frequency of the $i^{th}$ class interval
$g_K$	Objective function $K$

---

**Nomenclature**

$H_l$	The weighted sum of inputs to the $l^{th}$ hidden node
$H'_l$	The value of the $l^{th}$ hidden node
$H'_0$	The value of the hidden layer bias node (+1)
$I_{ri}$	The value of the $i^{th}$ indicator variable representing the $r^{th}$ input variable
$I_r$	The value of the $r^{th}$ input variable/node
$I_0$	The value of the input layer bias node (+1)
IQR	Interquartile Range
$ld$	The leading digit in a random number
$O_t$	The weighted sum of inputs to the $t^{th}$ output node
$O'_t$	The value of the $t^{th}$ output node
PB	Portfolio budget before contingency addition
PB*	Portfolio budget after contingency addition
$q1$	The first (25%) quartile
$q2$	The second (50%) quartile
$q3$	The third (75%) quartile
$RMSP_t$	Batch root mean square percentage error or performance error for output node $t$
$RW_i$	Relative importance weighting of risk $i$
$S_{BSF}$	Best solution so far
$S_n$	Random sum of sample elements
TC	Total project cost

**Nomenclature**

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TE	Neural network training error
Temp	Temperature of the simulated annealing algorithm
TP	Number of neural network training patterns
TS <sub><i>i</i></sub>	Total Score of risk <i>i</i>
UO' <sub><i>t</i></sub>	Unscaled output of the <i>t</i> <sup>th</sup> output node
VE	Validation error
$\Delta W_{rl}$	Calculated change for $W_{rl}$ according to backpropagation algorithm
$\Delta W'_{lt}$	Calculated change for $W'_{lt}$ according to backpropagation algorithm
$W'_{lt}$	The weight of the connection between the <i>l</i> <sup>th</sup> hidden node and the <i>t</i> <sup>th</sup> output node, where l=0 represents the hidden bias node with value +1
$W_{rl}$	The weight of the connection between the <i>r</i> <sup>th</sup> input node and the <i>l</i> <sup>th</sup> hidden node, where r=0 represents the input bias node with value +1
$\hat{y}$	Estimated response/dependent variable
$\bar{y}$	Sample mean

**Acronyms**

AACE	Association for the Advancement of Cost Engineering
ANN	Artificial Neural Network
BOM	Bill of materials
BOQ	Bill of quantities
BP	Backpropagation
CAIE	Computers and Industrial Engineering

**Nomenclature**

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CRA	Concept Release Approval
DRA	Design Release Approval
ERA	Execution Release Approval
FMECA	Failure Mode, Effect and Criticality Analysis
FRA	Finalisation Release Approval
HOA	Hand Over Approval
<i>iid</i>	Independent & identically distributed
IPRM	Integrated Project Risk Management
IRM	Integrated Risk Management
ISO	International Organisation for Standardisation
MLR	Multiple Linear Regression
PCM	Process Control Manual
PDMOSA	Multi-objective simulated annealing using Pareto-domination-based acceptance criterion
PLCM	Project Lifecycle Model
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PMO	Project Management Office
PRINCE	Projects in Controlled Environments
RBS	Risk Breakdown Structure
SAP PPM	Systems, Applications and Products (data processing) for Portfolio and Project Management

**Nomenclature**

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SA	Simulated Annealing
SMART	Simple Multi-Attribute Rating Technique
SOC	State Owned Company
SWIFT	Structured What If Technique
WBS	Work Breakdown Structure

## CHAPTER 1

## INTRODUCTION

This chapter serves as an introduction to the research presented in this thesis. The reasons for the inception of the research study are explained, followed by the research aim and an overview of the document's structure.

### 1.1 Background to the study

Everyday life is full of intuitive decisions that are made without conscious attribution of either quantitative or qualitative values to the risks involved. However, in some settings decisions need to be more objectively informed. A project is an example of an environment in which objectivity becomes necessary.

The current project contingency estimation method used in the capital program management department of Eskom Distribution Western Cape Operating Unit is not effective, and needs to be revised. At present, the estimation of the contingency amount for each network asset construction project is based on the "gut feel" of the project manager in question. Thus the accuracy of the estimated contingency impact is based on expert opinion, which is limited to previous experiences with similar projects.

The problem with this is firstly the assumption that all project managers in Eskom Distribution Western Cape Operating Unit are experts in their field, while in fact some are relatively inexperienced. Even if one were to assume that all project managers were indeed experts, the expert opinion method for contingency estimation is disadvantaged by the fact that the wide variation of skill, knowledge

## 1.2 The research aim

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and motivation between different individuals leads to subjectivity. This is evident from the fact that contingency estimates currently produced by project managers vary widely for different projects under similar circumstances.

As the Eskom Distribution Western Cape Operating Unit capital program management department has a project portfolio consisting of more than seven hundred projects, such a variation in contingency estimation is far from ideal for the management of the portfolio as a whole. A portfolio manager needs to have access to the portfolio-level influence of risks on all ongoing projects to be able to monitor the risks and vulnerabilities of the entire portfolio. It follows that if risks on projects comprising the portfolio are not quantified using a constant standard, risk management on a portfolio level would not be able to proceed as required.

### 1.2 The research aim

With the study background as summarised in the previous section, the research aim is formulated as follows:

Develop a contingency estimation tool to decrease the influence of subjectivity on contingency estimation methods throughout the project lifecycle so as to enable consistent project risk reflection on a portfolio level.

### 1.3 Structure of the document

The study will commence with a review of literature pertaining to project risk management and project contingency estimation, and a more detailed look at the structures and processes within the Eskom Distribution project management environment, including the Eskom Integrated Risk Management process. Hereafter, the study objectives will be discussed. For this purpose, the outline of the introductory chapters will be as follows:

- Project risk management
- Project contingency estimation
- Eskom Distribution project management background

### 1.3 Structure of the document

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- Eskom Integrated Risk Management method
- Study objectives

The **Project risk management** chapter will provide a very brief background on risk management in general, followed by a more detailed look at project risk. The management of project risk will be explored from the perspectives of several methods that are considered as best practice internationally. A brief discussion will be given on project risk management from an owner's perspective, and project risk management on program and portfolio level.

The **Project contingency estimation** chapter will provide a background on the importance of project contingencies in project management, distinguishing between cost and schedule contingencies, and discussing each contingency type briefly. Common errors in contingency estimation will be reviewed, followed by an outline of statistical theory often applied in project contingency estimation. Four general categories of contingency estimation methods will be described in detail, and a brief outline will be given of each of several other contingency estimation methods encountered in literature but not encompassed by the general categories. A statistical technique for the management of contingency costs on portfolio level will be discussed, after which the chapter will be concluded with brief descriptions of the influence that contract type as well as psychological and political factors have on project contingency estimation.

The **Eskom Distribution project management background** chapter will serve to outline the structure of an Eskom Distribution project management department (referred to within Eskom Distribution as a capital program management department) and the current processes that govern and facilitate project management of network asset construction projects within that structure. Important links between the current process and project contingency estimation as well as project risk management in general, will be identified.

The **Eskom Integrated Risk Management method** chapter will explore the management of project risk from the perspective of the Eskom Integrated Risk Management method, which is based on ISO31000 principles. The different steps in the process will be discussed alongside corresponding steps in the Integrated

### 1.3 Structure of the document

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Project Risk Management process for standard and repeatable projects, after which the process steps will be mapped back to the Eskom project lifecycle model.

A chapter on **study objectives** will conclude the introductory chapters. The problem with which the study is concerned will be identified in context of the reviewed literature and study environment, and corresponding objectives will be stated.

**Possible tool formulation strategies and solution techniques** will be discussed in the next chapter. The focus will be on the selection of the most suitable project contingency estimation method(s) to be applied in the contingency estimation tool to ensure that all objectives are met in the context of the study environment. The chapter will conclude with a look at the steps required for the practical execution of the proposed method: a hybrid neural network and expected value analysis contingency estimation tool.

The remaining chapters will focus on the practical steps in the development of the contingency estimation tool by outlining the following:

- Neural network design
- Obtaining the neural network training data
- Neural network results
- Integration of contingency estimation methods: systemic and project-specific
- Integrating the contingency estimation tool with the project lifecycle model and the enterprise risk management process

The chapter on **designing the neural network** will give a brief introduction to neural networks and the types of problems to which they are applied, before considering the architecture of the neural network designed to solve the problem at hand in this study. The selection of the relevant algorithm(s) for neural network training will be discussed, and an overview of model logic will be given. The chapter will conclude with a brief description of the application of the developed neural network model to a multi-objective test problem.

A chapter on **obtaining neural network training data** will then describe how an interview process is applied to enable the distinction of cost and duration

### 1.3 Structure of the document

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growth due to project-specific risks from cost and duration growth due to systemic risks.

**Neural network results** will be discussed in the next chapter. The construction and comparison of model scenarios (possible combinations of model input variables and number of hidden nodes) to identify the scenario minimising training and validation errors, will be described. The chosen scenario will then be evaluated and compared to a multiple linear regression model.

The **integration of contingency estimation methods (systemic and project-specific)** will be discussed in the following chapter. A brief summary of the overall proposed approach will be provided. Hereafter, the project-specific contingency estimation method and the application of interview outputs regarding project-specific causes for cost and duration growth in this method, will be discussed. The practical integration of the two methods will be outlined alongside a description of model inputs, outputs and advantages. Finally, the research importance of the proposed integrated method will be briefly discussed.

A chapter on **integrating the contingency estimation tool with the project lifecycle model and enterprise risk management** will examine the integration of the developed contingency estimation tool with these two important structures in the Eskom environment.

Hereafter, a chapter on the **research summary and conclusions** will complete the description of the study and provide possible avenues of future research.

## CHAPTER 2

# PROJECT RISK MANAGEMENT

All projects are inherently risky because of the uncertainty they present. [Zhao \(2006\)](#) states that the management of risk is the primary responsibility of the project manager – decision-making, giving directions, selection of optimal options, spending of large amounts of money – all of these elements of project management combine to necessitate a very complex risk management and decision-making process.

This chapter will provide a very brief background on risk management in general, followed by a more detailed look at project risk. The management of project risk will be explored from the perspectives of several methods that are considered as best practice internationally. A brief discussion will be given on project risk management from an owner’s perspective, and project risk management on program and portfolio level.

### 2.1 Background on risk in general

Modern civilisation prides itself on its ability to monitor and control risks. [Bernstein \(1998\)](#) argues that our ability to manage risk is the boundary that separates us from our ancient counterparts, as our growing ability to analyse and manage risks has eradicated the popular notion amongst earlier societies – that our future is no more than the whim of the gods. By analysing and managing risks, we as humankind have become increasingly aware that we are not passive before nature,

## 2.2 Project risk

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but able to record and analyse data that enable us to predict and mitigate/exploit expected future events.

A further demonstration of the nature of risk is found in the word itself: it is derived from the early Italian word *risicare*, which means “to dare”, illustrating that risk is a choice rather than a fate.

Nohria & Stewart (2006) separate risk from other commonly used terms, *i.e.* uncertainty and doubt, saying that risk is calculable (it can be expressed in terms of odds), while uncertainty is incalculable (there is no scientific basis on which to form any calculable probability). By way of example, “a game of roulette is risky but not uncertain” (Nohria & Stewart, 2006). Doubt is different altogether from risk and uncertainty, as the former two presuppose that the decision maker knows what he/she wants; when doubt comes into play this is not the case.

Though the perspective provided by Nohria & Stewart (2006) does give a good partial view of the difference between the terms, it is important to note that risk is expressed not only in terms of odds (probability), but also in terms of consequences (impact). Also, uncertainty is more commonly described as a lack of knowledge, and probability as inclusive of components pertaining to both uncertainty and variability (Barnardo, 2012) – these interpretations of the terms will be applied throughout this study.

The purpose of this chapter is to focus on a specific type of risk, *i.e.* project risk, and to discuss how estimated risk probabilities and impacts can be used in project risk management process structures to manage risks in a way that enables predefined objectives to be met. After a brief introduction to the concept of project risk, its management, and key terms associated with its discussion; different techniques deemed as best practice in the management of project risk will be presented.

## 2.2 Project risk

The Project Management Body of Knowledge (PMBOK) (PMI®, 2008) defines project risk as an uncertain event or condition that, if it occurs, has an effect on at least one project objective. Project objectives can be classified into four categories: scope, schedule, cost, and quality.

## 2.2 Project risk

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The Association for the Advancement of Cost Engineering (AACE) (Hollmann *et al.*, 2009) defines risk as a “downside uncertainty” (negative risk) and opportunity as an “upside uncertainty” (positive risk), with the impact of risk quantified as *risk + opportunities*. A project risk has one or more possible **causes**, and on occurrence it could have one or more **impacts**. A cause could be a requirement, assumption, constraint or condition. Causes create the possibility of negative or positive outcomes/impacts.

Project risks do not only include risks that could materialise due to project execution, but also risk conditions that are inherent to the project’s environment / organisation’s environment. For example, immature project management practices in an organisation would be a risk that applies to all projects in that organisation. By this logic, project risks can be broadly classified into two categories, *i.e.* systemic and project-specific risks (Hollmann *et al.*, 2008a):

- *Systemic* refers to the fact that the risk is a product of the project “system”, culture, politics, business strategy, process system complexity, technology, etc.
- *Project-specific* refers to the fact that the risk is specific to the project, for example the possibility of rain on a specific project site during a certain time of year

Systemic risks are stochastic in nature, and can also be called **inherent** risks (Karlsen & Lereim, 2005) – risks that are inherent in all projects. Conversely to systemic risks, the link between project-specific risks and cost and/or duration impacts is comparatively deterministic in nature.

Another important classification of risks is the difference between internal and external risks (Smith & Bohn, 1999):

- *Internal* risks are those found within the project – they are often controllable risks
- *External* risks are generated outside the project and, in many circumstances, are not controllable

## 2.2 Project risk

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Once an anticipated risk has materialised, it is no longer termed a risk, but an *issue*. If a risk that was not anticipated during risk identification, materialises and needs to be monitored during the rest of the project lifecycle, it is termed an *emergent* risk.

The level of remaining risk at any point in the project, for example a certain stage gate, is termed *residual* risk. Also, a risk caused by an action taken to mitigate another risk is called a *secondary* risk.

Project risk analysis methods can be roughly divided into two categories *i.e.* qualitative and quantitative risk analysis, both of which will be described in more detail in the following sections (alongside the description of the PMBOK project risk management method). The choice between qualitative and quantitative techniques depends on the nature of the application of the results and the purpose of the risk analysis (Redmill, 2002). In order to effectively discuss different project risk management processes later in this chapter, a brief outline of risk probability and impact in the following subsection will precede these sections.

### 2.2.1 Probability vs impact

It is common practice to qualify/quantify a project risk in terms of two parameters, namely probability and impact.

Probability is used to qualify/quantify the likelihood or chance that an outcome of a random event will occur (Montgomery & Runger, 2003). The likelihood of an outcome is either qualified as low, medium or high, or qualified/quantified by allocating a number from the interval  $[0, 1]$  or a percentage from zero to hundred to the outcome.

Impact refers to the severity of the effect if a risk were to materialise. The risk impact can be viewed from either a quantitative or qualitative perspective. Prasad (2007) provides the following definition of risk in a very simple model:  $Risk = Probability \times Impact$ . This is also referred to as the *certainty equivalent*, which aims to find a value that is equivalent to a definite impact (Barnardo, 2011). Noor & Tichacek (2009) describe different variables that affect the probability and impact of a risk as the project lifecycle progresses:

- **Knowledge variable:** Risk is proportionate to the level of knowledge

## 2.2 Project risk

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- **Time variable:** Probability diminishes/increases with passing time (impact might increase)
- **Status variable:** Probability decreases with increasing completion of work (impact might increase)
- **Constant:** Some risk probabilities are constant throughout the project, for example extreme weather conditions

Risks with low probabilities and very high impacts (for example natural disasters) are difficult to estimate – owners are therefore often biased against this type of risk even if the certainty equivalent is not high, and attempt avoid them by transferring them to another party (*e.g.* the purchase of insurance) (Barnardo, 2011).

The degree of the ability to model a certain probability is dependent on the nature of said probability – six types that come into play when modelling project risks (listed in decreasing ability to model) are (Barnardo, 2011):

- Randomness (natural variability; inherent property)
- Statistical uncertainty (lack of data)
- Model uncertainty (simplified models)
- Vagueness (imprecision in definitions)
- Gross errors (human factors)
- Ignorance (lack of knowledge; option to obtain additional information)

Having given a brief introduction to the concept of project risk, different methods of project risk management can now be considered. As there are many accepted project risk management approaches, this chapter will aim to focus on only three of those deemed as industry best practice, *i.e.* the risk management processes as governed by the Project Management Body of Knowledge (PMBOK) (PMI®, 2008), the Projects in Controlled Environments (PRINCE2) process (Office of Government Commerce, 2009), and the ISO31000 standard (International Organisation for Standardisation, 2009).

## 2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

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### 2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

Three approaches to project risk management will be discussed in the following subsections, namely those proposed by PMBOK, PRINCE2 and ISO31000.

#### 2.3.1 PMBOK project risk management

Project risk management is defined by the Project Management Institute (PMI®<sup>®</sup>, 2008) as: “The systematic process of identifying, analysing and responding to risk as project-related events, or managerial behaviour, that is not definitely known in advance, but that has potential for adverse consequences on a project objective.” It is interesting to note the distinction between systemic (“managerial behaviour”) and project-specific (“project-related”) risks in this definition.

The Project Management Institute (PMI®<sup>®</sup>, 2008) proposes six risk management processes, each linked to each other and other knowledge areas in the project:

- Risk management planning
- Risk identification
- Qualitative risk analysis
- Quantitative risk analysis
- Risk response planning
- Risk monitoring and control

Each process should occur at least once in every project, and can occur in one or more project phases. Figure 2.1 emphasises the six risk management processes, and illustrates their links with other project knowledge areas. A brief overview of the individual processes will be given in the following subsections.

2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

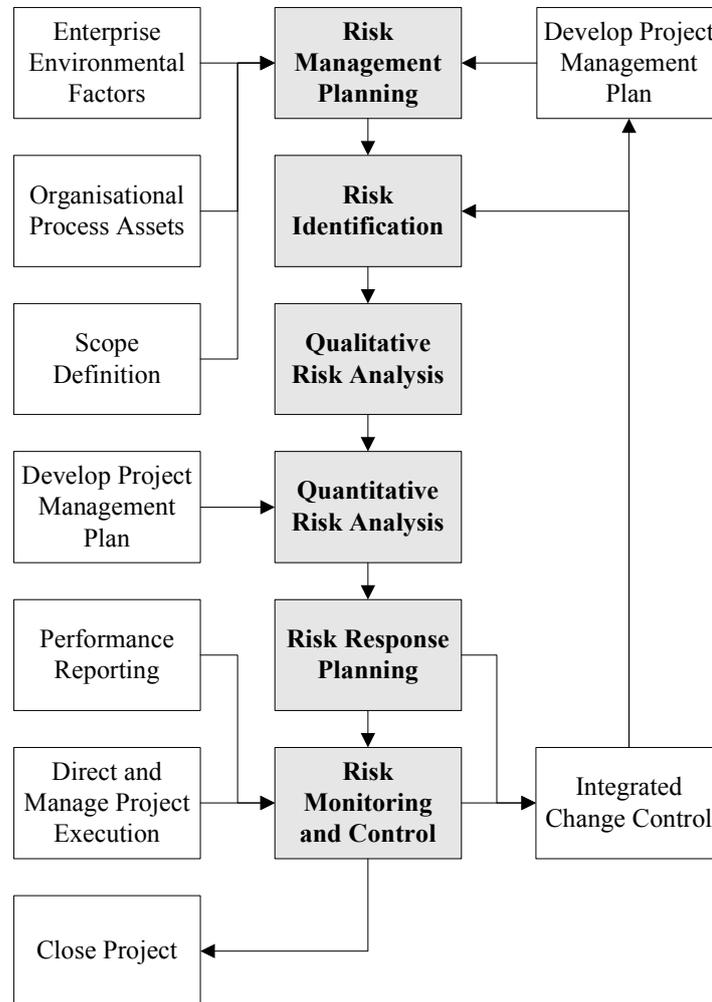


Figure 2.1: The PMBOK project risk management process.

2.3.1.1 Risk management planning

During this process, the project team conducts a planning meeting to develop the risk management plan. This meeting should involve the project manager, selected project team members and stakeholders, and anyone else responsible for the management of risk planning and execution activities. The risk management plan describes how risk management will be structured and performed on the project, and should therefore be part of the overall project management plan. It considers the following risk management aspects:

## 2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

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- Methodology (approaches, tools, and data sources)
- Roles and responsibilities on risk management team
- Budgeting of resources and costs needed for risk management
- Timing of risk management processes throughout the project lifecycle
- Risk categories to be used (for example work breakdown structure vs risk breakdown structure)
- Definitions of risk probability and impact (for example tables providing an impact rating for a given monetary impact)
- Probability and impact matrix denoting risk rating for specific probability vs impact combinations
- Stakeholders' risk tolerances
- Reporting formats for the risk registers and other risk reports
- Tracking (how risk management activities will be recorded)

### 2.3.1.2 Risk identification

The purpose of the risk identification process is to determine which risks might affect the project, and document their characteristics. The process is iterative, as new risks may become apparent as the project progresses. It is important that the participants in this meeting are varied and represent all the knowledge areas pertaining to the project. Subject matter experts from outside the project team may also be required, but the project team should always remain involved to maintain a sense of ownership. Risk identification can be performed using the following tools and techniques:

- **Documentation reviews** of, for example, project plans and assumptions, as these can indicate project risks
- **Information gathering techniques** *e.g.* brainstorming, Delphi techniques, Interviewing, Root cause identification, SWOT analysis

## 2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

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- **Checklist analysis** using a risk identification checklist based on historical information and accumulated knowledge
- **Assumption analysis** to explore the validity of the assumptions that the project scope is based on
- **Diagramming techniques** *e.g.* cause-and-effect diagrams, system or process flow charts, influence diagrams

The output of risk identification is the risk register, which becomes part of the risk management plan, and contains the outcomes of all other risk management processes as they are conducted. The risk register contains: a list of identified risks, a list of potential responses, the root causes of risk, and the updated risk categories.

### 2.3.1.3 Qualitative risk analysis

Qualification of risks is “the process of prioritising risks for further analysis or action by assessing and combining their probability of occurrence and impact”, says the PMBOK (PMI®, 2008). The priority of identified risks as captured on the risk register is assessed using their relative probability, the corresponding impact on project objectives if the risks occur, and other applicable factors such as the time frame for response upon risk realisation and the organisation’s risk tolerance. Qualification can occur as a stand-alone risk analysis process, or as an input to quantitative risk analysis. Tools and techniques used for qualitative risk analysis are as follows:

- **Risk probability and impact assessment**
- **Probability vs impact matrix:** Prioritisation using risk rating (low, medium or high priority) based on probability and impact outcomes
- **Risk data quality assessment:** Examining the degree to which each risk is understood and the accuracy, quality, reliability and integrity of the data regarding each risk

## 2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

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In all of the above steps, expert judgement can be used as a tool to obtain the necessary information. After these steps have been completed, the risk rating obtained as outcome from the probability and impact matrix can be used to reassess risk categorisation and conduct a risk urgency assessment on risks requiring near-term responses.

Outputs of the qualitative risk analysis include a risk register updated in terms of risk ranking, risk categories, urgent risks, risks for additional analysis and response, a watchlist of low priority risks, and trends in qualitative risk analysis results.

### 2.3.1.4 Quantitative risk analysis

The PMBOK (PMI®, 2008) goes on to describe quantification of risks as “the process of numerically analysing the effect of identified risks on overall project objectives”. Quantitative risk analysis can be used to assign a numerical rating to risks individually or to evaluate the aggregate effect of all risks affecting the project. This type of risk analysis is not always required, and when conducted, is often performed on risks that have been prioritised during the qualitative process as potentially and substantially impacting the project’s competing objectives.

The process needs to be repeated as part of *risk response planning* and *monitoring and control* to determine whether overall project risk has been decreased as planned. Experienced risk managers might commence the process directly after risk identification if qualitative results are not explicitly required. Tools and techniques for quantitative risk analysis include:

- **Data gathering and representation techniques**
  - Interviewing to gather quantitative data (for example probability distribution parameters)
  - Probability distributions to represent possible ranges of probability/impact values
- **Quantitative risk analysis and modelling techniques**
  - Sensitivity analysis to determine which risks have the most potential impact under varying conditions
  - Expected value analysis

## 2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

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- Modelling and simulation to translate specified uncertainties to potential impact on project objectives (for example range estimation using Monte-Carlo simulation)

- **Expert judgement to validate data and techniques**

Outputs of a quantitative risk analysis include a risk register updated in terms of a probabilistic analysis of the project, the probability of achieving cost and time objectives, a prioritised list of quantified risks, and trends in quantitative risk analysis results.

### 2.3.1.5 Risk response planning

Risk response planning involves developing options and determining actions to enhance opportunities and reduce threats impacting the project's objectives. A responsible person must be assigned to each agreed response action, and corresponding activities must be added to the project schedule, budget, and project management plan as needed.

The process immediately follows the qualitative and/or quantitative risk analysis processes – risks are addressed as per their priorities. The chosen risk response must be appropriate to the significance of the risk. Tools and techniques for risk response planning include:

- Strategies for negative risks or threats
  - **Avoiding** risk by changing the project management plan to eliminate the threat
  - **Transferring** risk by shifting impact and ownership to a third party
  - **Mitigating** risk by reducing probability and/or impact to an acceptable threshold
- Strategies for positive risks or opportunities
  - **Exploiting** risk to ensure that the opportunity is realised
  - **Sharing** risk by allocating ownership to a third party best able to capture the opportunity
  - **Enhancing** risk by increasing probability and/or impact

## 2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

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- Strategy for both threats and opportunities
  - **Accepting** risk passively (do nothing) or actively (for example contingency allocation)
- Contingent response strategy

In this context, the allocation of a contingency cost/duration is seen as an action mitigating the impact of risk acceptance.

Outputs of risk response planning include an updated risk register in terms of agreed-upon response strategies, risk owners and assigned responsibilities, specific actions to implement chosen response strategies, warning signs indicating risk occurrence, budget and schedule activities required to implement chosen responses, and contingency cost/duration to provide for stakeholders' risk tolerances. Other aspects that can also be included in the risk register at this stage are contingency plans, residual risks and secondary risks arising from implemented risk responses. The project management plan should be updated with response activities, and risk-related contractual agreements (for example risk transfer through insurance) should be put in place as necessary.

### 2.3.1.6 Risk monitoring and control

Risk monitoring and control refers to the identification and analysis of emergent risks, planning for emergent risks, keeping track of identified risks, reanalysing existing risks, monitoring trigger conditions for contingency plans, monitoring residual risks and reviewing the execution of risk response actions to evaluate their effectiveness. The process, which is ongoing for the entire project lifecycle, also determines whether project assumptions are still valid, if proper risk management policies and procedures are being followed, and whether contingency cost/duration should be modified. The following tools and techniques are used in interpreting project performance data to monitor and control risks:

- **Risk reassessment** using risk assessment processes
- **Risk audits** to examine and document the effectiveness of risk responses and risk management processes

## 2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

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- **Variance and trend analysis** to determine potential deviations from baseline plan
- **Technical performance measurement** (planned vs actual functional output at a certain point)
- **Reserve analysis** to compare remaining (residual) risks to remaining contingency
- Project **status meetings** with project risk management on agenda

Outputs of risk monitoring and control include an updated risk register in terms of risk reassessments, risk audits, periodic risk reviews, actual outcomes of risk and risk responses. The project management plan is updated with requested changes necessary to respond to risks. Corrective actions (contingency plans and workaround plans to address risks and emergent risks) and preventive actions (to bring project in compliance with project management plan) are recommended.

At project close-out, the final version of templates used for the risk management plan (*e.g.* probability and impact matrix, risk register) and lessons learned from project risk management activities are captured in the organisation’s databases for future reference.

Having discussed the PMBOK (PMI®, 2008) approach, project risk management as described by PRINCE2 (Office of Government Commerce, 2009) will be outlined in the following subsection.

### 2.3.2 PRINCE2 project risk management

PRINCE2 (Office of Government Commerce, 2009) defines risk as “uncertainty of outcomes (whether positive opportunity or negative threat)”. The task of risk management is defined as: “To manage a project’s exposure to risk (that is, the probability of specific risks occurring and the potential impact if they did occur)”. Thus, a project’s exposure to risk is managed by taking action to keep said exposure at an acceptable level in a cost-effective way.

Three important risk principles are defined, *i.e.*:

1. **Risk tolerance:** Amount of risk the project stakeholders and organisation are prepared to tolerate (risk appetite)

## 2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

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### 2. Risk responsibilities:

- The project manager is responsible for risk identification, recording and review
- The project board notifies the project manager of external risk, makes decisions on recommended reactions to risk, balances the level of risk to potential benefits, and notifies corporate/program level of risks affecting corporate or program level objectives
- The communication and escalation between project and program level is very important – risk management procedures on project and program level must be consistent

3. **Risk ownership:** An owner is identified for each project risk as suggested by the project manager and approved by the project board; the project manager keeps an eye on all project risks

The main steps in the risk management cycle are shown in figure 2.2, and described in more detail in the following subsections. Note that the six step process is divided into two subprocesses *i.e.* risk analysis and risk management.

#### 2.3.2.1 Identify the risks

This is the first step in the risk analysis subprocess of the PRINCE2 project risk management process. During this step, potential risks or opportunities facing the project are identified. Risk categories (*e.g.* strategic, organisational/management/human factors) and subcategories (*e.g.* market fluctuations, management incompetence) are used as a starting point for risk identification. All identified risks are entered into a risk log containing all risk details that will be populated throughout the risk management process (assessment, owners, status, etc.).

#### 2.3.2.2 Evaluate the risks

Risk evaluation addresses the assessment of risk probability and impact of individual risks, taking into account external factors and risk interdependencies to determine said probabilities and impact. Some risks, for example financial risks, lend themselves to quantitative evaluation. Others, such as reputational risks, can only be considered qualitatively. Along with risk probability, the immediacy

2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

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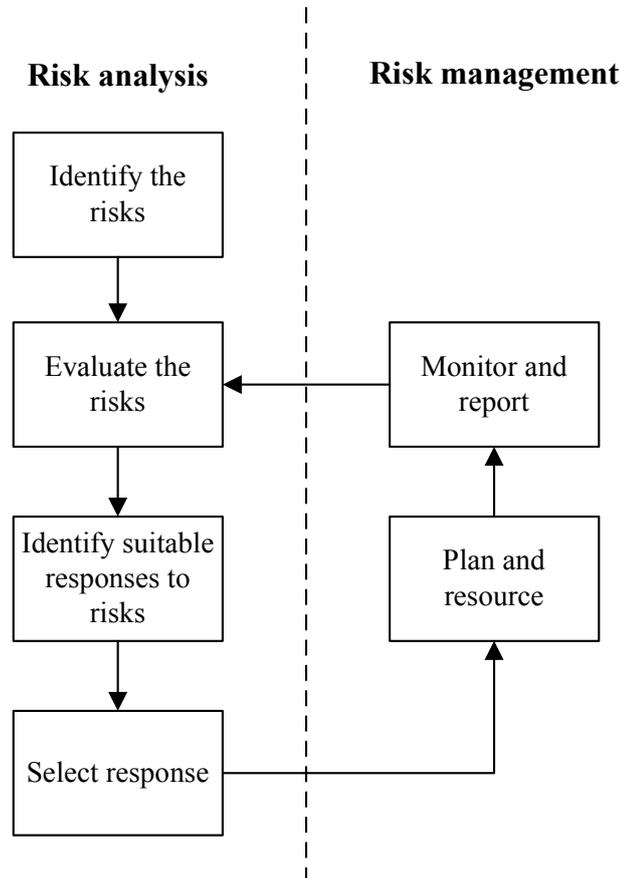


Figure 2.2: The PRINCE2 project risk management process.

of the risk should be considered – this is called the risk’s proximity, and it aids the project board in deciding which risks should be addressed first.

Results of the risk evaluation are captured in the risk log. If the project is part of a program, the impact of project risks on the program as a whole should be considered, and added to the program risk log if necessary.

### 2.3.2.3 Identify suitable responses to risk

Suitable responses to risks can be broadly categorised into five types:

1. **Prevention:** Remove the risk by doing things differently

## 2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

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2. **Reduction:** Treat the risk by taking action to control it in some way (reduce likelihood or impact)
3. **Transference:** Pass risk to a third party, for example using insurance policies
4. **Acceptance:** Tolerate the risk (because risk impact is acceptable, or mitigation at a reasonable cost is not possible)
5. **Contingency:** Actions planned/organised to be executed as and when risk occurs

Contingency actions can include setting aside a contingency fund or duration buffer to address project cost increase or schedule delay.

If a risk is too costly to be mitigated and has to be accepted, but its acceptance causes project feasibility to be questioned, the justification for the project must be revisited to determine whether project termination is necessary.

### 2.3.2.4 Select response

As the last step in the risk analysis subprocess, selection involves the identification and evaluation of options for treating risks, and the preparation and implementation of risk management plans. During this step it is important to ensure that the control action put into place is proportionate to the risk in terms of the associated control cost and value added by its implementation. The value added is determined by balancing the cost of taking the action against the likelihood and impact of “allowing” the risk to occur.

When there is more than one possible action, they need to be considered in terms of the value they add and the impact of the risk action on:

- The team, stage and/or project plans
- The business or program
- The business case
- Other parts of the project

Risk tolerances must be taken into account while making these considerations.

## 2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

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### 2.3.2.5 Plan and resource

After the selection has been made, the risk management subprocess can be commenced by planning and resourcing the selected actions.

*Planning* addresses the quantity and type of resources required, the development of a detailed plan of action to be included in the project plan, the confirmation of the desirability of carrying out the selected actions in light of new information, and the approval by management of the plans being produced.

*Resourcing* concerns the identification and assignment of actual resources to conduct the selected actions, the addition of the assignments to the project plan, the funding of prevention, reduction and transference actions from the project budget, and the setting up of a contingency budget to fund contingency actions.

### 2.3.2.6 Monitor and report

This step ensures that there are mechanisms in place to monitor and report on risk management, including actions selected to address risks. Monitoring consists of checking that execution of planned actions have the desired effect, watching for early warning signs that a risk is developing, modelling trends and predicting potential risks/opportunities, and checking that the overall management of risk is applied effectively. If monitoring indicates that actions are not having the desired effect, or that a project risk tolerance may be exceeded, a report should be generated.

A risk profile or risk matrix is proposed as reporting mechanism to graphically display each risk in terms of probability vs impact to show whether the risk in question is above or below the risk tolerance line. All risks above said line should be escalated to the next managerial level.

Having discussed the PRINCE2 ([Office of Government Commerce, 2009](#)) approach, project risk management as described by ISO31000 ([International Organisation for Standardisation, 2009](#)) will be outlined in the following section.

### 2.3.3 ISO31000 project risk management

The ISO31000 approach to project risk management employs seven steps as shown in figure 2.3, *i.e.*:

- Communicate and consult

2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

- Establish the context
- Identify the risks
- Analyse the risks
- Evaluate the risks
- Treat the risks
- Monitor and review

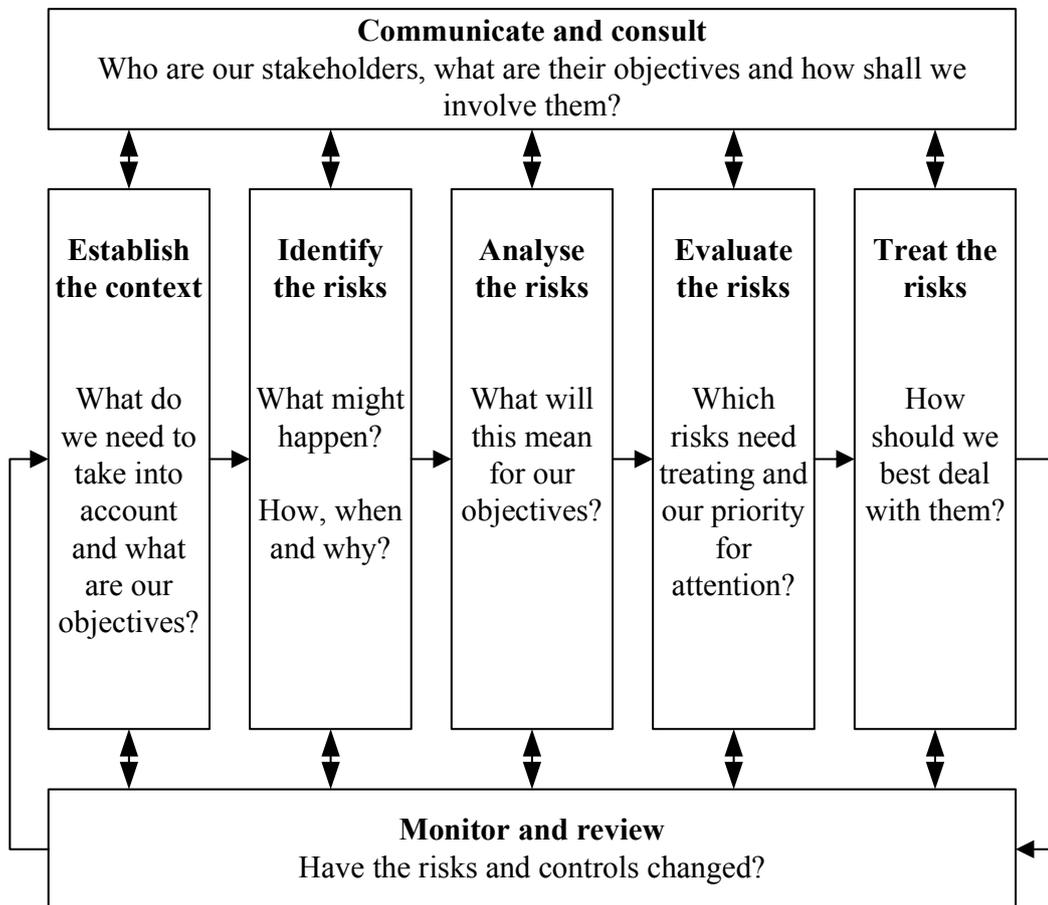


Figure 2.3: The ISO31000 risk management process.

This process is adopted by the Integrated Risk Management methodology as applied in Eskom, and will be fully discussed in chapter 5.

## 2.3 Project risk management – PMBOK, PRINCE2 and ISO31000 approach

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### 2.3.4 Summary of best practice methods

There are many different standards outlining accepted best practice processes for project risk management, *e.g.* the PMI standards (PMBOK), Office of Government Commerce (PRINCE2) and International Organisation for Standardisation (ISO31000). [Kutsch & Hall \(2010\)](#) state that all of these standards have in common an overall activity concerned with planning actions that will be implemented to reduce exposure to risk. Further, all standards comprise of four steps (some best practices include interim/sub-steps) as follows:

- **Planning:** Risk management activities are planned
- **Identification:** Risks that may affect project objectives are identified
- **Analysis:** Risk probabilities and impacts are evaluated quantitatively and/or qualitatively
- **Response:** Procedures and techniques are developed to
  - Mitigate and track risks
  - Identify emerging risks
  - Implement risk response plans

It should be noted that not all research support the principles that the widely used methods explained above, employ. Most traditional risk management methods are based on probability theory to manage risk. This necessitates assumptions regarding the project, *e.g.* its repeatability (to enable reference to historic information) and the randomness of project events ([Pender, 2001](#)). Though this would be a comprehensive approach if only risks with calculable probabilities were prevalent on the project, many uncertainties and doubts also exist in the project management environment; *e.g.* non-random human decisions, and unknown future states. Also, probability-based techniques assume that decision parameters and outcomes fall into well-defined, mutually exclusive categories.

As Albert Einstein said: “Everything that can be counted does not necessarily count; everything that counts cannot necessarily be counted”. However, for the purpose of this study, the focus will remain on **risks** with stochastic properties.

## 2.4 Project risk management from an owner's perspective

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Also, the emphasis will be on risks that may **negatively** affect the achievement of the objectives.

Having considered project risk and methods applied to manage it, the following sections will discuss other important aspects to consider regarding the topic for the purpose of this study, *i.e.* project risk management from an owner's perspective, and project risk management on a portfolio level.

### 2.4 Project risk management from an owner's perspective

As this study will focus on project risks from an owner's (Eskom's) perspective, this viewpoint needs to be differentiated from other perspectives on project risk. [Hollmann \*et al.\* \(2009\)](#) states that from an owner's perspective, systemic risks are especially important, as these risks normally pertain to early definition, planning, technology and decisions prevalent early in the project that cannot be readily transferred to execution contractors.

The use of external consultants/contractors to complete design and construction work transfers a great deal of design and construction risk, while the owner retains the general project risk ([Smith & Bohn, 1999](#)). The amount of risk that remains with the owner depends on the chosen contract type. This is discussed alongside the influence of contract type on project contingencies in section 3.7.

For a large owner employing small or medium-sized construction contractors, it is important to note that though some construction risks are owned by the contractor and must thus be included in the contractor's estimate, many contractors do not invest in analytical tools to assist in risk management and/or contingency estimation ([Smith & Bohn, 1999](#)). Also, in times when competition is high, contractors tend to leave anticipated contingency from their estimate to be more competitive. Owner company contingency estimates should not include risks that are the responsibility of the contractor according to the project contract. However, modelling techniques and tables of risk factors on the owner's side should make provision for the fact that an estimate that seems like a bargain during the bidding stage in competitive times, may in fact result in many changes claimed during the construction period.

It is especially important to note the contrast in owner's risks and contractor's risks, as the owner and contractor must manage these side-by-side during

## 2.4 Project risk management from an owner's perspective

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project execution. Fang *et al.* (2004) states that objectives differ between owners and contractors: The main objective of a contractor is to make profit, while an owner should aim for a balanced combination of time, cost and quality. This results in a misalignment of goals in the project risk management sphere, which ultimately leads to adversity between project participants. The objective of a comprehensive risk management approach should be to balance the risks taken on by participating parties. The construction industry is starting to move in this direction, attempting joint risk management through partnering principles.

As experiences of individuals from various organisations differ, each organisation's risk management participants tend to focus on risks that are prevalent in their organisation. This prevents a holistic view of all risks that can affect a project. Open communication with other organisations regarding risk management systems and processes could help alleviate this (Fang *et al.*, 2004). Clients and contractors need to have input into each other's risk management process.

Jerling (2009) proposes the following steps to ensure alignment between contractor and owner risk management approaches:

1. Contractors should take owner-generated risks into account when planning risk mitigation strategies
2. The contractor's perspective on owner-related risk should be debated with the owner – this could lead to a better understanding between parties of the risks faced from both perspectives
3. If the contractor feels that contractual conditions favour the owner, the impact of this from the perspective of the contractor should be highlighted to the owner
4. Owners should be encouraged to involve contractors in risk management activities from an earlier project stage
5. Owners and contractors should jointly review construction risks for particular projects – owner-generated risks should be discussed and debated, enabling project participants to assess the impact of these risks as a team

## 2.5 Project risk management on portfolio level

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6. Contractor staff should undergo formal risk management training, particularly in the area of owner-generated risk

The aim of these steps should be to allocate risks to the party that is most suited to handle them, as this could lead to more certainty regarding project budget and duration.

The next and final section of this chapter will consider project risk management on a portfolio level.

### 2.5 Project risk management on portfolio level

Portfolio risk management refers to the management of project risks at enterprise level ([DOE Committee for Oversight & Assessment of U.S. Department of Energy Project Management, 2005](#)). Though a portfolio in this case consists of projects and not stocks and bonds, the analogy with stock portfolios is intentional.

A knowledgeable owner, whether of stocks and bonds or of projects, needs to be able to balance the portfolio to achieve an acceptable overall risk level. High-yield, high-risk ventures need to be balanced by low-yield, low-risk projects.

One of the main challenges that separate project portfolio management from investment portfolio management is decreased flexibility, in that projects cannot be bought and sold with fluctuations in the market as investments are. Furthermore, some of the projects that an organisation takes on may not be freely chosen, but motivated, for example, by political influence. This further illustrates the need that the owner has to understand the risks associated with a project. An owner who performs a large number of projects should therefore aim to maintain a database of past projects using a consistent methodology for assessing risks so that valid statistical judgements can be made based on the gathered data.

Another challenge is the influence of subjectivity on risk management results, especially when risk analysis and evaluation steps for different projects belonging to the portfolio are conducted by a wide variety of different project teams in a large owner organisation. This affects the usefulness of information as a basis for decision-making analysis when rolled up to portfolio level.

Subjectivity is not only found during the risk analysis itself ([Redmill, 2002](#)), but also in many steps during preparation for the workshop *e.g.* decision on

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## 2.6 Concluding remarks on chapter 2

workshop scope, participants, and risk evaluation criteria (if these are not standardised). Other sources of subjectivity in the workshop can be traced to small, seemingly unrelated decisions, *e.g.* the project manager's/analyst's opinion on what information should be circulated between workshop participants, and how long before the workshop this information should be sent to participants.

All techniques of risk identification are dependent on some form of human observation, judgement, and/or creativity. The choice of risk identification technique also becomes an influence factor made subjectively by the workshop facilitator (if the method is not prescribed). The timing of the workshop itself is also often a subjective decision which can largely impact the session's outputs.

Checklists can be used to minimise subjectivity or bias, says Redmill (2002), but have the disadvantage that they need to be used in the same circumstances as they were created to avoid dangerously misleading their users.

It should be considered that subjectivity is also a major benefit of risk analysis – the requirement of thought and judgement throughout the process. However, where subjectivity can be reduced or better understood to improve accuracy, it should be done (Redmill, 2002).

## 2.6 Concluding remarks on chapter 2

This chapter provided a background on risk in general, and project risk specifically. Key terms and definitions surrounding project risk were outlined. The management of project risk was explored from the perspectives of several project management methods that are considered as best practice internationally. The chapter concluded with a discussion on project risk management from an owner's perspective, and project risk management on program and portfolio level.

In each of the project risk management methods, the role played by project contingencies was mentioned briefly. Having discussed the most pertinent concepts and methods related to project risk management in general, the following chapter will discuss in more detail the estimation of project contingencies.

## CHAPTER 3

# PROJECT CONTINGENCY ESTIMATION

The extremes of project risk management lie on two sides of a spectrum; one end referring to complete mitigation (possibly involving some level of contingency cost/duration to cover mitigation actions), and the other end to the acceptance of risk and subsequent management through contingency. A contingency allowance enables project owners to “live with risks and deal with them as they occur” (Khamooshi & Cioffi, 2009), and risk management and contingency reserves are critical for the successful development of projects in a complex and uncertain environment (Dillon *et al.*, 2005).

This chapter will provide a background on the importance of project contingencies in project management, distinguishing between cost and schedule contingencies, and discussing each contingency type briefly. Common errors in contingency estimation will be reviewed, followed by an outline of statistical theory often applied in project contingency estimation. Four general categories of contingency estimation methods will be described in detail, and a brief outline will be given of each of several other contingency estimation methods encountered in literature but not encompassed by the general categories. A statistical technique for the management of contingency costs on portfolio level will be discussed, after which the chapter will be concluded with brief descriptions of the influence that contract type as well as psychological and political factors have on contingency estimation.

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### 3.1 Importance of project contingencies

#### 3.1 Importance of project contingencies

The Project Management Institute's (PMI) Project Management Body of Knowledge (PMBOK) (PMI®, 2008) defines a contingency reserve as a separately planned quantity (cost, schedule, or both) used to allow for “future situations that may only be planned for in part”. Contingency reserves are intended to reduce the effect of missing cost or schedule objectives.

In discussions of project risk, contingency allocation addresses uncertainty in the project budget or schedule (Nassar, 2002). The term “contingency” refers to an amount added to an estimate for project costs or durations to cover some element of risk or uncertainty, confirms the DOE Committee for Oversight & Assessment of U.S. Department of Energy Project Management (2005). It can also be described as the funds/time set aside for accepted risks (some risks are accepted rather than mitigated) (Cioffi & Khamooshi, 2009; Mak & Picken, 2000).

Noor & Tichacek (2009) explain the concept of contingency from a different perspective, stating that the criteria for a project's success are set up using assumptions: certain things are correct (for example budget), certain things will happen (for example resources will be available as planned), and certain things will not happen (*e.g.* strikes and bankruptcies). These assumptions lead to risk, which are dealt with by planning sufficient additional time and/or money to compensate for the possible realisation of these risks.

From the dictionary definition of the word (Gove, 1968), we see that a contingency is described as “the condition that something may or may not occur” or “the happening of anything by chance”. This implies that the actual expenditure of a project contingency is in itself an event occurring by chance. One would therefore not expect a contingency to be used under normal circumstances. It should not be used to address changes in scope or hide poor estimating, but rather to cover omissions and unforeseen expenses caused by incomplete engineering information, uncertainty in the data used to prepare the estimate, and the risk associated with the venture (Minassian & Jergeas, 2009).

Thus the contingency is used to absorb the impact of project risks, and while some would term this risk acceptance (Khamooshi & Cioffi, 2009), it can also be seen as a form of risk mitigation for unforeseen or under-predicted events (Prasad, 2008). However, contingency should not be a first alternative; it should

### 3.1 Importance of project contingencies

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only be used as a part of a complete risk mitigation effort. Noor & Tichacek (2009) prescribe that the contingency should be sufficient to cover the cost or time required to avoid, transfer, mitigate or bear the realisation of risks – a contingency can be linked to any of these risk response actions.

In this study, the term contingency will be used to describe the cost or time required to support the chosen mitigation strategy (regardless of strategy type) as described by Noor & Tichacek (2009).

It is important to remember that both schedule and cost contingencies have a significant impact on the feasibility of a project, says Burger (2003) – incorrect calculation might result in a project not being selected for execution due to an apparent lack of, for example, economic viability.

Having outlined the importance of project contingencies and basic principles regarding contingency application, the following two subsections will describe different types of contingencies, *i.e.* cost contingencies and scheduling contingencies.

#### 3.1.1 Cost contingencies

In project management, financial/cost contingencies have the objective of accounting for probable cost increases (risks) above target estimates (Barazza & Bueno, 2007). Because of the risks in every unique project, a completely accurate cost estimate will never be achievable (Zhao, 2006). As they play a key role in cost performance evaluation, project cost contingencies should not only be properly calculated, but also properly assigned in the budget estimation process and wisely controlled during project execution.

In **deterministic** methods, cost contingency is often presented as a single fixed percentage of direct costs, normally in the region of 5% to 10% (Smith & Bohn, 1999). In methods with **stochastic elements** (probabilistic methods), a total cost distribution can be determined and used to indicate the level of confidence that the project budget will not be exceeded at a certain level of contingency reserve. The project owner then establishes the contingency levels for each project based on the desired confidence level for meeting baseline requirements, confirm Cioffi & Khamooshi (2009). Curran (1989), Moselhi (1997) and Touran (2003) criticise the discussion of contingency if the confidence level associated

### 3.1 Importance of project contingencies

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with the contingency amount is unknown (*i.e.* a fixed deterministic percentage is used).

Karlsen & Lereim (2005) provide three categories of monetary risk reserves for a project in which probabilistic methods are employed to determine the total cost distribution, and emphasise the importance of distinguishing the different types:

- Contingency, which is the amount added to the base estimate to obtain the expected value (probability of cost underrun is equal to probability of cost overrun)
- Allowance, which refers to the amount added to obtain an even higher level of certainty in project cost, for example only 15% probability of cost overrun
- Budget risk reserve (management reserve), which is set aside to cover changes in project assumptions or other major unforeseen impacts that were not identified during the risk analysis to determine contingency and allowance amounts

Figure 3.1 depicts the difference between contingency and allowance values as determined from the cumulative project cost distribution (note that in this example, the most likely value shown on the figure refers to the base estimate). The contingency and allowance should be managed by the project manager, whereas the expenditure of the budget risk reserve (also called management reserve) should be overseen between the project manager and the project owner. Some organisations/publications include the concept of allowance in the definition of contingency, where the level of certainty in project cost brought about by the contingency amount is chosen according to risk appetite, and not always taken at the median point of the cumulative cost distribution (where probability of cost overrun equals probability of cost underrun). However, many specialists (Bent, 2006; Burroughs & Juntima, 2004; Karlsen & Lereim, 2005; Prasad, 2008) persist that the median point of the cumulative cost distribution is the point at which contingency should be determined. It should therefore be noted that not all sources agree on the necessity of an allowance over and above the median contingency amount.

### 3.1 Importance of project contingencies

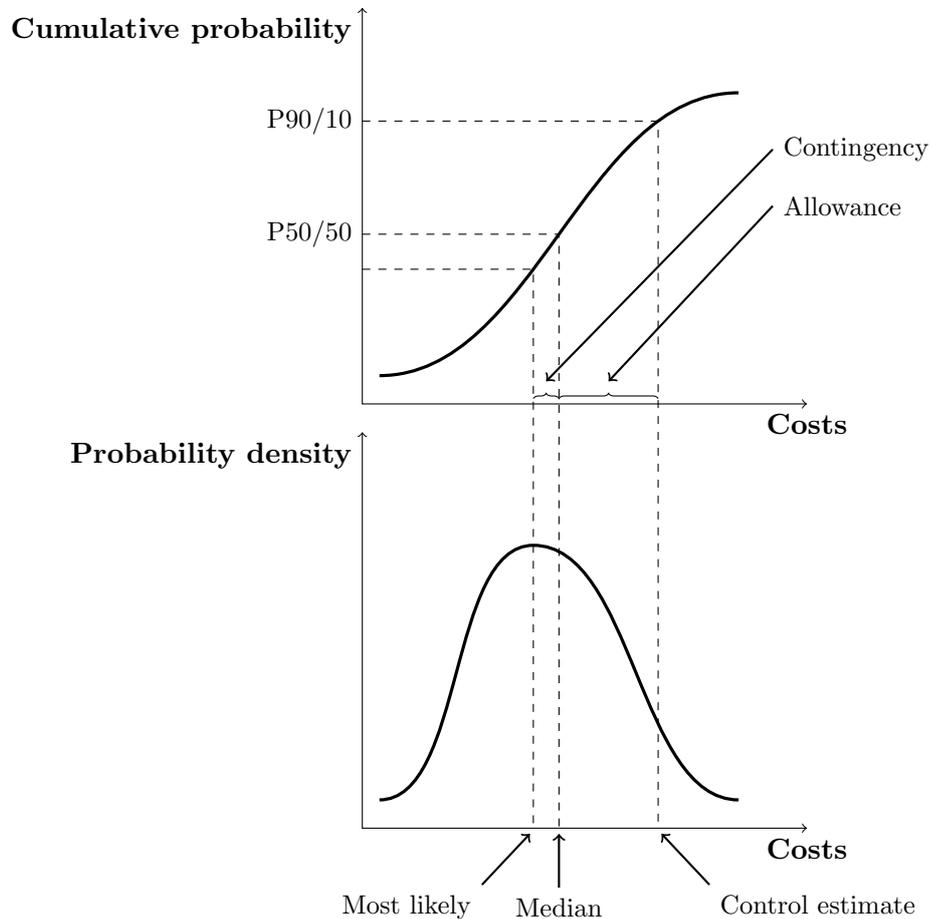


Figure 3.1: Cumulative project cost distribution.

Noor & Tichacek (2009) support definitions of contingency and budget risk reserve provided by Karlsen & Lereim (2005), but counter that allowances are not risk-based or dependent, but rather a budget line item used to compensate for *e.g.* quantity uncertainties early in the project lifecycle, or other such elements that are within the project scope but not clearly defined in all project stages. Prasad (2008) substantiates this view, stating that any scope changes should be funded from the management reserve. Gunhan & Arditi (2007) combine the concept of contingency and management reserve in their research, stating that owner's contingency can be used to cover scope change.

When viewing projects in isolation, overallocation of contingencies would have

### 3.1 Importance of project contingencies

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a smaller effect on project execution than underallocation. For a program/portfolio containing multiple projects, the correct estimation of contingency values becomes even more critical. Inadequate contingency will, as for individual projects, lead to project scope reductions, schedule delays, and even terminations. But at the program/portfolio level, large cost underruns on the overall budget could be attributable to an excessive contingency. This ties up the owner's capital or borrowing capacity unnecessarily in reserves that are not needed or could have been used to support other desirable projects. Also, unspent contingency funds are often used to fund scope changes and enhancements or other elements that should be purchased with budget reserve. Therefore overallocation of contingencies to ensure the availability of funds is not a desirable option. Mak & Picken (2000) state that contingency overallocation is especially detrimental in government funded projects, as it disturbs the important fiscal functions of public sector spending in provision of social goods, distribution of income and wealth, and maintenance of a stable economy. In short, the proper allocation of contingency costs becomes a mechanism for accountability for public money.

To avoid overallocation, a program with many projects should set its budget amount (base cost plus contingency) at the same level of the total cost distribution for all projects (for example the median value) – some projects will be under budget and some over budget, minimising the effect on the total program budget (Noor & Tichacek, 2009; Prasad, 2008). This confirms the reason that many experts disregard the need of an allowance over and above the median value of the total cost distribution as mentioned earlier: For a once-off project where it is very important that the budget should not be exceeded, contingency level (or contingency plus allowance level) should be set to a point higher than the median value, but for a program/portfolio of projects, this could lead to an overly conservative retention of funds.

For the purpose of this study, the terminology prescribed by Karlsen & Lereim (2005) will be adopted when probabilistic methods are employed, *i.e.* the term **contingency** will be used to refer to the amount added to the base estimate to obtain the median value (probability of cost underrun is equal to probability of cost overrun), and the term **allowance** will be used to refer to the amount added to obtain an even higher level of certainty in project cost. **Management reserve**

### 3.1 Importance of project contingencies

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will not be discussed, as capital to cover changes in project assumptions or other major unforeseen impacts are not assigned per project in the environment this study considers (as will be addressed in chapter 4).

Having discussed the basic definitions, categories and considerations linked to project cost contingencies, the next subsection will focus on schedule contingencies.

#### 3.1.2 Schedule contingencies

Schedule contingencies are similar to cost contingencies, but have the objective of accounting for probable *duration* increases (schedule risks) above target duration estimates. As with cost contingencies, the intention of schedule contingencies are not to account for scope growth. As the impact of all risks pertaining to a project can never be completely known at early stages in the project, an infallible schedule is very hard to create.

Schedule contingency can be applied either as a total float value providing duration “leeway” to the project as a whole, or as individual float values assigned to each schedule activity based on the evaluated risk for the activity in question. In the former case, a single fixed percentage of project duration can be applied, or the overall float can be determined from individual duration distributions using methods with stochastic elements to obtain a distribution for total project duration. As with cost contingencies, the required float duration is then read from the distribution as the duration corresponding to a certain level of confidence that the project duration will not be exceeded.

Schedule risk analysis can also be used as a basis for contingency cost estimating by integrating the project cost estimate with the project schedule (costing and resource-loading the schedule’s activities), and simulating the cost-loaded schedule using Monte-Carlo techniques (Hulett, 2010). The result is an estimate of both schedule and cost contingencies, permitting the impacts of schedule risk on cost risk to be calculated. This method is the most well-documented integrated cost and schedule contingency estimation approach in literature (Hollmann, 2010).

Though cost and schedule contingencies both play a critical role in project management, the focus of this study will be the estimation of cost contingencies and integrated estimation of schedule and cost contingencies. The reasoning

### 3.2 Common errors in contingency estimation and application

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behind this decision will be discussed in chapter 6, when study objectives are outlined.

Having established cost and integrated cost-schedule contingency estimation methods as the main focus of the remainder of the chapter, following sections will first discuss common errors, general principles and statistical theory linked to these methods before considering the descriptions of the different contingency estimation methods themselves.

### 3.2 Common errors in contingency estimation and application

A common problem with contingencies is the fact that they are often not viewed as described in the previous sections, but rather taken to refer to funds/durations that can be completely expended in the course of the project, no matter what happens.

Another common error is to add escalation or inflation in contingency costs, which is not good practice (Moselhi, 1997). Acts of God, force majeure, fire, natural disasters, strikes, and human error should also not be considered when estimating contingencies.

Moselhi (1997) continues that contingency is intended to cover incomplete design, construction accidents and breakdown, regulatory risk, estimating inaccuracies, technological change and abnormal construction start-up problems. It is not intended to make provision for profit, changes in scope, overhead or cash allowance.

As a clear definition of contingency and the errors often linked to its estimation have been discussed, the following section will consider statistical theory necessary as background for the contingency estimation methods to be discussed later in the chapter.

### 3.3 Background on statistical theory used in contingency estimation

There are many statistical methods applied in the calculations and assumptions used to estimate project contingency cost/duration. The most prevalent are

### 3.3 Background on statistical theory used in contingency estimation

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briefly reviewed in the following subsections *i.e.* the Central Limit Theorem, distributions used to describe risk, and the binomial distribution.

#### 3.3.1 Central Limit Theorem

The Central Limit Theorem states that, for large sample size  $n$ , the random sum  $S_n$  has an approximately normal distribution with mean  $n\mu$  and variance  $n\sigma^2$ .

[Kroese \*et al.\* \(2011\)](#) describe the Central Limit Theorem using (3.1):

*Let  $X_1, \dots, X_n$  be iid (independent and identically distributed) with mean  $\mu$  and variance  $\sigma^2 < \infty$ . Then,*

$$\frac{S_n - n\mu}{\sigma\sqrt{n}} \xrightarrow{d} Y \sim N(0, 1) \text{ as } n \rightarrow \infty. \quad (3.1)$$

This theorem is often applied when a number of individual risks, each with their own cost/duration distribution type, are combined to obtain a total project cost/duration distribution.

#### 3.3.2 Distributions used to describe individual risks and overall risk

As touched on in the previous subsection, the normal distribution is often used to represent total project cost/duration. The reasons for this are:

- It is intuitively simple (requiring only a mean and standard deviation as parameters)
- It is particularly suited to represent a budget/schedule comprising a number of stochastic cost/duration elements by the Central Limit Theorem

However, the normal distribution is not particularly suited to the representation of individual risks as it cannot be skewed, and is therefore not flexible enough to reflect the expert's judgement ([Yang, 2005](#)). The triangular and beta distributions can be skewed, and are therefore often used to represent individual stochastic cost/duration elements in risk analysis. A special form of the beta distribution, *i.e.* the beta-PERT distribution, is often applied (note that application of the PERT method is discussed in more detail in subsection [3.5.4](#)). The triangular and beta-PERT distributions can both be characterised on the bases of

### 3.3 Background on statistical theory used in contingency estimation

three parameters (minimum, mode and maximum), making them relatively simple to apply in a risk workshop setting. Additional scale and shape parameters would be required if the beta distribution were applied in its standard form.

In the case of the triangular distribution, either the normal triangular distribution as shown in figure 3.2 or the double triangular distribution as shown in figure 3.3 can be used. The practical application of these two forms of the triangular distribution will be discussed in subsection 3.4.3.2.

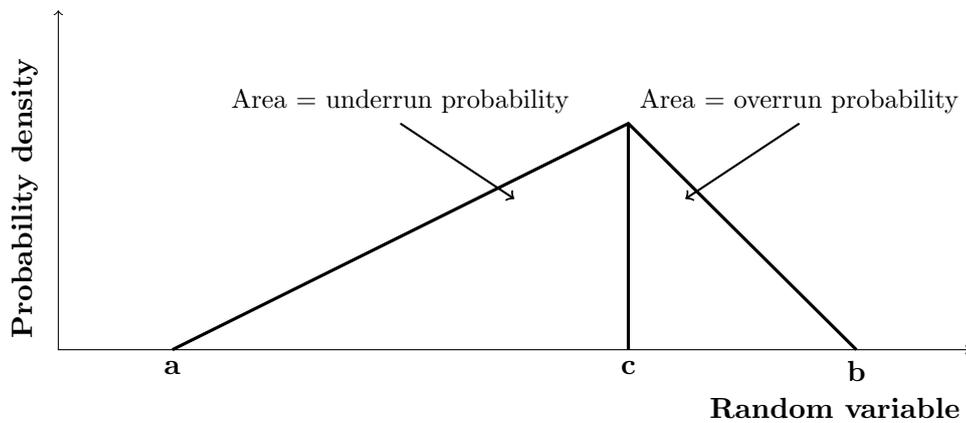


Figure 3.2: The triangular distribution.

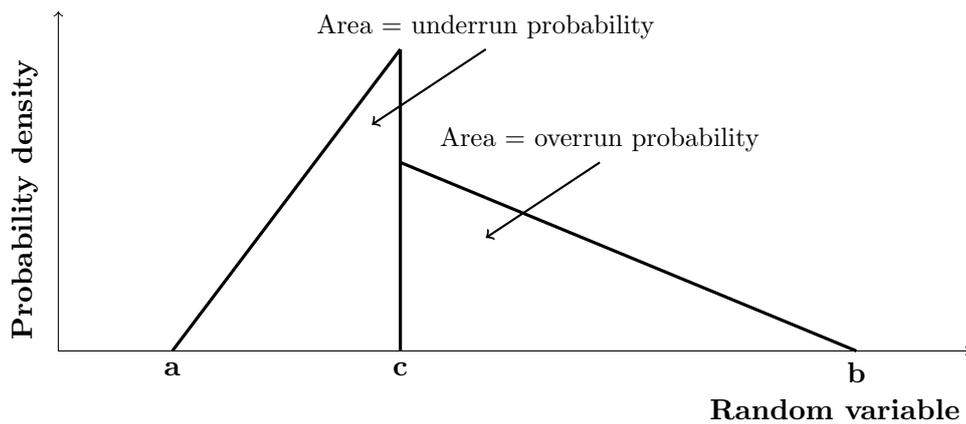


Figure 3.3: The double triangular distribution.

### 3.3 Background on statistical theory used in contingency estimation

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#### 3.3.3 Binomial distribution

Binomial distribution sampling is one of many proposed methods to assist with the estimation of contingency presented in this chapter – in this case, the estimation of a contingency value is based on the anticipated discrete number of risks that occur. As the discussion of this approach requires a basic understanding of a distribution not regularly encountered in discussions on project risk, this subsection aims to provide a brief background on this distribution type for reference purposes.

A Bernoulli trial is a trial with two possible outcomes (“success” or “failure”) that is often used as the building block of a random experiment. It is normally assumed that the individual trials making up a random experiment are independent, and the probability of success in each trial is constant (Montgomery & Runger, 2003). The **binomial distribution** can be described as an experiment consisting of  $m$  Bernoulli trials.

The random variable  $B$  representing the number of successful trials has a binomial random variable with parameters  $0 < p < 1$  and  $b = 1, 2, \dots, m$ . The probability mass function of  $B$  is

$$f(b) = \binom{m}{b} p^b (1-p)^{m-b}, \quad b = 0, 1, \dots, m. \quad (3.2)$$

The mean and variance of a binomial random variable can be calculated as

$$\mu = E(B) = mp \quad (3.3)$$

and

$$\sigma^2 = Var(B) = mp(1-p). \quad (3.4)$$

This distribution can be used to model the expected number of risks that will occur on a project, as will be discussed in more detail in subsection 3.5.1.1.

Having discussed the basic statistical *theory* that needs to be understood to proceed with a discussion of specific contingency estimation methods, the next section will move on to the discussion of general categories of contingency estimation methods.

### 3.4 General categories of contingency estimating methods in practice

#### **3.4 General categories of contingency estimating methods in practice**

The estimation of contingency is among the most controversial topics in cost engineering. While most cost engineering specialists agree on what contingency is, there is much less unanimity on how it should be determined. Some methods are deterministic, while others are stochastic (probabilistic).

[Hollmann \*et al.\* \(2008a\)](#) define four general classes of methods used to estimate cost/time contingencies that respect the basic principles of risk estimation when applied correctly:

- Expert judgement
- Predetermined guidelines (making use of varying degrees of judgement and empiricism)
- Simulation analysis (predominantly expert judgement incorporated in a simulation)
  - Range estimating
  - Expected value
- Parametric modelling (empirically-based algorithm, with varying degrees of judgement used)
  - Regression analysis
  - Neural network analysis

More detailed background on these methods is provided in the following subsections.

##### **3.4.1 Expert judgement**

The term “expert” refers to the fact that the exercised judgement must have a strong basis in experience, and be supported by competency in risk management and analysis ([Hollmann \*et al.\*, 2008a](#)). Most contingency estimation methods contain some form of expert judgement, but applying it on its own is highly subject to the imposition of iatrogenic (self-imposed) risk when judgement is

### 3.4 General categories of contingency estimating methods in practice

inconsistent or biased. Bias can be minimised by obtaining the consensus of several experts or an experienced team, provided there is varied, independent opinion (*i.e.* avoidance of “group-think”).

Methods using expert judgement to obtain a project cost distribution often result in a distribution that is skew to the right (Karlsen & Lereim, 2005), as estimates tend to be conservative – the base estimate tends to be less than the even chance (50/50) estimate. Another challenge with the method is the fact that experts whose understanding of project cost risk and estimate competitiveness can be relied on, are hard to come by (Burroughs & Juntima, 2004).

Examples of methods using only expert judgement are as follows (Burroughs & Juntima, 2004):

- Considering bounds or norms (formal or informal) for total contingency outcomes
- Selecting predetermined contingency levels based on discrete risk levels (*e.g.* 15% for high risk, 10% for average, and 5% for low risk)

#### **3.4.2 Predetermined guidelines**

Predetermined guidelines can be employed on various levels of complexity, the most simple of which being the provision of a single contingency or float value (for example a percentage of base cost/duration) for use on all estimates or schedules of a certain type (Hollmann *et al.*, 2008b). The other end of the scale would be to use complex tables or scoring mechanisms that employ elements of parametric modelling. A frequently used approach is to establish a table of contingency values and ranges for each cost estimate or schedule class with alternative values and ranges provided for common risks.

An advantage of this approach is that it is simple, understandable and consistent (Prasad, 2008). A disadvantage is that it cannot effectively address risks that are unique to a specific project, or risks that are common, but have disproportionate impacts on a given project. For that reason it is most useful for estimates early in the project lifecycle, when systemic (non-project-specific) risks such as the level of scope definition are dominant. In all cases, outcomes must be sup-

### 3.4 General categories of contingency estimating methods in practice

ported with expert judgement. As the development of predetermined guidelines is often informed solely by expert judgement, results can be subjective.

[Mak & Picken \(2000\)](#) found that using the single contingency float value or single lump sum approach normally amounts to an educated guess at best – using statistical methods of contingency allocation was found to be more effective at reducing unnecessary and exaggerated allowance for risk. The predetermined guideline method tends to underestimate contingency requirements for complex or poorly defined projects, and overestimate contingency requirements for simple or well-defined projects ([Burroughs & Juntima, 2004](#)). These sentiments are echoed by [Noor & Tichacek \(2009\)](#) and [Prasad \(2008\)](#).

As the application of expert judgement and predetermined guidelines as contingency estimation methods have been discussed, the following sections will focus first on simulation analysis and then on parametric modelling.

#### **3.4.3 Simulation analysis**

In the simulation analysis method, expert judgment is combined with an analytical model that is then used in a simulation routine to provide probabilistic output ([Hollmann \*et al.\*, 2008b](#)). An advantage of this method is that the experience and input of the risk analyst is combined with that of the project team, which makes it particularly well suited to project-specific risks.

The complexity of the method can be seen as a disadvantage, as it requires expertise in application (which also makes it subject to manipulation). Another drawback is that the outcomes of the method are not highly consistent as they are dependent on analyst and team input. Also, because these methods are not empirically based, it can be difficult to apply them effectively for systemic risks which are predominant for early estimates. Finally, it is important to note that the model requires estimating and schedule expertise throughout the exercise.

*Range estimating* and *expected value* are the most common simulation analysis methods, both of which often use Monte-Carlo or similar simulation routines. A discussion of the Monte-Carlo method and the two simulation analysis methods are presented in the following subsections. It is important to note that even though these methods are viewed as sophisticated, their results are far from accurate if incorrectly applied, especially on projects with poorly defined scopes,

### 3.4 General categories of contingency estimating methods in practice

or in cases where the risk practitioner does not clearly define the interdependencies between risks (Hollmann, 2007).

#### 3.4.3.1 Monte-Carlo simulation

Monte-Carlo analysis (also described as random simulation sampling) is a quantitative simulation technique used in many different types of decision analysis models (Lorance & Wendling, 2001). The first step in the analysis process is to define probability distributions and corresponding parameters for each identified simulation variable, for example cost/schedule elements. Interrelationships between variables must be identified during this step. Thereafter, repeated simulations are run to determine the overall distribution of outcomes – normality is often assumed when many components are present due to the Central Limit Theorem. During each run, a value is selected randomly for each variable based on its specified probability distribution. As the simulation is run, the model calculates and collects results to be presented as the overall probability distribution.

The crude Monte-Carlo algorithm (so named because there are many potential methods to improve it) can be summarised as follows (Kroese *et al.*, 2011):

1. Generate  $Y_1, \dots, Y_n \stackrel{iid}{\sim} h$  (for example, from independent simulation runs)
2. Calculate the point estimate  $\bar{Y}$  and confidence interval of the generated data

Often the output  $Y$  is a function of some underlying random vector or stochastic process  $Y = H(E)$ , where  $H$  is a real-valued performance function (Kroese *et al.*, 2011). If independent copies of  $Y$  can be generated in finite time, the algorithm can be used for static simulation models (where  $E$  is a random vector) and dynamic models (where  $E$  represents a time-dependent stochastic process).

The size of the population and/or number of iterations is based on the number required to achieve convergence. If the distribution of the population of outcomes is skewed in an unexpected direction or to an unexpected degree, or if there are multiple humps (modes) in the distribution, the simulation may need to be run again with a different population size / iteration amount.

### 3.4 General categories of contingency estimating methods in practice

Cioffi & Khamooshi (2009) argue that Monte-Carlo simulations are not ideal, as most projects are to do with something new, and project teams lack the information to inform the ranges and interdependencies necessary to make this method successful. Karlsen & Lereim (2005), Burroughs & Juntima (2004), Curran (1990) and (Moselhi, 1997) further substantiate this, stating that ignorance of the correlation between risk elements leads to an underestimation of the variance of total project cost/duration.

Other challenges with the Monte-Carlo method according to Hollmann (2007) include the following:

- It is difficult to quantify the impact of systemic risk drivers (for example poor scope definition) on specific line items (for example civil engineering), and therefore the relationships of some risk drivers to cost/schedule outcomes are not modelled
- When evaluating the effect of risks on line-by-line items, it is tempting to assign a contingency to each line / Work Breakdown Structure (WBS) element, which might sometimes be unnecessary
- Project risk teams fail to recognise the difference between systemic and project-specific risks

#### 3.4.3.2 Range estimating

The range estimating method as presented by Curran (1989) is a risk analysis technique that combines Monte-Carlo sampling, a focus on critical items and heuristics to rank critical risks and opportunities. The approach as laid out by Humphreys *et al.* (2008) makes use of cost estimates to establish the range of the total project estimate and to define how contingencies should be allocated among the critical items. Simplistic approaches may use the project's work breakdown or cost account structure, while more refined approaches might focus on critical elements in the cost estimate (which are identified using a process that considers each cost element's significance to the total project cost). The project team then assigns each cost element with a range and distribution based on their understanding of the risks. Significant correlations among cost elements, if any, are

### 3.4 General categories of contingency estimating methods in practice

incorporated into the analysis at this point. A Monte-Carlo (or similar) simulation program is run with the cost element parameters and distributions as input. The resulting output is a total cost distribution and other data to aid the decision making process. This process should be applied regularly through all phases of project design and construction.

Noor & Tichacek (2009) promote the use of the work breakdown structure (WBS) as a basis for range estimating, stating that this makes contingency allocation more meaningful: Unused contingency funds can be made available to other projects as the activities they are assigned to, pass (this applies to unused contingency durations in the project schedule as well). Prasad (2008), Zhao (2006) and Bent (2006) confirm this, stating that the available contingency should reflect these adjustments through periodic reassessment. Zhao (2006) further promotes the WBS as basis for the range estimating method as a logical approach that increases the project manager's accountability with regards to contingency fund management. A model that can be used to calculate the amount of contingency that should be reserved at different percentages of project completion (based on historical data from light rail projects) is outlined by Rowe (2006).

Zhao (2006) discusses an alternative to the WBS in risk management, *i.e.* the risk breakdown structure (RBS), which uses the same principles but involves a breakdown of risk elements rather than work elements. While the WBS helps provide visibility to important or risky work efforts, the RBS can assist in understanding the distribution of risk on a project or across a business, aiding effective risk management. It follows that the RBS would also be a reasonable choice as basis for a range estimating simulation.

Curran (1990) states that the method of range estimating coupled with Monte-Carlo reduces the risk of neglecting interdependencies between simulation elements; fewer critical elements are included in the simulation (see following subsections), and important interrelationships are considered and incorporated. However, Prasad (2008) criticises the range estimating method in general, saying that as there is no clear guidance for range determination, it becomes difficult to reconstruct the thought process and therefore also challenging to maintain consistency.

There are five steps in the range analysis method:

### 3.4 General categories of contingency estimating methods in practice

1. Identifying the critical items
2. Identifying the risks
3. Determining the ranges
4. Probability density functions for Monte-Carlo analysis
5. Contingency calculation

Project risk analysis using range estimating is dependent on the proper identification of those items that can have a critical effect on the project outcome and applying ranges to them and only them. There are typically less than 20 (but more than 10) critical items. This is supported by Pareto's Law, says [Curran \(1988\)](#) – the law of the significant few and the insignificant many. An item is only considered as critical if it can change enough to have a significant effect on the bottom line, thus a very large item is not necessarily critical. Positive changes are also considered – it is the degree of change (not the direction) that is the deciding factor.

The project team must determine the ranges for the critical items by predicting their possible extreme values using all the identified risks, past experience, knowledge of the project at hand and available databases / benchmarking information. It is important to note that the range does not translate to the expected accuracy of the item, as risk analysis is not an analysis of estimate accuracy; it is a reflection of risk of not completing the project within the estimate.

After executing the first three steps, the project team will have the necessary information for conducting the risk analysis, *i.e.* they will have the following for each critical item:

- Its estimated value
- The probability that its actual value will not exceed its estimated values
- Its minimum possible value
- Its maximum possible value

### 3.4 General categories of contingency estimating methods in practice

The minimum and maximum possible values should be set to have less than one in a hundred chance of being overrun/underrun (Curran, 1988).

Having defined the ranges of the critical items, the next step in the analysis, *i.e.* the Monte-Carlo analysis, can be completed. In the rare case where it is known that a specific probability density function applies to a certain critical item, this should be applied. In other cases, the item's probability density function can usually be reasonably approximated by the triangular or the double triangular distribution.

A common error is to assign the triangular distribution without verifying whether it applies. As illustrated in figure 3.2, the areas of the two sides of the triangles to the left and the right of the estimated value are proportional to the probability of a value being greater than or less than the estimate. If, for a certain item, this is found to not hold true for the range and probability of not exceeding the estimated value as determined by the project team, the double triangular distribution should be used. The area under the left hand side of the double triangular distribution as shown in figure 3.3 should correspond to the probability of not exceeding the estimate.

Using Monte-Carlo simulation, the distribution curve for the total cost/duration estimate is found, and contingency/allowance determined as previously illustrated in figure 3.1. This result should be compared to past results and expert expectations for verification.

For risk management purposes, this contingency amount can be divided between the critical items based on their relative potential contribution to cost/schedule variances (Curran, 1989).

Having discussed the range estimation method, the following subsection will focus on an alternative simulation analysis method, *i.e.* the expected value method.

#### **3.4.3.3 Expected value method**

This method differs from the range estimation method in that it directly estimates the cost/schedule impact(s) of each significant identified risk instead of conducting range analysis on cost elements or schedule activities (Hollmann *et al.*, 2008a).

### 3.4 General categories of contingency estimating methods in practice

After a list of risks pertaining to the project is identified, the probability of occurrence and cost/schedule impact (if the risk occurs) of each risk is estimated. The “expected value” is obtained by multiplying the cost and/or duration impact by the probability of occurrence. Where the expected value or “certainty equivalent” of the risk that a certain event will occur is affected by a number of interrelated events, it can be informed using a decision tree in event-consequence format (Barnardo, 2011). It should be noted that in this context, one risk can have an impact on one or more schedule/budget items. If no Monte-Carlo or similar simulation will be run, the project contingency can be determined at this stage as the sum of the expected values of the individual risks.

If a Monte-Carlo or similar simulation is required, the project team then assigns each probability and cost/schedule estimate with a range and distribution based on their understanding of the risks. This assigned probability replaces the previous estimate. Significant correlations amongst risks and cost/schedule elements, if any, are incorporated into the analysis at this point. A Monte-Carlo (or similar) simulation program is then run with the probability and cost/duration distributions as input. The resulting output is a total cost/duration distribution and other data to aid the decision-making process.

Lofton & Coppo (2007) state that overlooking the correlations between analysis elements is less detrimental in risk-based expected value analysis than in, for example, WBS-based range analysis, as identified risks can be linked to more than one cost/schedule element, thereby to some extent automatically incorporating correlations.

According to the recommended practice on the subject by Hollmann *et al.* (2008b), the use of the method in general is common, but is less frequent for contingency estimation specifically. The reason for this is that while it is beneficial for risk management to link risk drivers explicitly to their impacts, it becomes challenging to estimate contingency values linked to the risk drivers using this method in the case of systemic risks, as this requires high cost estimating / scheduling competency which is not always available in the project team. This is due to the fact that the link between systemic risks and cost/schedule impacts is stochastic in nature – this proposes a challenge as it is very difficult for teams to understand and estimate the impact of these risks on particular cost items

### 3.4 General categories of contingency estimating methods in practice

or schedule activities. Therefore it is suggested that the use of expected value methods, which are more deterministic in nature, be limited to project-specific risks.

Two significant advantages of the expected value method are firstly that it does not require that the team change its basic risk quantification methods between decision analysis and risk screening/control, and secondly that it can provide a contingency estimate without using Monte-Carlo simulation.

The two steps of the expected value method are as follows:

1. Risk identification using the expected value method
2. Quantification / contingency estimating
  - (a) Probability of occurrence
  - (b) Impact if risk occurs and screening

After risks have been identified, screened according to significance, and addressed in revised plans, the team must again look at the residual risks, and introduce iatrogenic risks if necessary. This will result in a list of significant risks and opportunities for which probability and impacts need to be estimated.

For the expected value method, cost estimating expertise is required to successfully complete the process. Further, the estimator should have or know where to procure historical experience / lessons learned with respect to risks and their impacts for comparable projects.

If multiplication of the probability and the impact yields a value that does not have a significant impact on cost/schedule, then it should be dropped from consideration for contingency estimation (but kept on the risk register).

In the case where a risk has a very high impact with a very low probability, it is deemed better practice for the risk to be owned by the project organisation than by the project itself. A contingency value should therefore not be assigned to the risk on project level. The reason for this is that the expected value would be much smaller than the actual impact due to the low probability, and setting aside this amount will be of little help if the risk does realise. Also, if the risk does not occur (as will most often be the case), the contingency amount set aside is tying up owner capital unnecessarily. Thus these risks, if not transferred through

### 3.4 General categories of contingency estimating methods in practice

insurance, are better addressed at an organisational level (for example from a management reserve set aside for extreme cases on all projects, or from funds set aside for future projects that can be deferred).

As both simulation analysis methods have now been discussed, the next section will provide information on the final general contingency estimation category, *i.e.* parametric modelling.

#### **3.4.4 Parametric modelling**

In mathematics, the phrase “parametric equation” refers to the definition of a relation using parameters. A parametric cost-estimating model is made up out of one or more functions between the cost (dependent variable) and cost drivers (independent variables) (Hegazy & Ayed, 1998). A parametric estimate is one that has estimating algorithms or cost estimating relationships that are highly probabilistic in nature (AACE International, 2009).

In the project management domain, parametric methods are normally associated with cost estimation based on design parameters, but for contingency estimation, it is used to estimate contingency cost/duration based on risk parameters. For example, a risk driver such as the level of scope definition can be given a score for each project in a data set and this score can then be regressed against the actual cost/duration growth for those projects. In doing this, the regression will provide an algorithm and statistical information about the range. This method requires the availability of historical data with a range of risks and outcomes.

The relationship of the outcome (*i.e.* cost/duration contingency growth) and the inputs/parameters (*i.e.* risk drivers) are determined by studying empirical data using methods such as multi-variable regression analysis, neural networks, or even trial and error (Hollmann *et al.*, 2008a). The first two of these three techniques will be discussed in the following subsections.

The advantage of this method is that it is easy to use (if not easy to implement), understandable, and empirical by nature. The complexity of the development required can however be seen as a disadvantage. For example, the empirical methods require that the parameters have more or less predictable relationships with the outcomes, which is not always the case. Also, the method

### 3.4 General categories of contingency estimating methods in practice

cannot effectively address risks that are unique to a specific project, or common risks that have an uncommon impact on a specific project. It is therefore most useful when systemic risks (as defined in section 2.2) are dominant, as these risks are stochastic in nature, and very difficult for individuals and teams to understand and directly estimate. This is usually not a problem for estimates early in the project lifecycle. As the project progresses the method is often best used in conjunction with range estimating, event tree analysis or other more definitive methods, as project-specific risks become dominant at this stage, and they are not highly predictable between projects within a system. It is important to note that though project-specific risks become more dominant as the project lifecycle progresses, there are always systemic risks that should be analysed as thoroughly as possible.

The use of parametric models are typically limited to approximating overall project contingency that result from certain risk types. Parametric models are therefore useful in providing the raw materials for pre-determined guidelines. Outcomes should be reviewed through expert judgement in all cases.

**Burroughs & Juntima (2004)** define the following risk drivers for use in parametric modelling:

1. **Project definition level:** This is a very important driver as it can have a direct effect on the level of contingency used by a project
2. **Use of new technology:** This refers to projects that require more contingency due to the inclusion of technology that has no commercial history either within the owner company or elsewhere
3. **Process complexity:** This refers to the number of continuously linked process steps, counted on a block basis, in a facility
4. **Contracting and execution strategy:** This includes the type of project contract and strategy of execution
5. **Equipment percentage:** If a high proportion of the initial cost estimate constitutes equipment, the required project contingency is affected (typically reduced)

### 3.4 General categories of contingency estimating methods in practice

Hollmann *et al.* (2009) provides a similar list, focusing on process definition, project definition and the project management and estimation process.

One of the main advantages of a parametric model is that it “learns” as new historical data becomes available and are input to further validate the model (Trost & Oberlender, 2003). A drawback of the method is that the influences of certain systemic risk drivers may reduce as the project lifecycle progresses. If this is the case, to be able to apply a model at all stages in the project lifecycle, the model parameters would need to be interpreted dynamically at each project stage gate.

Having given a brief overview of parametric modelling basics as it applies to contingency estimation, the specific methods of regression analysis and neural networks will be discussed in the following subsections.

#### 3.4.4.1 Regression analysis

Regression analysis is a statistical technique for determining the equation that best fits sets of observations of a response variable and multiple explanatory variables in order to make the best estimate of the true underlying relationship between these variables (Burroughs & Juntima, 2004).

**Simple linear regression** considers a single regressor variable or predictor variable ( $x$ ) and a response or dependent variable ( $Y$ ) (Montgomery & Runger, 2003). This can be generalised to a probabilistic linear model by assuming  $Y$  as a linear function of  $x$

$$Y = \beta_0 + \beta_1 x + \varepsilon \quad (3.5)$$

where  $\varepsilon$  denotes the random error term with mean zero and unknown variance  $\sigma^2$  for a fixed value of  $x$ . The method commonly used to obtain  $\beta_0$  and  $\beta_1$  is the method of least squares, where the sum of the squares of the vertical deviations between observation values and corresponding values from the regression equation (sum of  $\varepsilon$  values corresponding to each  $x$  value) is minimised.

**Multiple regression** addresses the situation where there is more than one regressor variable (Montgomery & Runger, 2003); the multiple regression model

### 3.4 General categories of contingency estimating methods in practice

that can be used to describe this case is

$$Y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \dots + \beta_kx_k + \varepsilon. \quad (3.6)$$

The following example model denotes a plane in the three-dimensional space of  $Y$ ,  $x_1$  and  $x_2$ :

$$Y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \varepsilon. \quad (3.7)$$

**Polynomial regression models**, which are widely used when the response being modelled is curvilinear, are also categorised as a class of linear regression (Montgomery & Runger, 2003). Examples include the second-degree polynomial in one variable

$$Y = \beta_0 + \beta_1x + \beta_{11}x^2 + \varepsilon \quad (3.8)$$

and the second-degree polynomial in two variables

$$Y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_{11}x_1^2 + \beta_{22}x_2^2 + \beta_{12}x_1x_2 + \varepsilon. \quad (3.9)$$

When fitting polynomials, it is considered best practice to use the lowest-degree model consistent with the data. The quality of the fit of the regression model is often determined using the coefficient of determination,  $R^2$ , which can be calculated as (Montgomery & Runger, 2003)

$$R^2 = 1 - \frac{SS_E}{SS_T}. \quad (3.10)$$

$SS_E$  is the error sum of squares (sum of the squares of differences between actual values and predicted values of the response variable) determined using

$$SS_E = \sum_{i=1}^n (y_i - \hat{y}_i)^2 \quad (3.11)$$

and  $SS_T$  is the total sum of squares of the response variable determined as

$$SS_T = \sum_{i=1}^n (y_i - \bar{y}_i)^2 \quad (3.12)$$

### 3.4 General categories of contingency estimating methods in practice

where  $\bar{y}$  is the average of all  $y_i$  values (Montgomery & Runger, 2003).

As applied to project contingency estimation, regression analysis involves the collection of historical project data and finding the relationships between defined key factors that drive differences between project estimates and actual cost/duration outcomes. Unlike some other risk analysis techniques, regression is based on actual data, and therefore brings expert knowledge to the contingency setting process while simultaneously decreasing subjectivity and human resource time constraints. A disadvantage of regression analysis is the requirement of a defined mathematical form for the function describing historical data, and the general unsuitability of the method to deal with the numerous interactions between the large number of variables found in a project.

In regression problems, the expected result is to find dependencies between the response variable and the regressor variables, but in most regression problems, there are also dependencies among the regressor variables. It is important to note that when these dependencies are strong, **multicollinearity** exists – one or more of the independent variables can be approximated by a linear combination of the other independent variables. This can have a serious effect on the accuracy of estimated regression coefficients and the applicability of the model.

In cases where regression cannot be applied directly to the identified risk drivers due to multicollinearity in the data, factor analysis is proposed as a technique preceding regression (Trost & Oberlender, 2003). It is a technique used to describe variability among observed, correlated variables in terms of unobserved, uncorrelated variables called factors. The number of factors can potentially be less than the number of observed variables. The observed variables are modelled as linear combinations of the potential factors – this provides information on the interdependencies between observed variables that can be used to reduce the set of variables in the data set. In the context of the research discussed (Trost & Oberlender, 2003) the risk factors obtained from this technique are used as input to the multivariate regression analysis rather than the initial observed variables (risk drivers).

As regression analysis methods have been discussed, the next section will provide information on neural network analysis.

### 3.4 General categories of contingency estimating methods in practice

#### 3.4.4.2 Neural network analysis

“An Artificial Neural Network (ANN) is an information processing technology that simulates the human brain and nervous system”, define [Chen & Hartman \(2000\)](#). When presented with a number of input and output data (called the training set), the network has the ability to find the function that describes the relationship between them. When fed with new input data, output data can be obtained according to the approximation function.

A typical ANN comprises of a group of processing elements organised into a sequence of layers – successive layers are connected through connection weights ([Hegazy & Ayed, 1998](#)). Different layers contain different types of nodes, *i.e.* input, output and hidden. Input nodes accept data presented to the network, output nodes produce network outputs, and hidden nodes represent the relationships in the data (one or more hidden layers are found between input and output layers). All nodes “communicate” through connections with certain assigned weights. When the ANN is presented with an input data set, “training” occurs through continuous adjustment of the connection weights using a training algorithm until the obtained outputs are close enough to the desired outputs (from training examples). This mimics the nature of the human brain, where neurons are organised in layers and connected by synapses ([Bode, 1998](#)). A neural network without a hidden layer reduces to the linear autoregressive model ([Setyawati \*et al.\*, 2002](#)).

Note that, strictly speaking, neural networks are not classified as parametric models as both the parameters and the structure of the input-output relationship are approximated. For the purposes of this study, neural networks will be discussed alongside parametric modelling methods as proposed by [Hollmann \*et al.\* \(2008a\)](#).

Figure 3.4 ([Hegazy & Ayed, 1998](#)) represents the variables and steps in the construction of a simple three-layer, single output neural network:

1.  $Q$  training patterns are identified
2. Independent factors affecting the problem are identified and considered as  $R$  input parameters represented by nodes in the input layer, with input values for training samples contained in a  $Q \times R$  matrix

**3.4 General categories of contingency estimating methods in practice**

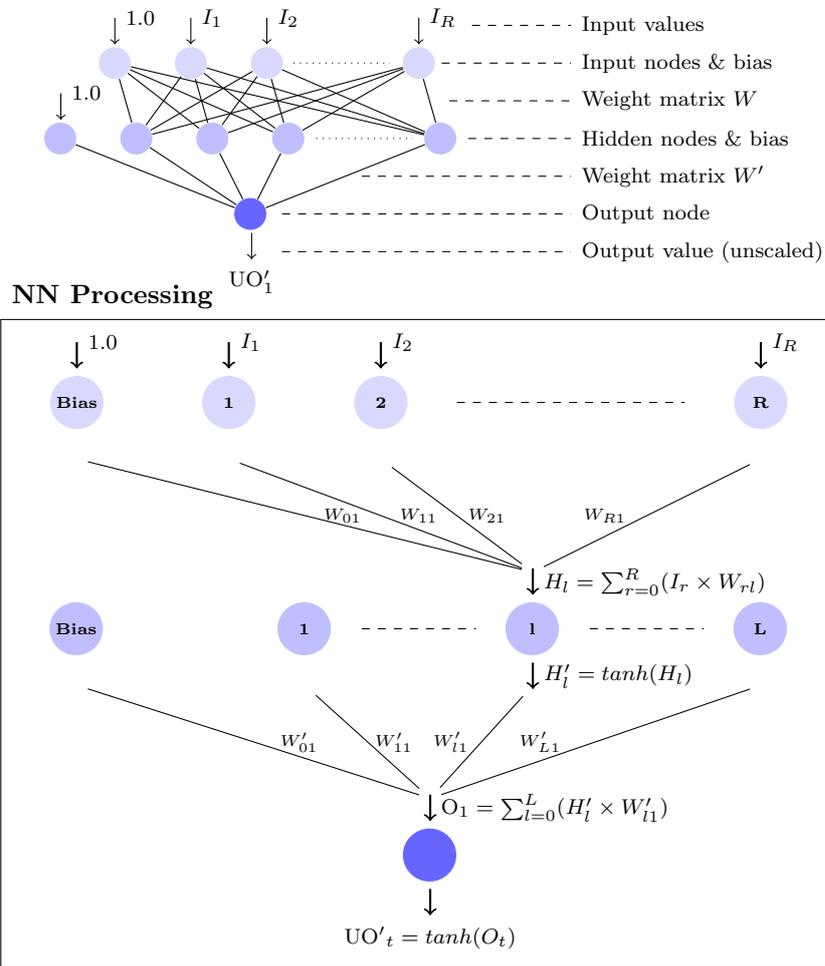


Figure 3.4: Schematic of a neural network.

3. The associated outputs are represented by  $T$  nodes at the output layer, with desired output values (from training set data) contained in a  $Q \times T$  matrix
4.  $L$ , the number of hidden nodes, is set
5. Input data ( $Q \times R$ ) are scaled to range from -1 to 1 using

$$\text{Scaled Value} = \frac{2(\text{Unscaled Value} - \text{Column Min})}{\text{Column Max} - \text{Column Min}} - 1 \quad (3.13)$$

### 3.4 General categories of contingency estimating methods in practice

6. A weight matrix is assigned and initialised between inputs, input bias node and hidden layer
7. The hidden node outputs are determined using the activation function shown in (3.15) with weighted sum values from (3.14) as input (note that other activation functions than the hyperbolic tangent applied in this example can be used):

$$H_l = \sum_{r=0}^R (I_r \times W_{rl}) \quad (3.14)$$

$$H'_l = \tanh(H_l) \quad (3.15)$$

where  $W_{0l}$  represents the connections between the input bias node ( $I_0 = +1$ ) and the hidden layer,  $W_{rl}$  is the weight of the connection between the  $r^{th}$  input node and the  $l^{th}$  hidden node, and  $I_r$  represents the value of the  $r^{th}$  input node

8. A weight matrix is constructed and initialised between the hidden layer, hidden bias node and outputs
9. The final unscaled neural network output  $UO'$  is determined using

$$O_t = \sum_{l=0}^L (H'_l \times W'_{lt}) \quad (3.16)$$

and

$$UO'_t = \tanh(O_t) \quad (3.17)$$

where  $O_t$  is the weighted sum of inputs to the  $t^{th}$  output node,  $W'_{0t}$  represents the connections between the hidden bias node ( $H'_0 = +1$ ) and the output layer, and  $W'_{lt}$  is the weight of the connection between the  $l^{th}$  hidden node and the  $t^{th}$  output node

10. The final output is scaled back using

$$O'_t = \frac{(UO'_t + 1)(\text{MaxOutput} - \text{MinOutput})}{2} + \text{MinOutput} \quad (3.18)$$

### 3.4 General categories of contingency estimating methods in practice

where  $O'_t$  represents the scaled output

The power of ANNs lie in their ability to learn from experience, generalise from previous examples to new ones, and theorise essential characteristics from inputs containing irrelevant data.

Chen & Hartman (2000) are of the opinion that methods based on statistical distributions may not truly represent the underlying time and cost variations on a project. Methods based on linear statistics can be completely inappropriate if the underlying mechanism is nonlinear. ANN based techniques are suggested for the prediction of project performance and the allocation of contingency at early phases in the project lifecycle.

In the project contingency field, ANNs can be used to develop models for assessing and quantifying risk by identifying the parameters driving risk on a project and correlating them to the risk encountered. The values assigned to these parameters (qualitative or quantitative) should describe a pattern that can be easily linked to the risks encountered in projects. The project patterns and associated level of risk (cost/duration growth) can then be used to train a neural network.

Results from a study conducted by Chen & Hartman (2000) indicate that neural networks outperform multiple linear regression, and can be satisfactorily used as an estimation model for predicting cost performance. Also, results were found to be more reliable when applied to homogenous projects, as functions between risk attributes and cost tend to be valid for only a limited range of attribute values (Bode, 1998). This can be remedied by grouping data into two or more disjunct sets based on, for example, project cost range, and handling each set with a separate neural network.

Though additional risk attributes aid the network in understanding the relationship and function between inputs and outputs, the addition of correlated attributes that do not supply much new information but do add to network complexity, could have a detrimental effect on network model accuracy. More attributes require more training examples to reach a given accuracy. As with regression analysis, statistical methods such as factor analysis (Trost & Oberlender, 2003) can be applied to reduce input attributes.

### 3.5 Other contingency estimation methods

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The primary advantage of the use of neural networks is the fact that they can operate where no explicit knowledge about cost/duration effects exist. Though the outputs of the method are easy to apply once the model has been generated (Moselhi *et al.*, 1992), disadvantages include extensive data collection and the fact that no decision supporting data is generated for a decision-maker's reference and inspection – it is a “black box” method.

Adeli & Wu (1998) state that simple neural network methods are flawed in that they are influenced by subjective elements decided by the analyst that are not governed by any fixed rules: *e.g.* the architecture of the neural network, the learning parameters or the number of iterations required. The number of input nodes has a larger effect than the number of hidden nodes, and a large training sample is helpful, but there are no clear guidelines evident in literature (Setyawati *et al.*, 2002).

Having provided detailed outlines of the four general classes of contingency estimation, the following subsection will provide a brief summary of the aspects discussed.

#### 3.4.5 Summary of general categories of contingency estimation

Figure 3.5 outlines the four contingency estimation classes proposed by Hollmann *et al.* (2008a) and a high-level summary of the execution requirements and method outputs for each category.

The discussion of contingency estimation methods pertaining to the classes defined at the beginning of this section being concluded, the following section will focus on other contingency estimation methods encountered in literature that did not fall into one of the four described categories.

### 3.5 Other contingency estimation methods

There are contingency estimation methods contained in literature not included in the scope of the classes defined by Hollmann *et al.* (2008a). A brief description of eight such methods encountered during this study will be presented in the subsections below. Note that these methods are presented separately from the four general categories as none of them can be classified purely as expert judgement, or as predetermined guidelines (all methods involve steps that deliver

### 3.5 Other contingency estimation methods

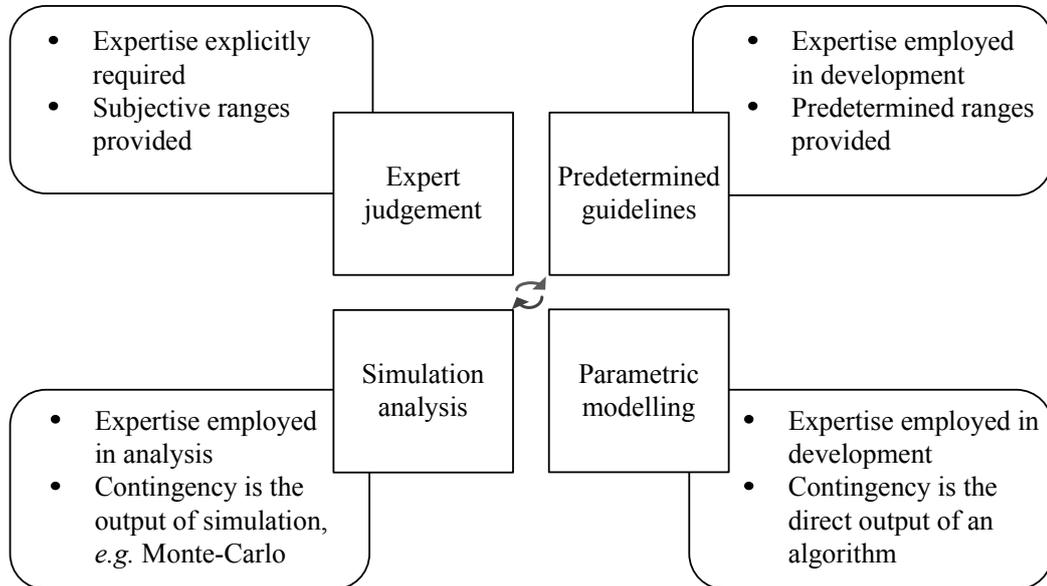


Figure 3.5: General contingency estimation classes.

unique outcomes for each project). The methods also do not fit into the range or expected value methods described under simulation, or the regression or neural network analysis methods.

These methods will not be discussed in detail, and do not aim to exhaustively address all possible methods of contingency estimation. The discussion of these methods is intended to provide additional perspective on the research area, *i.e.* contingency estimation methods encountered in the project management domain.

#### 3.5.1 “A practical method” by Cioffi and Khamooshi

Cioffi & Khamooshi (2009) present “a practical method” to estimate project contingency costs that alleviates the shortcomings of the “fixed percentage” method, suggesting their technique as an analytical calculation that links accepted identified risks and contingency funds in a statistically meaningful manner. The method makes use of a binomial distribution with a probability equal to the risks’ average probability, and consists of two distinctive steps not found in all contingency quantification methods. These will be outlined in the following two subsections.

### 3.5 Other contingency estimation methods

#### 3.5.1.1 Calculate the maximum number of risks to anticipate over the life of a project

[Khamooshi & Cioffi \(2009\)](#) show that for risks with reasonable probabilities, the probability of occurrence of many risks at the same time is low. From an accepted number of risks linked to a project, a certain number can be expected to occur: this reduces to a binomial scenario. [Cioffi & Khamooshi \(2009\)](#) show that a binomial distribution with  $p = \text{average probability of risk occurrence}$  can be used to approximate a distribution exhibiting with what certainty a specific number of risks can be expected to realise. Figure 3.6 shows an example of this binomial distribution for 20 accepted risks and increasing average probabilities of occurrence.

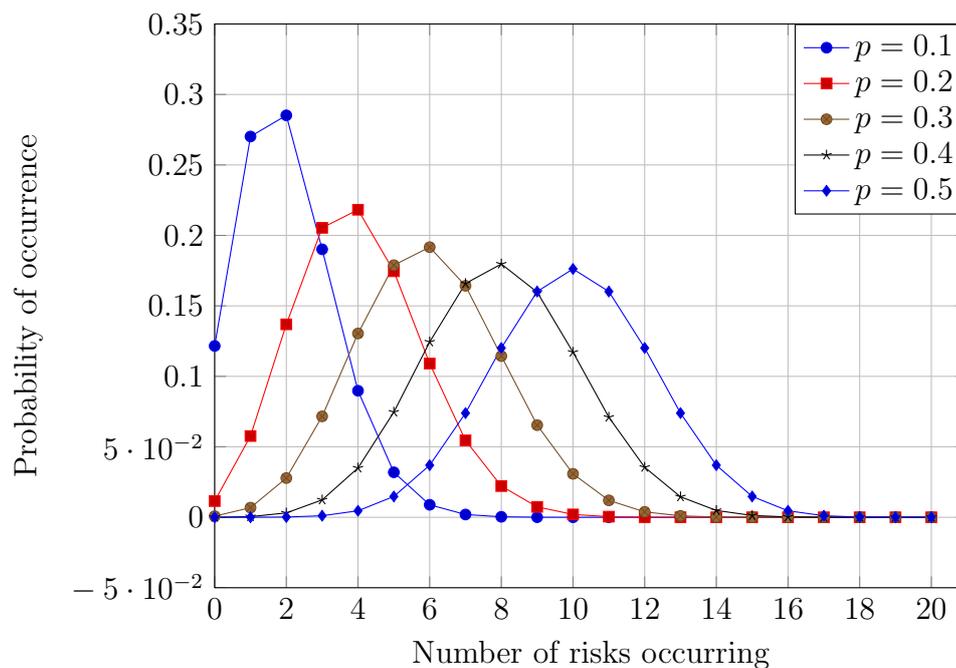


Figure 3.6: Probability distribution of the number of risks expected to occur when 20 risks are considered at five different average probabilities.

From here, an integer value representing the number of risks the contingency budget must account for is determined using a cumulative probability value chosen by the project team (for example 80%). Thus the integer value  $a$  denoting

### 3.5 Other contingency estimation methods

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the number of anticipated realised risks represents the “successes” in a binomial probability distribution of a fixed number of accepted risks evaluated at the average probability of the risks. For ease of use, [Khamooshi & Cioffi \(2009\)](#) provide tables from which to read this result when less than 20 risks are considered, and an approximation to use when more than 20 risks are considered by applying

$$a = 1.2np + 3.5 \quad (3.19)$$

where “ $p$ ” is the average probability of risk occurrence and “ $n$ ” is the total number of risks considered.

#### 3.5.1.2 Estimate the total contingency

The maximum number of anticipated risk events as obtained in the previous step is used as the number of risks to be included in the contingency calculation. Before doing this, risks must be ranked either by impact, or for a less conservative estimate, by expected value. The maximum anticipated number of risks can then be applied to reduce the list of ranked accepted risks, and thereafter estimate by summation the total damage that the team can expect over the life of the project to within a desired confidence level.

[Cioffi & Khamooshi \(2009\)](#) show that the contingency value obtained in this way agrees well with that obtained from numerical simulations.

The following subsection will discuss an influence factor based risk analysis method that can be applied to estimate contingency costs.

#### 3.5.2 Influence factor based risk analysis

[Prasad \(2008\)](#) suggests a method based on a standard list of generic interview questions (“yes” or “no” answers) for all possible factors that lead to risk. The answer of the question will either add cost or have no effect. Each question is linked to a certain element in the project cost estimate, and a probability distribution function is assigned to each question to represent the percent of risk introduced into the estimate. The costs of risk from all the questions are summed to obtain the contingency cost.

The advantage of this method is that its outputs are not influenced by the style of an individual facilitating a risk workshop – results are only affected by the

### 3.5 Other contingency estimation methods

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individual answering the questions. A clear disadvantage is the lack of adjustability to individual projects and the absence of a full risk analysis to determine where risks can be mitigated (and whether the allocation of contingency costs are in fact necessary).

In the next subsection, reference class forecasting as contingency estimation method will be presented.

#### 3.5.3 Reference class forecasting

[Flyvbjerg \(2006\)](#) asserts that costs (and contingencies) are continuously underestimated due to political pressures and an “inside view” taken by role players – the focus is on the specific planned action rather than on the outcomes of similar already-completed actions.

The recommended method to alleviate these psychological effects (optimism bias and strategic misrepresentation) is reference class forecasting, a method that systematically takes an outside view on planned actions through the following steps:

1. Identification of a relevant reference class of past, similar projects – the class must be broad enough to be statistically meaningful, but narrow enough to be truly comparable with the specific project
2. Establishing a probability distribution for the selected reference class – this requires access to credible, empirical data for a sufficient number of projects within the reference class to make statistically meaningful conclusions
3. Comparing the specific project with the reference class distribution, in order to establish the most likely outcome for the specific project

For example, instead of asking a project team how much they think a project would cost, history from other projects in the same chosen reference class would be used to construct a probability distribution for cost overruns, which would inform the chosen budget for the project at hand by allowing the project team to choose the required percentage of contingency corresponding to a certain probability of overrun.

### 3.5 Other contingency estimation methods

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Thus, reference class forecasting does not attempt to forecast the specific risk events that will affect a project, but rather places the project in a statistical distribution of outcomes from the class of reference projects. A disadvantage of this method is the lack of risk breakdown and linking of contingency amounts to specific risks for governance and contingency fund management purposes.

A variation on the PERT method and its application in the estimation of contingencies will be discussed in the next subsection.

#### 3.5.4 Variation on PERT method by Moselhi

The PERT (Program Evaluation and Review Technique) method is based on the Central Limit Theorem, and requires three costs/durations for each item being considered, *i.e.* optimistic, pessimistic and most likely. These costs/durations can either be estimated quantitatively using historical information, or qualitatively based on judgement and experience (Moselhi, 1997).

Each cost/schedule element must be assigned a statistical distribution – a special version of the beta function requiring inputs similar to that of the triangular distribution (minimum, maximum, most likely) is commonly used. The total cost/duration distribution is determined as a normal distribution with a mean equal to the sum of individual means, and a standard deviation equal to the square root of the sum of the individual variances. For the total duration distribution, only the means and variances of activities on the project's critical path are used in the calculation of overall mean and standard deviation (Mulcahy, 2011). Once the total distribution has been obtained, the confidence of project cost/duration underrun or overrun can be determined at a certain contingency level, or vice versa. The method is limited by the assumption that all items are independent.

Moselhi (1997) presents a variation of the PERT method, where the mean of the project cost is calculated as the sum of the individual means (as in PERT) but the variance is calculated (regardless of the type of individual cost distributions) according to

$$V(\text{TC})_{i=1} = \sum^n V(\text{BC}_i) + 2 \sum_{i=1}^n \sum_{j=1}^n \rho_{ij} \sqrt{V(\text{BC}_i)} \sqrt{V(\text{BC}_j)} \quad (3.20)$$

### 3.5 Other contingency estimation methods

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where

TC = Total cost of project

$BC_i$  = Cost item  $i$ ,  $i = 1, 2, \dots, n$

$V_i$  = Variance of cost item  $i$ ,  $i = 1, 2, \dots, n$

$R = \{\rho_{ij}\}$  = Matrix showing correlation amongst cost items,  $i, j = 1, 2, \dots, n$ .

The next subsection will consider contingency estimation through the integration of Zastrozny's method and the SMART method.

#### 3.5.5 Integration of Zastrozny's method and SMART method

Burger (2003) proposes an approach integrating a method presented by Zastrozny (1974) and the SMART (Simple Multi-Attribute Rating Technique) method. Zastrozny (1974) builds a method to determine project contingencies from a core set of assumptions as follows:

1. No project cost history can ever be perfect – uncertainty is assumed at 2%
2. Unforeseen events account for 5% risk
3. The effect of faulty or incomplete information can be negated through the use of an evaluation factor

From the assumptions above, cost history uncertainty and unforeseen events risk sum to 7% – this amount will be used in later equations. The steps in Zastrozny's method are as follows:

1. Establish the cost estimate, including a work breakdown structure, and calculate each cost element's percentage contribution to the total project cost
2. Evaluate each element and judge the accuracy of the information available to determine an evaluation factor (CE) percentage
3. Determine the contingency for each cost element using

$$\text{Contingency} = (100/\text{CE}) \times 7 \times (\text{percentage cost contribution}) \quad (3.21)$$

### 3.5 Other contingency estimation methods

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4. Repeat step 3 for each cost element, summing contingency percentages to obtain an overall project contingency percentage

**Burger (2003)** suggests the use of Zastrozny's method in combination with the SMART method to determine the evaluation factor, arguing that the accuracy of Zastrozny's method is too reliant on judgement of the estimator to determine this factor. The relevance of the SMART method to contingency calculation will be a scenario in which each cost element is judged according to predefined numerical dimensions. The steps in the SMART method are as follows:

1. Identify the entities that need to be evaluated (where for example "Ground composition" would be an entity affecting the cost element "Civil and Earthworks") – a number of entities will be linked to a single cost element in Zastrozny's method
2. Identify the dimension according to which each entity will be evaluated, and allocate a relative importance to each entity (normalise this so that entity weightings sum to 1)
3. Assign a score between 0 and a 100 to each entity to indicate level of information available – this can be read from graphs corresponding to standard entities encountered on all projects if these graphs are developed by the owner organisation
4. Multiply entity scores by weights and sum across entities within a cost element to obtain the evaluation factor for the cost element in question – this is substituted into Zastrozny's equation

**Burger (2003)** continues that data from previous projects can be used to identify entities, establish dimensions and build an entity-dimension database which can be used repeatedly across many projects.

A probabilistic method for the estimation of cost contingency will be discussed in the following subsection.

### 3.5 Other contingency estimation methods

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#### 3.5.6 Probabilistic model for cost contingency

Change orders are additions to the original construction contract that implement, for example, design changes, and result in a corresponding increase in project cost and delay in project schedule. [Touran \(2003\)](#) proposes a probabilistic method for the calculation of contingency costs and delays – the method assumes that contingency costs and delays are primarily applied to change orders occurring during the *construction phase* of the project lifecycle.

The method further assumes that change orders occur randomly in time according to a Poisson process. Each change order / incident affects the project cost and schedule by a certain amount, and these individual amounts can be summed to obtain the “total cost/delay of changes”.

A clear downside to this method is that it looks only at the construction phase, and not at, for example, design risk contribution to higher project costs in the preconstruction phases. It is therefore not ideally suited for use as contingency estimation method in an owner organisation, and further detail regarding this method will not be considered for the purpose of this study.

The estimation of contingency as the standard deviation of the cost estimate will be explored in the next subsection.

#### 3.5.7 Cost contingency as the standard deviation of the cost estimate

[Rothwell \(2005\)](#) proposes the use of the standard deviation of the total cost distribution as the contingency percentage. For a normally distributed project cost, the standard deviation is given by

$$\sigma = G/Z \tag{3.22}$$

where  $G$  is the required level of accuracy of the cost estimate at the project stage in question, and  $Z$  is read from the normal distribution tables based on the percentage confidence of the cost estimate level of accuracy. For example, if the level of accuracy for a preliminary estimate is 30% and the cost estimator has an 80% confidence in this range of accuracy,  $Z = 1.28$  and  $\sigma = 30\%/1.28 = 23.4\%$ .

The results obtained in this fashion align with levels of accuracy and corresponding contingency levels prescribed by the AACE ([Christensen \*et al.\*, 2005](#)) and EPRI ([1993](#)) for projects in different stages of the project lifecycle. The

### 3.5 Other contingency estimation methods

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method is therefore deemed a reasonable way of approximating the overall contingency percentage assigned to a project if the necessary data surrounding the total cost distribution is known.

The next subsection will consider the approximate reasoning method for contingency estimation.

#### 3.5.8 Approximate reasoning method

Minassian & Jergeas (2009) propose the use of the fuzzy set technique (approximate reasoning method) to solve problems associated with incorporating linguistic measures (qualitative evaluations) in the risk analysis process to produce a quantitative result. Fuzzy set theory is used to represent situations where memberships in sets cannot be defined unambiguously, because the distinction between sets is vague (Paek *et al.*, 1993). In classical set theory, an element's membership function would be either 1 (certainly part of the set) or 0 (certainly not part of the set). With fuzzy set theory, elements can belong partially to a certain set and partially to another, causing its membership function to be between 0 and 1 in the relevant set.

A risk analysis model capable of producing distributions for each defined risk and establishing a reasoning relationship between independent (cause – risk) and dependent (effect – contingency) variables in the system, is developed. Once the model has been built, the steps listed below are followed:

- List all risk variables
- Quantify each risk  $i$  in terms of probability ( $p_i$ ) and relative weight ( $RW_i$ )
- Calculate the total score of risks  $TS_i = RW_i p_i$
- Assign linguistic terms (*e.g.* very low, medium, serious) to the input (risk) and output (contingency) variables and define parameters for each linguistic term – the model uses this to develop membership distributions for each input and output membership function
- Use expert's knowledge to develop a rule-based matrix defining the level of contingency required for different combinations of input and output variables – the model uses this as “if-then” rule-based knowledge

### 3.6 Management of contingency costs on portfolio level

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- Run the model to produce aggregate membership distributions for all output results (*i.e.* contingency percentages for each risk)
- Change the total score of the input percentage (*i.e.* risk percentage) in the defuzzified model, and determine the numerical value of the output result (*i.e.* contingency percentage)

Paek *et al.* (1993) proposes the application of the fuzzy technique by describing each cost element's corresponding possible loss due to risk as a fuzzy number, and combining these to obtain an overall fuzzy number describing the total project loss due to risk (*i.e.* the contingency cost). An equation is provided to convert the parameters of the fuzzy number to a point estimate of the contingency value.

Pender (2001) contributes that “fuzzy set theory provides a natural way of dealing with problems in which the source of imprecision is the absence of sharply defined criteria of class membership rather than the presence of random variables”. Fuzzy theory deals with the possible, not only the probable: it considers whether an outcome *can* happen, as opposed to probability theory, which considers whether an outcome *will* happen.

In a discussion of the research by Paek *et al.* (1993), Moselhi (1995) showed that a much simpler PERT analysis provides a very similar result to that provided through the proposed fuzzy set approach, thereby questioning its competitive relevance.

Having concluded the discussion of project contingency estimation methods that are not classified into one of the four general contingency categories, the following section will consider a statistical method for the management of contingency costs on portfolio level. Thereafter, the chapter will be concluded with a brief consideration of the impact that contract type, psychological and political factors have on the estimation of project contingency.

### 3.6 Management of contingency costs on portfolio level

A company's project portfolio is based on its vision statement, and normally consists of a number of programs, where each program is a group of projects that “fit” together according to similarity in purpose.

### 3.6 Management of contingency costs on portfolio level

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**Touran (2010)** presents a method that considers contingency allocation per project in a portfolio of projects being funded by the same owner. The model focuses on the owner's desired confidence level that the planned portfolio budget will not be exceeded. When this confidence level and the base estimates for the budgets of the individual projects have been established, the model can be used to calculate the confidence level for each individual project within the portfolio. A sensitivity analysis enables the owner to evaluate the effect of increasing or decreasing the portfolio budget on the probability of cost overrun (both per project and on portfolio level).

The model assumes that the project budget will always be overrun, not under-run. The exponential distribution is also assumed as a reasonable choice for modelling individual project cost (it suggests that the probability of cost exceeding far above budget is relatively small, but not insignificant).

The main purpose of the model is to determine  $\eta$ , the desired confidence level of an individual project being completed within budget, given  $\gamma$ , the probability of sufficiency of the total portfolio budget. In the exponential distribution of project costs shown in figure 3.7, the original budget of the individual project is denoted by  $C_i$ , and  $C_i^*$  represents the budget required to limit the probability of project cost overrun to  $1 - \eta$ . **Touran (2010)** proposes that  $\eta$  be calculated using

$$\eta = 1 - (1 - \tau)e^{-[\Phi^{-1}(\gamma)/PB]\sqrt{(1-\tau^2)\sum C_i^2}-1+\tau} \quad (3.23)$$

where  $\Phi^{-1}$  represents the quantile function of the standard normal distribution. Other inputs include  $\tau$ , the probability that an individual project had sufficient budget originally (determined from historical data on completed projects), and PB, the portfolio budget before contingency addition.

Using the same information, the probability of sufficiency of the total portfolio budget can conversely be determined using

$$\Phi^{-1}(\gamma) = \frac{\sqrt{1 - \tau}PB}{\sqrt{(1 + \tau)\sum C_i^2}} \left[ \frac{1}{1 - \tau} \ln \left( \frac{1 - \tau}{1 - \eta} \right) - 1 \right]. \quad (3.24)$$

The model assumes that individual project cost distributions are independent – this will not always be true in practice, as some risks *e.g.* material shortage will affect all projects. This might result in a total cost distribution that exhibits

### 3.7 Influence of project contract type on project contingencies

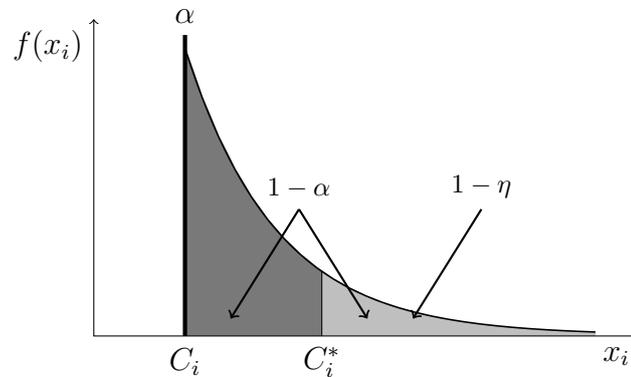


Figure 3.7: Exponential distribution of project costs.

an unrealistically low variance. The results from (3.23) and (3.24) can be plotted with  $\eta$  on the x-axis and  $\gamma$  on the y-axis to read off the corresponding required level of confidence on individual projects for a chosen level of confidence on portfolio level.

To determine the required contingency on a portfolio level, the ratio of new to old portfolio budget  $\frac{PB^*}{PB}$  can be calculated using

$$\frac{PB^*}{PB} = \left[ 1 + \frac{\nu - 1}{1 - \tau} \ln \left( \frac{1 - \tau}{1 - \eta} \right) \right] \quad (3.25)$$

where  $\nu$  is the average historical rate of cost overruns determined from completed projects.

In the following section, the influence of project contract type on project contingencies is discussed.

### 3.7 Influence of project contract type on project contingencies

The responsibility of contingency funding and its management belongs to different entities based on the type of project contract, but the principles of contingency estimation and management remain unchanged. Some examples of project contract types and corresponding risk management responsibilities are given below as outlined by [Noor & Tichacek \(2009\)](#).

### 3.7 Influence of project contract type on project contingencies

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#### 1. Lump sum contracts:

- The contractor completes the project for an agreed price – any expenditures exceeding this price (save for reimbursable scope changes) are covered by the contractor
- The owner is not at risk

#### 2. Time and material / Cost plus contracts:

- The contractor completes the project and is reimbursed for all costs incurred – expenditure exceeding the project budget estimate is covered by the owner; underruns are returned to the owner
- The owner is the sole party at risk

#### 3. Guaranteed maximum price contract:

- The contractor completes the project for an agreed price – any expenditures exceeding this price (save for reimbursable scope changes) are covered by the contractor
- The owner is not at risk of an overrun, but has an opportunity risk of forfeiting underruns

#### 4. Target with incentives contract:

- The contractor completes the project for a target price; both the owner and the contractor are affected by overruns or underruns
- The parties share the risks on an equal basis

Though Prasad (2008) also acknowledges these four contract types, he argues that the concepts for contingency formulation are based on the contract type being either lump sum or cost plus.

Eskom Distribution Western Cape Operating Unit makes use of the **time and material** contracting strategy – the contractor supplies per unit prices for all material and activities on the BOM (bill of materials) and BOQ (bill of quantities), and provides a total quote based on the corresponding quantities specified in the design. As most designs are performed in-house, it is generally the case that the contractor is at risk regarding the per unit price, but the owner is at

### 3.8 Psychological and political influence on contingency estimation

risk regarding the quantities provided (changes to the design occur at the owner's expense).

In the next and final section of this chapter, the effects of psychological and political influence on contingency estimation will be discussed.

### **3.8 Psychological and political influence on contingency estimation**

Flyvbjerg (2006) explains that inaccuracy in forecasting can be caused by technical, psychological and political-economical factors. Technical explanations (*e.g.* unreliable data and inappropriate models) are more common in literature, but this does not correlate with statistical data on the subject. If technical explanations were valid, the distribution of inaccuracies should be near-normal with an average near zero – in reality, the distribution is often significantly non-normal with averages significantly removed from zero. Also, as a large amount of effort has been put into improving both data and models for contingency estimation over the past few years, one would expect to see improvement in accuracy if only technical factors were at play. This has not been the case. Flyvbjerg (2006) concludes that the problem in many cases is not inaccuracy, but in fact bias caused by psychological and political factors.

Psychological factors account for inaccuracy in terms of perceptual and personal bias (Barnardo, 2011). Perceptual bias include factors such as the overestimation of risks that are unfamiliar to the individual, or the underestimation of risks that do not directly impact the individual. Personal bias includes factors such as motivation, optimism, peer pressure, and prejudice. Optimism bias is often encountered in the project management environment, and is defined by Flyvbjerg (2006) as “a cognitive predisposition found with most people to judge future events in a more positive light than is warranted by actual experience”. This tends to happen when political or organisational pressure is low, and results from forecasters taking an inside view, focusing on the planned action rather than the outcomes of already completed actions. “The tendency to underweigh or ignore distributional information is perhaps the major source of error in forecasting,” continues Flyvbjerg (2006).

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### 3.9 Concluding remarks on chapter 3

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On the other hand, political factors account for inaccuracy in terms of strategic misrepresentation, for example forecasters and managers overestimating benefits and underestimating costs in order to increase the likelihood that a project will gain approval and funding. This can be caused by high political and organisational pressures. Flyvbjerg *et al.* (2002) state that some project promoters and forecasters are of the opinion that underestimating the cost of government-funded projects, saves public money (by providing incentives for contractors to complete the work at a lower cost). Project costs are therefore underestimated deliberately. This point of view disregards the fact that underestimating project cost in this fashion leads to a deceptively high benefit-cost ratio during project selection, possibly leading to the wrongful prioritisation of projects.

Though it is difficult to gauge or prevent the effects that these factors have on contingency estimation, it is important to be aware of them during the selection and application of a contingency estimation method.

### 3.9 Concluding remarks on chapter 3

This chapter has provided a background on the importance of project contingencies in project management by discussing their general use, distinguishing between cost and schedule contingencies, and describing each contingency type briefly. Common errors in contingency estimation were reviewed. An outline of statistical theory often applied in project contingency estimation was given. Emphasis was placed on the discussion of four general categories of contingency estimation methods *i.e.* expert judgement, predetermined guidelines, simulation analysis and parametric modelling. Brief outlines of several other contingency estimation methods encountered in literature but not encompassed by the general categories, were provided. The discussion of contingency estimation techniques on project level was rounded off by the review of a statistical technique for the management of contingency costs on portfolio level. Finally, the chapter was concluded with brief descriptions of the influence that contract type as well as psychological and political factors have on contingency estimation.

Many points regarding project contingencies were discussed in this chapter, *e.g.* “*what are they*”, “*how are they applied*” and “*how are they determined?*” The question of which contingency estimation method would be most suitable

### 3.9 Concluding remarks on chapter 3

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in the project environment that is being considered in this study, remains to be answered after the problem background is considered in combination with the theory presented here.

For this reason, the following chapter will introduce Eskom Distribution's approach to contingency estimation by providing a background on the project management departmental structure and the current processes that govern and facilitate project management within that structure. The Eskom Integrated Risk Management method will also be discussed in a separate chapter. After this, the study objectives will be outlined in light of the reviewed literature and study environment, establishing the platform from which a contingency estimation method for the study can be selected.

## CHAPTER 4

# ESKOM DISTRIBUTION PROJECT MANAGEMENT BACKGROUND

Eskom Holdings SOC Ltd. is the largest power utility in Southern Africa. The company can be broadly divided into three main divisions, *i.e.* *Generation*, *Transmission* and *Distribution*. Generation encompasses the generation of electricity using a variety of methods (*e.g.* coal and nuclear), while Transmission concerns the transmission of high voltage electricity between power stations and Distribution networks. The main purpose of the Distribution division within Eskom is to operate, maintain and create network assets (high, medium and low voltage) that enable the distribution of electricity to all customers.

This chapter will serve to outline the structure of an Eskom Distribution project management department (referred to within Eskom Distribution as a *capital program management* department) and the current processes that govern and facilitate project management of **network asset construction** projects within that structure. Important links between the current process and project contingency estimation as well as project risk management in general, will be identified. Project categorisation, project lifecycle and approval gates, and macro level planning will also be considered.

#### 4.1 Eskom Distribution capital program management departmental structure

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#### 4.1 Eskom Distribution capital program management departmental structure

Figure 4.1 illustrates the resource structure supporting what is termed a project portfolio within an Eskom Distribution capital program management department. The structure can be divided into:

- Contracts management, which deals with quantity surveying and contracts administration
- Project services, which monitors and updates project progress on various systems as a service to portfolio managers, program managers and project managers
- Program management, which is the section devoted to project management, and therefore the section on which this study will focus

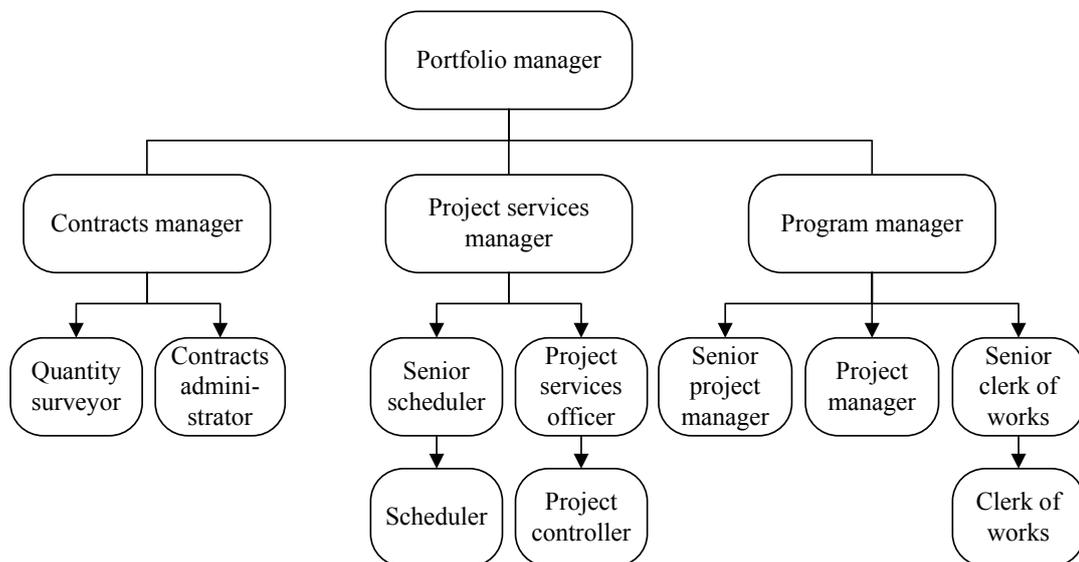


Figure 4.1: Eskom capital program project portfolio structure.

As discussed in section 2.5, a company’s project portfolio is based on its vision statement. The portfolio consists of a number of programs, where each program is a group of projects that “fit” together according to similarity of purpose. In

## 4.2 Project categories

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Eskom Distribution, projects are grouped into programs according to their categories (as will be discussed in section 4.2). Individual projects are run by project managers, who are responsible for the delivery of key milestones and the management/coordination of project resources. The clerk of works is responsible for quality through site inspections and regular site visits. Program managers are each in charge of a program, and a portfolio manager would generally be responsible for the entire project portfolio. However, due to the large number of projects managed by the capital program management department of Eskom Distribution Western Cape Operating Unit (in excess of 700 projects), there are two portfolio managers.

The following section will discuss the categorisation of projects on which program allocation is based.

### 4.2 Project categories

Network asset construction projects are initiated due to identified business needs, and can be classified into one of four **business categories** (Rabie, 2010):

1. Electrification
2. Direct Customer
3. Strengthening
4. Refurbishment

All of these project types are also called *major* projects, with the exception of Direct Customer projects, which can be classified as either *major* or *minor* projects.

**Electrification** refers to projects that are initiated to provide electricity to an area that is not yet electrified, for example an informal settlement (South African Department of Energy, 2010). According to the constitution of South Africa, every citizen (regardless of his/her location) has a right to basic services, and this includes electricity. In line with the Energy White Paper, government supports the electrification of residential and unproclaimed/informal areas. The Department of Energy / City of Cape Town funds the electricity reticulation and service connections of qualifying informal settlements.

## 4.2 Project categories

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**Direct Customer** projects are those projects that are initiated due to a customer application for a new service (Rabie, 2010). As mentioned before, this category can be subdivided into major and minor projects. Direct Customer major projects are initiated by a customer application with an estimated project cost of more than R1,000,000 for overhead networks and/or more than R1,500,000 for underground networks. Direct Customer minor projects are initiated by a customer application where the project cost estimated for overhead and underground networks are less than the aforementioned values.

**Strengthening** projects involve the expansion or upgrading (betterment) of all networks that supply electricity to customers or groups of customers that are not readily identifiable (Rabie, 2010).

**Refurbishment** projects involve modifications of an asset to extend its useful life (without upgrading the asset, as is the case with Strengthening projects) (Rabie, 2010). More than 50% of an asset needs to be modified in order for the work to qualify as a Refurbishment project. If less than 50% of the asset is modified, the cost needs to be captured against a **Major Maintenance** project, which is in turn classified as an operational expenditure rather than a capital expenditure.

In addition to the business category, a project is classified in terms of its **voltage category** and **job category**. Voltage category refers to the voltage level at which the work is executed – Subtransmission, Distribution or Reticulation. The job category indicates whether the project involves a line, cable, or substation.

Another important distinction is the difference between **mega**, **standard** and **repeatable** projects. Repeatable projects are those that are repeated regularly, for example the construction of small substations. Standard projects refer to those projects that are not repeated in their entirety, but do follow a standard process. Mega projects are large once-off projects such as the construction of a power station. Projects in the Distribution environment are classified as standard or repeatable.

For the purpose of this study, the focus will be on the analysis of major standard and repeatable projects, and the next section will discuss the project lifecycle and approval gates from this perspective.

4.3 Project lifecycle and approval gates

4.3 Project lifecycle and approval gates

A project is initiated as a result of a **micro level** need identification and analysis in the business (Walker, 2011). Projects are defined and prioritised to best meet identified needs, and released into a project process consisting of the following phases as shown in figure 4.2:

- Pre-project planning
- Concept
- Definition (detailed design)
- Execution
- Finalisation (close-out)
- Post project

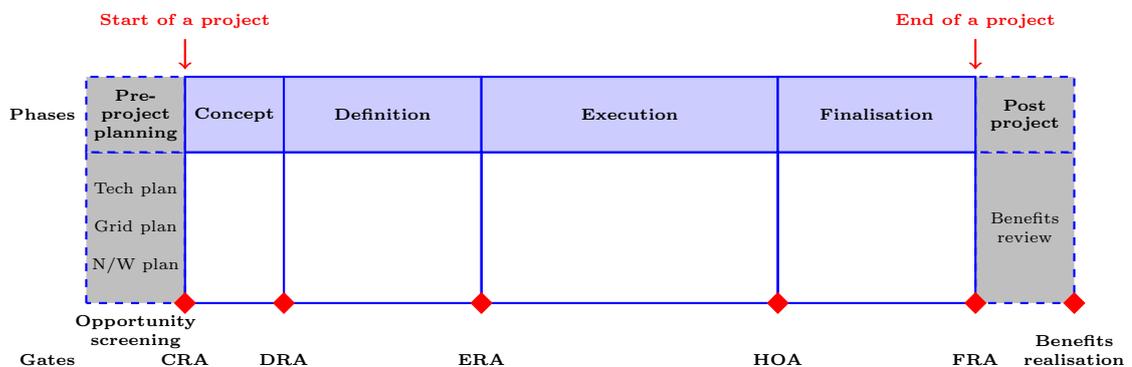


Figure 4.2: Standard Eskom capital project lifecycle.

Once a project is initiated, these various phases are managed and controlled by a series of project forms (indicated as stage gates in figure 4.2), *i.e.* CRA (Concept Release Approval), DRA (Definition Release Approval), ERA (Execution Release Approval), HOA (Handover Approval) and FRA (Finalisation Release Approval). All of these approvals save the HOA must be obtained from investment committees at relevant points in the project lifecycle. Different investment

### 4.3 Project lifecycle and approval gates

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committees exist at different levels in the business, with pre-determined authorisation limits. The function of these committees is to make effective decisions on how to ensure maximum return on investment while maintaining acceptable quality of supply to customers, and providing for future network requirements.

Important terms to distinguish here are a project vs a job. A **project** is defined as one or more interdependent jobs, where each job must have its own approval forms at the relevant project stage gates. A **job** can be either independent, dependent or interdependent with respect to other jobs. An independent job can stand alone, while a dependent job has a one-way dependency on another job. Both of these job types should be initiated as separate projects – for dependent jobs, a relationship must be established between the relevant projects in the scheduling system. In the case of interdependent jobs, if any one of the jobs is stopped or not completed, the other jobs cannot realise their stated objective: a two-way dependency exists. As stated before, these interdependent jobs should be grouped to form a single project. Due to the “Back to Basics” SAP roll-out that is currently being conducted throughout Eskom, the terms for project and job will soon change to initiative (project) and item (job) as per SAP terminology. Having identified this distinction, the project lifecycle stages shown in figure 4.2 can each be considered.

In the **pre-project planning** phase, a planning solution is released in order to fulfil one or more business needs. Concept design costs are approved for resources to investigate all possible requirements, and in selected cases, funds for long lead time materials may be approved. Resource teams or individuals are allocated to the job. This phase’s outcome for approval is the CRA (Concept Release Approval) form.

In the **concept** phase, the planning solution defined in the CRA form is thoroughly investigated with the involvement of all necessary stakeholders. Various design alternatives are summarised into project proposals, and these are evaluated by a technical forum to ensure the best possible design solution from a technical and financial perspective (total asset lifecycle cost is considered in conjunction with capital cost). The outcome for approval of this phase is the DRA (Design Release Approval) form. The scope of works and costing for each job should have an 85% confidence at this point, and long lead time material funds

### 4.3 Project lifecycle and approval gates

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are approved. The project team should not be penalised if the variance between the CRA value and DRA value is significant, as the purpose of deeper investigation by the appointed team after CRA approval is to ensure that all avenues have been covered.

The **definition** phase concerns the conversion of the approved design alternative to a final design package suitable for going out on tender or being given to an internal team to quote for the construction phase of the job. The outcome for approval is the ERA (Execution Release Approval) form. This is the stage at which all project funds are released if approved by the investment committee. The scope of work and costing for each job should be at 95% confidence. Any significant variance between the approved values and completion dates in the DRA and ERA forms need to be justified.

The **execution** phase involves the construction of a network asset, and the commissioning of the asset. At the end of this phase, a hand over approval (HOA) must be obtained from the party taking over the asset.

The project is closed out in the **finalisation** phase, where all job contracts are finalised and all materials are reconciled. The outcome for approval is the FRA (Finalisation Release Approval) form, which captures the final job scope, costs, and actual completion date. A project review presentation is made.

As briefly mentioned in discussion of some of the phases above, Eskom follows a prescribed guideline for the necessary confidence level in the scope of work at each stage gate. The cost should be accurate in terms of the known scope and risks, and is therefore assumed to be at a corresponding level of accuracy for project cost tracking purposes. As more detail is defined during each phase, the confidence level grows until at ERA approval, scope is frozen and only 5% variance is permitted. The permitted variance excludes contingencies, which may be planned for and approved as part of the project budget. Planned contingency cost values should be fully substantiated for approval by the relevant investment committee. The allowable variances between approval forms are shown in table 4.1.

In general the CRA and DRA forms of a job should not be revised for cost and time variances – any changes should be captured in the form linked to the next project phase. As the ERA form releases the full job value for expenditure,

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### 4.3 Project lifecycle and approval gates

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Form	CRA	DRA	ERA	FRA
CRA	0%	±20%	±30%	±35%
DRA		0%	±10%	±15%
ERA			0%	±5%

Table 4.1: Allowable variances between project forms.

any cost variance outside the limits shown in table 4.1 would prompt an ERA form revision. Though this is not considered as best practice in industry, current practice is that the contingency amount is available to “buffer” any growth in project cost, irrespective of whether the cause of cost growth was initially identified as a risk. The ERA form would also need to be revised if the job duration increases by more than four months. Scope variance necessitates a change control process regarding the technical approval for the job design. Where changes can be dealt with through site instruction and fall within the approved contingency value, it is allowed that this change control process be sidestepped. Once again, this is not in line with industry best practices.

Throughout the project management process, there is no formal method for determining or allocating project contingencies, as is the case with many other established organisations (Khamooshi & Cioffi, 2009). In the past, contingency cost was often applied as a single percentage of base cost (most often between 5% and 15% of project cost), determined according to the previous experience of the project manager in question on similar projects. No breakdown of this contingency percentage was required. At present, investment committees mandate that the contingency cost requested alongside the project budget be fully motivated as the sum of its parts, but no formal contingency duration representation is required. It is often found that the presented contingency cost breakdown lacks detail – no standard project risk analysis template exists, and no analysis of cost/duration growth data has been conducted to serve as guideline for contingency quantification. Van Zyl (2011) confirms that no specific approach is currently recommended; the decision-maker’s “gut feel” is followed. It should be the purpose of the risk management and contingency estimation approach to identify and analyse risks in sufficient detail to reduce the level of uncertainty

#### 4.4 Macro level planning

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to within acceptable levels as the project is developed through its various stages (Mak & Picken, 2000). The current method does not align to this.

Thus concerning contingency quantification, project managers are left to their own devices both in terms of method and reference data – in most cases, only past experience is used as decision support.

It should be noted that the contingency cost approved by the investment committee currently fulfills the role of both the contingency and allowance, but not that of the management reserve (refer to section 3.1.1). If project assumptions do change, or other major unforeseen events are encountered, the project budget and schedule must be revised and resubmitted for approval by the investment committee – thus no management reserve is assigned upfront per project.

Having outlined the lifecycle that a single project follows, the next section will consider planning on a macro level that spans across all projects within a portfolio.

#### 4.4 Macro level planning

At a **macro level**, planning of projects is done in two formats to ensure effective management of the business investment in capital projects (Walker, 2011), *i.e.*:

1. A five year business plan (compiled annually)
2. A three year rolling plan (reviewed bi-annually)

Both plan formats are based on business, job and voltage categories, and planning is done on a high level per project.

The **business plan** is derived from the three year rolling plan, with the fourth and fifth year's cost derived from projects listed in a prioritised projects register for the time in question, and by assessing trends and market intelligence for the project categories not included in the prioritised project register. A new five year business plan is compiled annually.

The **rolling plan** consists at any given time of a twelve month fixed plan for the first year (ERA and DRA forms), and twelve month semi-fixed plans for the second and third years (DRA and CRA forms). For all three years in the rolling plan, physical assets (for example transformers) that will be commissioned are

4.5 Concluding remarks on chapter 4

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indicated alongside cost. The relationship between the business and rolling plan is shown in figure 4.3. The rolling plan is revised every six months, so the first six months of the rolling plan must be a firm forecast with 95% confidence level.

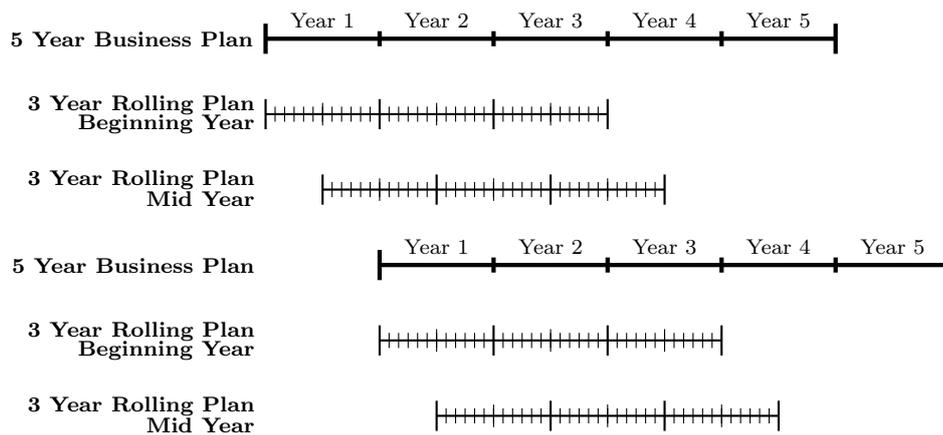


Figure 4.3: Business plan and rolling plan relationship.

Current practice concerning contingency costs is to exclude them from the monthly breakdown in the rolling and business plans – they are available for use at project level if necessary, and are indicated on the plan on the project root element, but are not phased with other costs in these high-level plans. The present stance is that planning for contingencies on this level results in an inflated view of capital portfolios from a national perspective, which wrongfully amplifies the perception that project portfolios are underspent if contingency costs are not applied. It is however encouraged that schedule contingency (which is not formally required at phase gate approval by investment committees) be taken into account when planning the monthly phasing of costs in the rolling plan.

**4.5 Concluding remarks on chapter 4**

This chapter outlined the structure of an Eskom Distribution capital program management department and the current processes that govern and facilitate project management within that structure. Project categorisation, project lifecycle and approval gates, and macro level planning were also considered. Important

#### 4.5 Concluding remarks on chapter 4

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links between the current process and project contingency estimation as well as project risk management in general, were identified.

The following chapter will consider the Eskom Integrated Risk Management method.

## CHAPTER 5

# ESKOM INTEGRATED RISK MANAGEMENT METHOD

This chapter will explore the management of project risk from the perspective of the Eskom IRM method, which is based on ISO31000 principles as outlined in chapter 2. The different steps in the process are discussed alongside corresponding steps in the Integrated Project Risk Management process for standard and repeatable projects, and the process steps are mapped back to the Eskom PLCM (project lifecycle model).

### 5.1 IRM process

Risk Management in Eskom is performed according to the Integrated Risk Management (IRM) process, which is based on the ISO31000 risk management process as shown in figure 5.1, as was briefly discussed in subsection 2.3.3. The steps in the process are as follows: Communicate and Consult, Establish the context, Identify the risks, Analyse the risks, Evaluate the risks and Treat the risks. Throughout the process, risks should undergo Monitoring and Review.

As the IRM process is more suited to enterprise risk management than project risk management (especially on a standard and repeatable project level), an additional subprocess defining evaluation criteria and reporting hierarchies applicable to the standard and repeatable project environment, was developed (Theron & Van Niekerk, 2012). This process is called the Integrated Project Risk Manage-

5.1 IRM process

ment Process (IPRM) for standard and repeatable projects, and slots in as one of the documents contained in the Eskom IRM suite. Throughout the description of the IRM approach, deviation points as applicable to standard and repeatable projects (which are the focus of this study) will be highlighted.

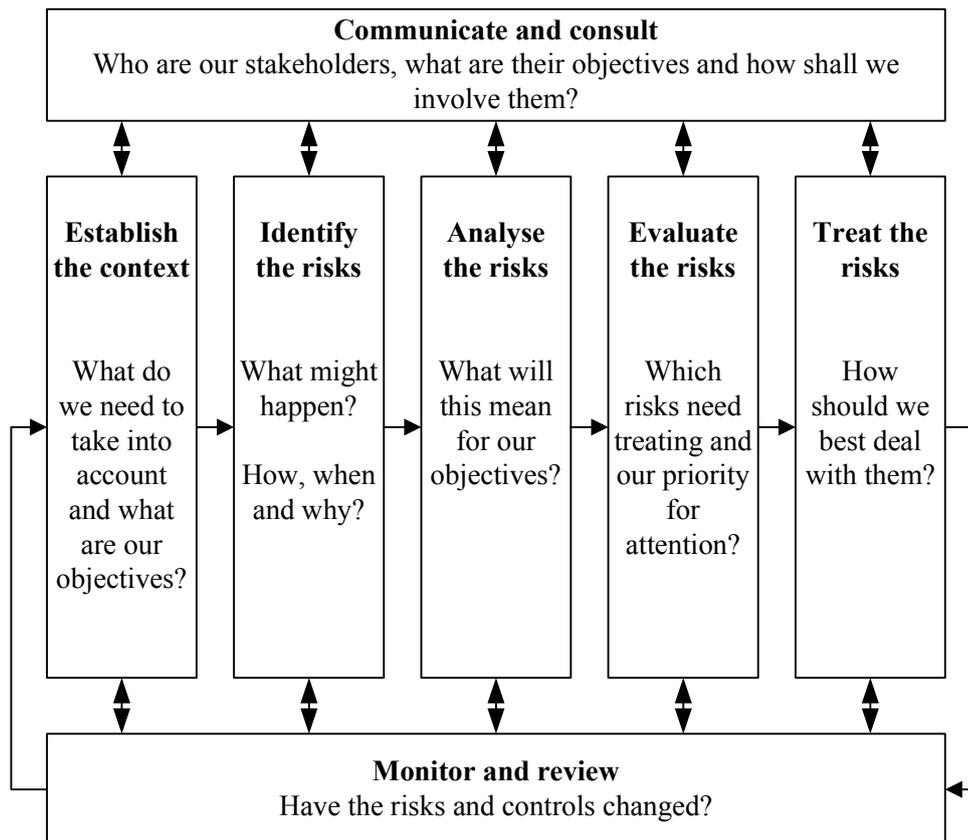


Figure 5.1: The ISO31000 risk management process.

The IRM methodology defines risk as the “effect of uncertainty on objectives”. The guidelines for each of the steps in the Integrated Risk Management process are described in the following subsections, with the exception of the two overarching process steps, which are briefly outlined here: *Communicate and consult* refers to the involvement of all necessary project stakeholders in the entire project risk management process, while *Monitor and review* refers to the continuous evaluation of the nature/status of identified risks and the effectiveness of implemented treatment strategies.

Note that the IRM methodology refers to probability as *likelihood* and impact as *consequence*. For the purpose of this study, these terms will be taken as synonyms and used interchangeably in this chapter and remaining chapters.

### 5.1.1 Establish the context

During context establishment, the stage for risk management is set in terms of project objectives, project context, risk criteria, etc. Actions to be completed during this step in the risk management process include:

- **Define the project objectives**
- **Identify the internal and external context of the project:** Ensure that external stakeholders and their objectives are considered and that externally generated threats and opportunities are properly taken into account
- **Identify risk criteria:** These criteria serve as terms of reference against which the significance of risks will be evaluated, and are established using the requirements of key stakeholders and the related measures of success

For enterprise risk management, an acceptable risk rating must be chosen to correspond to each consequence category as shown in table A.1, Appendix A. For example, a risk criterion could be that for the project to be viewed as successful, the consequence rating of any environmental risks may not be higher than three. The risk criteria are used later in the process to assess the significance of risks. Note that as per the IPRM process, standard and repeatable project risks are only evaluated in terms of two consequence categories (as will be fully discussed in subsection 5.1.3).

Bear in mind that risk assessments can be logically structured by grouping risks according to key elements *e.g.* project phases, functions, activities, contracts etc. A key element method should be chosen and key elements should be identified at this stage. These key elements can later be used as aid in identifying risks.

### 5.1.2 Identify the risks

It is accepted practice that the project manager should orchestrate the compilation of the risk register by convening a workshop with key strategic stakeholders

## 5.1 IRM process

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and experienced participants. It is not good practice for the project manager to compile the risk register single-handedly, unless the project is:

- repetitive (as before – “brown fields”)
- uncomplicated (generic risks rather than project-specific risks with many assumptions)

Once the risk management context has been set, risks can be identified according to the guidelines below in a workshop setting:

- Describe each identified risk in the following format during identification: “[Something occurs] leading to..., caused by..., controlled by...”
- Use one of the following workshop structures to identify risks in a session including all key risk management stakeholders involved in the project:
  - Top-down techniques:
    - \* Brainstorm with project team and stakeholders
  - Bottom-up techniques:
    - \* Task Analysis
    - \* Structured “What If” Technique (SWIFT)
    - \* Definition of Hazard and Operability (HAZOP)
    - \* Failure Mode and Effect Analysis / Failure Mode, Effect and Criticality Analysis (FMEA/FMECA)
- Populate all identified risks pertaining to the project onto a risk register

### 5.1.3 Analyse the risks

Identified risks should be analysed according to the following guidelines:

On project level, risks should be analysed using cost and schedule consequence criteria. As these project-level consequence criteria vary for different divisions in the business, the IPRM (Integrated Project Risk Management) process for standard and repeatable projects (Theron & Van Niekerk, 2012) proposes the use of percentage-based consequence levels as shown in table 5.1 for cost and schedule risk consequence analysis. These consequence criteria for cost and schedule refer

to the damage/impact that all consequence types (including, for example, environmental) have on the cost and schedule of the project (*i.e.* inevitably, most project risk will be converted to cost and delay for analysis and ranking purposes). The worst case of the cost and schedule consequence rating is used as the **project consequence rating** for the risk.

Once a risk is escalated to portfolio level (discussed in section 5.1.4), and therefore might constitute an enterprise risk, the consequence rating of each risk should be determined using the descriptions of different levels of enterprise consequences for each consequence type listed in table A.1 in Appendix A. By identifying which rating applies to the risk in question for each consequence type, the prevalent consequence of the risk in question can be identified as the consequence type with the highest rating. The rating of the identified consequence becomes the **enterprise consequence rating** of the risk. For example, if a risk has a People Effects rating of 4, and this is higher than the ratings of all the other consequences for that risk, the risk's prevalent consequence is People Effects.

The **likelihood rating** of the risk should be determined from table 5.1 for project-level risk and from table 5.2 for enterprise-level risk by assigning a probability percentage between 0 and 100% to the risk and reading off the corresponding rating.

The consequence rating should then be applied in conjunction with the likelihood rating to read the **risk rating** from the corresponding risk matrix. The enterprise risk matrix is shown in figure 5.2. A similar matrix with five risk rating levels was developed for standard and repeatable projects as part of the IPRM process. Note that the purpose of this risk rating is not to quantify the risk, but rather to provide a means through which risks can be relatively ranked.

#### 5.1.4 Evaluate the risks

Before a treatment strategy can be chosen, results from the risk analysis must be evaluated as follows:

- Determine whether the risk falls above or below risk criteria established while setting the context
- Determine the priority for attention (according to the risk rating)

5.1 IRM process

Consequence: Schedule		Consequence: Cost		Likelihood	
Schedule Consequence Level	Schedule Consequence Percentage Overrun	Cost Consequence Level	Cost Consequence Percentage Overrun	Likelihood Level	Likelihood Percentage
5	≤100.00%	5	≤100.00%	E	≤100.00%
4	≤80.00%	4	≤80.00%	D	≤65.00%
3	≤40.00%	3	≤40.00%	C	≤35.00%
2	≤15.00%	2	≤15.00%	B	≤20.00%
1	≤5.00%	1	≤5.00%	A	≤10.00%

Table 5.1: IPRM consequence and likelihood criteria – Project-level.

Consequences	6	III	II	I	I	I
	5	III	II	II	I	I
	4	IV	III	II	I	I
	3	IV	III	II	II	I
	2	IV	IV	III	II	II
	1	IV	IV	III	III	III
		A	B	C	D	E
Likelihood						

Figure 5.2: The Eskom IRM enterprise-level risk matrix.

- Determine whether treatment can be justified (cost-benefit analysis – is the cost of treating the risk proportional to the cost benefit of avoiding the risk)
- If the law or a standard dictates that a certain type of risk should be treated, there is no need for a cost-benefit analysis; the treatment should proceed irrespectively

If the risk is below a tolerable criterion it is not worth treating the risk; it should be monitored (on a watchlist of low-priority risks). This priority for

## 5.1 IRM process

Rating	Criteria
E	99% probability, or impact is occurring now, or could occur within “days to weeks”
D	larger than 50% probability, or balance of probability will occur, or could occur within “weeks to months”
C	larger than 20% probability, or may occur shortly but a distinct probability it will not, or could occur within “months to years”
B	larger than 5% probability, or may occur but not anticipated, or could occur in “years to decades”
A	less than 5% probability, or occurrence requires exceptional circumstances, or exceptionally unlikely, even in the long term future, or only occur as a “100 year event”

Table 5.2: IRM likelihood criteria – Enterprise-level.

attention will determine whether or not risks must be communicated to a higher level, *e.g.* program or portfolio.

### 5.1.5 Treat the risks

Having identified, analysed and evaluated project risks, a treatment strategy can be chosen. Risk treatment can either be focused on treating the likelihood that the risk will occur, or treating the impact of the risk should it occur. It is wise to try addressing the likelihood first, as the risk is then being prevented, but both options should be considered and compared for synergies. The final decision can be made using a cost-benefit analysis. There are five possible mitigative actions, which must be considered in the order presented:

- Risk avoidance – avoiding a (detrimental consequence) risk by deciding not

## 5.1 IRM process

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to proceed with the activity likely to create risk (where this is possible)

- Changing the likelihood of the risk, to enhance the likelihood of beneficial outcomes and reduce the likelihood of negative outcomes
- Changing the consequences to increase the gains and reduce the losses. This may include emergency response, contingency and disaster recovery plans
- Risk sharing
- Risk toleration without further treatment (involving an explicit decision to retain risk)

The preferred method of treating a specific risk would be guided by the overall strategies relating to the project. The chosen treatment method should be outlined in a risk register. Note that if a risk treatment is chosen, the cost of the treatment should be incorporated into the project budget, and the likelihood or consequence (cost/schedule) of the risk addressed by this treatment should be decreased as applicable. Responsibility should be assigned for each risk mitigation action by linking a person to that action – if an action is not allocated to someone, the responsibility will fall on the project manager.

It is important to note that, as the IRM method makes use of a reporting system designed for enterprise risk management (CURA), it does not enable the user to assign time delay of project execution linked to each risk, and also does not enable a summary view of all risks pertaining to a project in terms of cost and schedule impact, expected value of each risk or any form of contingency calculation. The consequence and likelihood criteria which the system uses to generate reports (for example, risk matrices), are aligned to the five enterprise-level requirements (and are therefore not applicable on standard and repeatable project level). For these reasons, a separate system/tool is required on project level for standard and repeatable projects to enable the analysis of cost and schedule risks.

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## 5.2 Concluding remarks on chapter 5

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### 5.1.6 Application of IRM steps to the project lifecycle model

The steps in the IRM process as outlined in this chapter are not singular occurrences per project; some IRM steps need to be performed at more than one, if not all, stages in the project. Table 5.3 outlines the way in which the IPRM process maps the IRM steps against the phases in the standard and repeatable project lifecycle.

IRM Step	Pre-project planning	Concept	Definition	Execution	Finalisation
Communicate & consult	Y	Y	Y	Y	Y
Context setting	Y				
Identify	Y	Y	Y	Y	
Analyse		Y	Y	Y	
Evaluate		Y	Y	Y	
Treat		Y	Y	Y	
Monitor & review	Y	Y	Y	Y	Y

Table 5.3: IRM (IPRM) application throughout PLCM.

## 5.2 Concluding remarks on chapter 5

This chapter discussed the management of project risk from the perspective of the Eskom IRM method. The risk management process steps were mapped back to the Eskom PLCM (project lifecycle model). Though this does provide a high-level guideline on the timing of contingency estimation, specific guidelines regarding the points in each project phase at which contingencies should be estimated (and possibly the frequency of such estimation should it be required more than once per phase), is lacking.

At the conclusion of this chapter, the following aspects pertaining to contingency estimation have been reviewed:

- Project risk management theory and best practice methods in industry
- Project contingency estimation methods encountered in literature, both within and outside four identified general categories

## 5.2 Concluding remarks on chapter 5

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- Background on the structure of a capital program management department in Eskom Distribution, and the processes governing project management within this structure
- The Integrated Risk Management (and Integrated Project Risk Management) method as applied by Eskom

Having considered these background topics, the following chapter will summarise the study objectives in the light of reviewed literature and the study environment.

## CHAPTER 6

# OBJECTIVES OF THE STUDY

This chapter will serve to outline the objectives of the study. Previous chapters considered the following aspects pertaining to contingency estimation:

- Project risk management theory and best practice methods in industry
- Project contingency estimation methods encountered in literature, both within and outside four identified general categories
- Background on the structure of a capital program management department in Eskom Distribution, and the processes governing project management within this structure
- The Integrated Risk Management (and Integrated Project Risk Management) method as applied by Eskom

As project risk management and contingency estimation theory and application have now been studied alongside relevant Eskom Distribution project management structures and processes, the study objectives can be defined in sufficient detail taking into account all reviewed information.

### **6.1 Study objectives**

The current contingency estimation method used in the capital program management department of Eskom Distribution Western Cape Operating Unit is not

## 6.1 Study objectives

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effective, and needs to be revised. There is no formal method for estimating or allocating project contingencies. Though investment committees mandate that the contingency cost requested alongside the project budget be fully motivated as the sum of its parts, it is often found that the presented contingency cost breakdown lacks detail – no standard project risk analysis template exists, and no analysis of cost/schedule growth data has been conducted to serve as guideline for contingency estimation.

Currently, this estimation of the contingency amount approved per project by Eskom Distribution’s investment committees is based on the “gut feel” of the project manager of the project in question. Thus the accuracy of the estimated contingency impact is based on expert opinion, which is limited to previous experiences with similar projects (Sonmez *et al.*, 2007).

The problem with this is firstly the assumption that all project managers in Eskom Distribution Western Cape Operating Unit are experts in their field, while in fact some are relatively inexperienced. Even if one were to assume that all project managers were indeed experts, the expert opinion method for contingency estimation is disadvantaged by the fact that the wide variation of skill, knowledge and motivation between different individuals leads to subjectivity. This is evident from the fact that contingency estimates currently produced by project managers vary widely for different projects under similar circumstances.

Burger (2003) aptly describes this problem by observing the following on subjective contingency estimation methods such as the one currently employed: “If ten estimators are asked to determine the risk for a project, ten different contingency estimates will be delivered,” even when all estimators receive the same data. “If the same estimator is given the same data set today and again in two weeks, two different estimates will again be delivered.”

As the Eskom Distribution Western Cape Operating Unit capital program management department has a project portfolio consisting of more than 700 projects, such a variation in contingency estimation is far from ideal for the management of the portfolio as a whole. A knowledgeable portfolio manager needs to maintain a portfolio-level risk analysis of all ongoing projects so as to be able to monitor the risks and vulnerabilities of the entire portfolio (DOE Committee for Oversight & Assessment of U.S. Department of Energy Project Management,

## 6.1 Study objectives

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2005). It follows that if risks on projects comprising the portfolio are not quantified using a constant standard, risk management on a portfolio level would not be able to proceed as required.

This study aims to develop a tool that would enable project managers to estimate project contingencies more accurately using a formalised and standard approach. The research aim is as follows:

Develop a contingency estimation tool to decrease the influence of subjectivity on contingency estimation methods throughout the project lifecycle so as to enable consistent project risk reflection on a portfolio level.

Though cost and schedule contingency need to be determined for each project, the need for improvement in contingency estimates relates more strongly to a consistent approach for contingency costing. Therefore an integrated cost and schedule contingency estimation tool will have to be applied, but the focus in the selection of methods to comprise the tool will be on those approaches aligning to the improvement of contingency cost estimation.

In the light of topics discussed in the literature study, the objectives can be summarised as the following:

- Determining the **most suitable method(s)** to be included in the contingency estimation tool to enable integrated cost-schedule contingency estimation
- Developing a **contingency estimation tool** that
  - Can be easily applied by a project manager without statistical knowledge or experience as a risk practitioner
  - Is applicable to all levels of project definition
  - Addresses systemic and project-specific risks
  - Determines the following when provided with suitable risk driver information:
    - \* The cumulative probability distribution of total project cost

## 6.2 Concluding remarks on chapter 6

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- \* A breakdown of contingency amounts (cost and duration) assigned to project-specific risks
- \* The level of project risk at portfolio level
- Providing standard guidelines regarding the points in the project lifecycle at which the contingency estimation tool should be applied

### 6.2 Concluding remarks on chapter 6

The problem with which this study is concerned has now been identified in context, and corresponding objectives have been stated. The following chapter will focus on the selection of the most suitable project contingency estimation method(s) to be incorporated in the tool to ensure that all study objectives are met.

## CHAPTER 7

# POSSIBLE TOOL FORMULATION STRATEGIES AND SOLUTION TECHNIQUES

Industry has seen the development of various contingency estimation techniques in an ongoing search for reliable approaches, as discussed in chapter 3. These techniques range from simple to extremely complex in their development and application, but in the end all have the same goal: improving the accuracy of project estimates (Burroughs & Juntima, 2004). Some methods are however more suited to the needs of certain environments and project types. This chapter will discuss which contingency estimation method(s) encountered in chapter 3 are most applicable in the context of projects performed by Eskom Distribution Western Cape Operating Unit and the objectives defined in chapter 6. The chapter will conclude with a look at the steps required for the practical execution of the proposed method.

### 7.1 Choosing the contingency estimation method(s)

Recall from earlier discussion (section 3.4) the four general classes of contingency estimation methods:

- Expert judgement
- Predetermined guidelines
- Simulation analysis (range estimating and expected value analysis)

## 7.1 Choosing the contingency estimation method(s)

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- Parametric modelling (regression analysis and neural network analysis)

The current expert judgement method employed in the study environment has been deemed ineffective. The predetermined guidelines method would not be effective as stand-alone approach in this study due to the subjectivity and wrongly implied certainty linked to a single contingency value, as well as the inability of more complex predetermined guidelines to deal with project-specific risks.

The two simulation methods (range estimating and expected value analysis) would in turn not be sufficient on their own as neither method is well-adapted to the identification and analysis of systemic risks. They are also not ideally suited to the Eskom Distribution environment as they require risk practitioner expertise in their execution, especially in cases where Monte-Carlo simulation is employed. The environment in question has a shortage of resources with the necessary experience and knowledge.

Parametric modelling would be more suitable as a contingency estimation method in this environment as it requires an initially complex set-up of a parametric model (which could be supplied as the output of this study), but thereafter does not require a high level of expertise in application. It is not suited to the analysis of project-specific risks, but is suited to the analysis of systemic risks.

A best practice contingency estimation tool should address systemic risk drivers using empirical knowledge to produce stochastic models that link these drivers to bottom-line project cost/duration growth. The tool should however also include a deterministic approach for the estimation of contingency requirements linked to project-specific risks (Hollmann, 2007). Therefore a **hybrid method** in line with that suggested by Hollmann (2010) is proposed, incorporating both a **neural network** and an **expected value analysis** tool.

Neural network analysis is favoured above regression analysis due to research conducted by Chen & Hartman (2000) demonstrating the superior performance of neural networks to that of regression analysis in the project environment. Also, the lack of upfront knowledge on the nature of relationships between inputs (risk drivers) and outputs (project cost/duration growth) opens up the possibility that regression analysis will not be successful as the method requires the cost/duration

## 7.1 Choosing the contingency estimation method(s)

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function to adhere to a defined mathematical form. The following conditions stated by [Bode \(1998\)](#) for a successful neural network analysis (with respect to cost estimation), hold in the Eskom Distribution Western Cape Operating Unit environment:

- A sufficient case base
- Known cost-driving attributes
- Few cost drivers
- No explicit knowledge about cost effects (knowledge of this nature might make other methods more suitable by comparison)

The expected value analysis method is favoured above the range analysis method as the second component of the hybrid approach as it does not necessitate the use of a Monte-Carlo simulation. Such a simulation would require expertise during application (due to, for example, the high impact that the lack of identification of correlation between risks has on the reliability of model output), and such expertise is not readily available to all projects in the study environment.

Research done by [Burroughs & Juntima \(2004\)](#) shows that expert judgement techniques outperform predetermined guideline techniques, especially on poorly defined projects. Simulation analysis performs slightly better than either of the first two methods on well-defined projects, but lags behind on poorly defined projects as project teams try to address both the poor quality of the base estimate and other risk factors, and tend to be overly optimistic. Parametric modelling (regression analysis / neural networks) shows slightly weaker performance than expert judgement on poorly defined projects, but keeps up with simulation analysis on well-defined projects, therefore showing the best combined performance for both levels of project definition. It follows that the suggested hybrid approach of a neural network with an expected value tool (which incorporates elements of expert judgement) would offer performance that is further improved above that of any of the stand-alone methods.

To test this initial proposal, it will be weighed against the other methods reviewed in chapter 3 to see if any of these methods would be preferable or could possibly be used to augment the proposed approach.

## 7.1 Choosing the contingency estimation method(s)

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“**A practical method**” by [Cioffi & Khamooshi \(2009\)](#) applies a binomial distribution to an expected value approach to determine how many risks would be “successful” (occur) and thereby enables the establishment of project contingency values that are not overly conservative without the application of Monte-Carlo analysis being required. This method could possibly be used to augment the expected value component of the proposed hybrid tool.

The **Influence factor based risk analysis** proposed by [Prasad \(2008\)](#) is not considered relevant to the study as the method is not fully adaptable to different projects, and does not encourage full risk analysis as per industry best practice ([International Organisation for Standardisation, 2009](#); [Office of Government Commerce, 2009](#); [PMI® \(2008\)](#)).

**Reference class forecasting** ([Flyvbjerg, 2006](#)) will not be applied as the absence of a risk breakdown structure and resulting lack of direct link between specific risks and contingency amounts would complicate governance and contingency fund management, which is far from ideal on government funded projects.

As the PERT method will not be applied in full, the proposed **Variation on the PERT method** by [Moselhi \(1997\)](#) will also not be applicable.

The **Integration of Zastrozny (1974) method and the SMART method** proposed by [Burger \(2003\)](#) will not be applied as the “unforeseen events uncertainty” assumed as applicable to all projects is analogous to the systemic risk output of the proposed neural network model, and such an outcome would be more relevant if determined specifically for the environment in question as will be the case in the proposed hybrid approach. Also, the remainder of the method is similar to the range estimation method, which will not be applied for reasons discussed earlier.

The **Probabilistic model for cost contingency** proposed by [Touran \(2003\)](#), is not sufficient as it considers only the construction phase, and not, for example, design risk contribution to higher project costs in the preconstruction phases.

The calculation of the **Cost contingency as the standard deviation of the cost estimate** as proposed by [Rothwell \(2005\)](#) can only be applied once the project’s total cost distribution is known. In the case of the study environment, the total cost distribution is not available as the output of any other estimation

## 7.2 Further substantiation of the proposed approach

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steps. Therefore the method cannot be used to initially determine said contingency values. However, it might be used to translate the proposed model output in terms of cost (contingency value) to a total project cost distribution. This total cost distribution could then be applied to support the selection of a final contingency cost corresponding to a required level of certainty that the budget not be exceeded.

As it is not necessary that risk impact and probability be defined in linguistic terms, the **Approximate reasoning method** proposed by [Minassian & Jergeas \(2009\)](#) to “defuzzify” linguistic qualification inputs is not necessary.

The method proposed by [Touran \(2010\)](#) for the **Management of contingency costs on portfolio level** is not applicable to the workings of the proposed model on project level, but could possibly be incorporated as means to translate output data from the proposed method to portfolio level.

## 7.2 Further substantiation of the proposed approach

To summarise the discussion of the previous section, the proposed approach is to develop a hybrid tool enabling neural network analysis of systemic risks and expected value analysis of project-specific risks. Possible integration with other methods include the practical method presented by [Cioffi & Khamooshi \(2009\)](#), the calculation of cost contingency as the standard deviation of the cost estimate ([Rothwell, 2005](#)), and the method for management of contingency costs on portfolio level proposed by [Touran \(2010\)](#).

Chapter 6 stated the need for a contingency estimating tool considering both cost and schedule. On the topic of integrated cost-schedule contingency estimation, [Hollmann \(2010\)](#) evaluates a hybrid parametric model / expected value method as opposed to a Monte-Carlo simulation approach based on a cost-loaded schedule. The latter method of range simulation applied to a cost-loaded schedule is the method to determine cost and schedule contingency simultaneously that is best covered in literature. [Hollmann \(2010\)](#) suggests that contingency estimation is better achieved through a hybrid parametric model / expected value method. The logic behind the hybrid approach is motivated as follows:

## 7.2 Further substantiation of the proposed approach

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- Parametric modelling is used on data from past projects to evaluate the impact of systemic risks that are not readily quantifiable by traditional risk analysis
- The expected value method is used to evaluate the impact of project-specific risks that are suitable for traditional risk analysis
- The simultaneous use of the two methods leverages their strengths

In his first published description of the proposed method, [Hollmann \(2010\)](#) explains that the two methods are integrated by including the cost and schedule outputs of the parametric model as a one-line risk item (with 100% probability of occurrence) in the expected value tool. Therefore all risks influencing the contingency estimation are contained in a single tool providing cost and schedule output.

Other advantages and disadvantages of the hybrid method and two other integrated cost-schedule approaches using Monte-Carlo analysis of cost-loaded schedules are compared in table 7.1. In this table, *cost-loaded schedule with activity ranging* refers to range analysis based on a cost-loaded project schedule, and *cost-loaded schedule with risk driver* refers to range analysis where risk drivers are identified independently and related back to the cost-loaded project schedule.

From this, the following characteristics of cost-loaded schedule methods can be identified as detrimental with respect to the application of a project contingency estimation tool in Eskom Distribution Western Cape Operating Unit:

- High scheduler competency and a high quality schedule are required
- The methods are not applicable to projects at early definition stages
- The methods are weak for systemic risks
- As the methods are not empirically based but rely on the opinion of the facilitator of the range estimating session, the methods are not very objective

This further promotes the use of a hybrid model incorporating neural network modelling and the expected value method, as such a combined method is applicable to a schedule of any quality at any stage of the project lifecycle, is partially

**7.2 Further substantiation of the proposed approach**

<b>Method</b>	<b>Strengths</b>	<b>Weaknesses</b>
Cost-loaded schedule with activity ranging	<ul style="list-style-type: none"> <li>• Explicit cost / schedule integration for time dependent costs</li> <li>• Encourages use of quality planning and scheduling methods</li> <li>• Commercial software / many users</li> </ul>	<ul style="list-style-type: none"> <li>• No explicit risk-impact linkage</li> <li>• No empirical basis</li> <li>• Requires quality schedule (cost-loaded) and competent scheduler</li> <li>• Not applicable to projects at early definition stages</li> <li>• Static logic / risk response assumed</li> <li>• Weak for systemic risks</li> </ul>
Cost-loaded schedule with risk driver	<ul style="list-style-type: none"> <li>• Explicit risk-impact linkage (but not for systemic risks)</li> <li>• Explicit cost/schedule integration for time-dependent costs</li> <li>• Encourages use of quality planning and scheduling methods</li> <li>• Commercial software / some users</li> </ul>	<ul style="list-style-type: none"> <li>• No empirical basis</li> <li>• Requires quality schedule (cost-loaded) or competent scheduler</li> <li>• Not applicable to projects at early definition stages</li> <li>• Static logic / risk response assumed</li> <li>• Weak for systemic risks</li> </ul>
Hybrid parametric / expected value	<ul style="list-style-type: none"> <li>• Explicit risk-impact linkage</li> <li>• Empirical basis</li> <li>• Applicable to schedules of any quality</li> <li>• Applicable to all levels of project definition</li> <li>• Addresses logic / risk response scenarios</li> </ul>	<ul style="list-style-type: none"> <li>• No commercial software / few users</li> <li>• Lesser quality schedules require more intuitive assessment</li> <li>• Cost/schedule integration for time dependent costs not explicit</li> <li>• Does not encourage use of quality planning and scheduling methods</li> </ul>

Table 7.1: Integrated cost-schedule contingency estimation methods – Strengths and weaknesses.

### 7.3 Steps for practical execution of the proposed method

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empirically based and indicates explicit risk-impact linkage. The fact that no commercial software is available for the task will be addressed (for the study environment) by the output of this study. Also, though quality planning methods are not necessitated by the hybrid approach, they are prescribed by other governing project management processes within the Eskom Distribution environment, and are therefore not cause for concern. The other possible weaknesses of this approach will be addressed during tool development.

### 7.3 Steps for practical execution of the proposed method

The development of a hybrid tool integrating neural network analysis and the expected value method would first address the neural network component, and thereafter integration with the expected value method.

The steps as summarised by [Hollmann \*et al.\* \(2009\)](#) for the development of the neural network model will be followed as listed below (note that tool requirements have already been determined in the previous chapters):

1. Determine requirements
  - Classes of estimates (based on organisation type)
  - Types of projects and risks
  - Corporate risk management strategies
  - Resources and competencies available
2. Gather historical data
3. Analyse data and develop tool
  - Clean data: Remove outliers, normalise data (for escalation, currency and scope changes not covered by contingency)
  - Ensure output relationships are statistically significant and causal in nature
  - Ensure variables are independent and not co-linear
  - Ensure model is not overly biased by outlier data points
  - Validate model output against industry standards

## 7.4 Concluding remarks on chapter 7

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The model will be implemented as a tool wherein users enter parameter values, and the tool generates the predicted contingency value as a percentage of the base estimate value. The model will select the contingency value as the point value providing equal probability of budget over- or underrun (Hollmann *et al.*, 2009). To provide a probabilistic view of this point value, the assumption can be made that project cost after contingency allowance is normally distributed with a standard deviation equal to the model output contingency value (Rothwell, 2005).

As mentioned earlier in this chapter, the neural network model is then integrated with the expected value method by including the cost and schedule outputs of the model as a one-line risk item (with 100% probability of occurrence) in the expected value tool. As stated by Hollmann (2010), no commercial tool enabling contingency estimation using a hybrid neural network model / expected value method, currently exists. Both components of the tool will therefore be developed as output of this study. The risk register that will be used to incorporate project-specific risks will be designed in Microsoft Excel, and the neural network used to model systemic risks will be programmed in Visual Basic for Applications to enable automatic interaction between the two components of the tool.

The steps in model application (Hollmann *et al.*, 2009) are summarised below:

1. Identify and quantify systemic risk parameters
2. Estimate contingency
3. Coordinate with contingency estimates for project-specific risks

## 7.4 Concluding remarks on chapter 7

In this chapter, the proposed approach for the contingency estimation tool was identified as the following: Develop a hybrid tool enabling neural network analysis of systemic risks and expected value analysis of project-specific risks. Possible integration with other methods include the practical method presented by Cioffi & Khamooshi (2009), the calculation of contingency as the standard deviation of the cost estimate (Rothwell, 2005), and the method for management of contingency costs on portfolio level proposed by Touran (2010).

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## 7.4 Concluding remarks on chapter 7

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This approach was further substantiated by contrasting it to methods delivering similar integrated cost-schedule contingency outputs and comparing the advantages and disadvantages as applied to the study environment. Finally, practical steps in model development were considered.

The remaining chapters will discuss the design and practical implementation of the contingency estimation tool.

A chapter on the design of the neural network will give a brief introduction to neural networks before considering the architecture of the neural network designed to solve the problem at hand in this study. The following chapter will discuss how neural network training data was obtained by describing the interview process, the processing of interview data to obtain training patterns, and the confirmation of input data integrity. Hereafter, neural network results will be given in a separate chapter.

After the neural network has been trained, it will be applied to new projects to estimate contingency due to systemic risks alongside an estimation of contingency due to project-specific risks. A chapter will be devoted to the summary of the overall proposed approach, the project-specific contingency estimation method and the role of interview outputs regarding project-specific causes for cost and duration growth in this method. The practical integration of the two methods will be discussed alongside a description of model inputs, outputs and advantages.

The penultimate chapter will examine the integration of the developed contingency estimation tool with the project lifecycle model and the enterprise risk management process within Eskom, followed by a chapter containing the research summary and conclusions.

## CHAPTER 8

## DESIGNING THE NEURAL NETWORK

Neural networks, as previously discussed in subsection 3.4.4.2, form part of the Artificial Intelligence field of computer science, which aims to endow computers with “humanlike abilities” (Heaton, 2005). The human brain is an example of a *biological* neural network consisting of over 100 billion connected neurons, where each neuron processes small amounts of information and then activates other neurons to continue the process. The type of neural networks to be discussed in this chapter are designed to mimic *biological* neural networks, and are therefore termed *artificial* neural networks (ANN). In this study, when the term neural network is used without the prefix “biological”, it refers to an artificial neural network.

This chapter will give a brief introduction to neural networks and the types of problems to which they are applied, before considering the architecture of the neural network designed to solve the problem at hand in this study. The selection of the relevant algorithm(s) for neural network training will be discussed, and an overview of model logic will be given. The chapter will conclude with a brief description of the application of the developed neural network model to a multi-objective test problem.

## 8.1 Application of ANNs

ANNs do not attempt to imitate an entire human brain, but rather the individual cells, or neurons, of which the brain is composed (Heaton, 2005). When a neuron in a biological neural network receives (accepts) a signal, it may “fire” to transmit the signal to the next neuron. Each neuron makes the decision: to fire or not to fire.

An ANN approximates this decision process through nodes representing neurons linked by connections representing synapses. These connections allow nodes to transmit signals to one another, and thereby process information. Not all connections are equal – each connection is assigned a connection weight, and these weights determine the output of the neural network. As the neural network “learns”, these weights are changed, and therefore act as the memory of the neural network. A connection weight of zero indicates the lack of a connection between nodes.

Heaton (2005) describes problems that are not well suited to ANN analysis as opposed to those that are. Neural networks should not be applied to problems that can be solved through programs easily mapped in a flowchart format, or by a program where the logic is not likely to change (due to *e.g.* a certain business rule). Also, ANNs are not ideally suited to problems where it is necessary to know exactly how the solution was reached – a neural network cannot explain why it gives certain answers. ANNs are suitable for problem-solving that cannot easily be expressed as a number of steps, *e.g.* pattern recognition, classifying into groups, series prediction and data mining.

The following section will justify the chosen architecture of the neural network model for this study in terms of the input, output and hidden layer contents and the chosen activation function.

## 8.2 Architecture of the neural network

A general **feedforward** neural network consists of one input layer, one or more hidden layers, and one output layer. An example of a feedforward neural network with contingency cost and duration due to systemic risks as outputs and one hidden layer is shown in figure 8.1. In some neural networks, no hidden layers

## 8.2 Architecture of the neural network

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are used (single-layer feedforward networks), while in other, “backward” feedback loops exist (recurrent networks) (Haykin, 1999). Recurrent neural networks are rarely applied, and this study will focus on the design of a feedforward neural network.

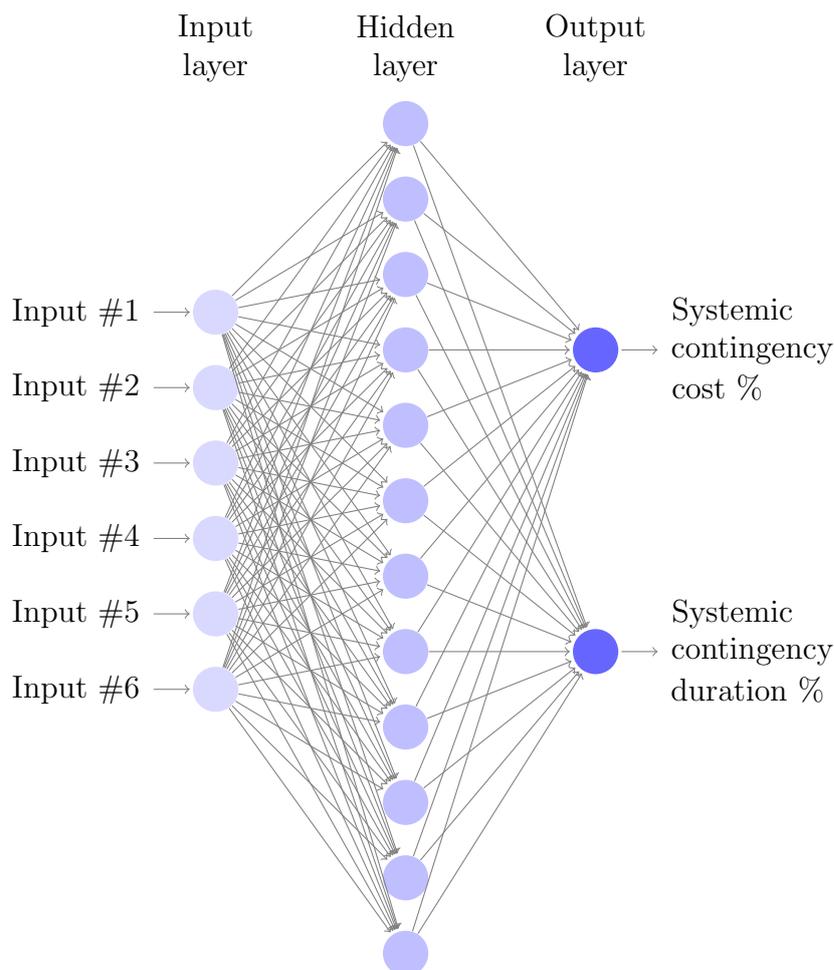


Figure 8.1: Multilayer feedforward neural network example.

Every possible interconnection/synapse between the nodes in different layers possesses its own weight. Therefore, for example, the weight matrix between the input and hidden layer has  $R \times L$  dimensions, where  $R$  is the number of input nodes and  $L$  is the number of hidden nodes. The hidden nodes and the output nodes are connected by a similar weight matrix, and a bias is also added to each

## 8.2 Architecture of the neural network

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node in the hidden and output layers to scale the node's input values before they pass through the node's activation function. This bias value can be modelled as an input signal fixed at +1 in the input and hidden layer (refer to figure 3.4), with a corresponding synaptic weight equal to the bias value connecting it to the nodes in the subsequent layer (Haykin, 1999). The activation function, sometimes called the transfer function, takes the sum of all a node's weighted inputs and uses the value to calculate the node's output. The activation function is used to "squash" the output values to within an acceptable range based on model application – the output value of the activation function is normally between zero and one or minus one and one, depending on which function is used, as will be discussed in subsection 8.2.4.

The next three subsections will discuss the input, output and hidden layers of the ANN.

### 8.2.1 The input layer

Data is presented to the neural network from the "outside world" through the input layer. For each set of data that is presented to the input layer, the output layer will produce a set of data. Every node in the input layer represents an independent variable that has an influence on the output of the neural network. For this study, six systemic risk drivers were identified as input variables:

1. Project definition level
2. Latest approved project cost
3. Latest approved project duration
4. Business category
5. Voltage category
6. Job category

**Project definition level** refers to the required level of definition at the project stage in question. This is calculated as one minus the *allowable variance* from the latest relevant approval form to the FRA form as was shown in table

## 8.2 Architecture of the neural network

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4.1. It is assumed that these required levels of definition represent the actual level of project definition at the relevant stage gate with reasonable accuracy. **Latest approved project cost** and **latest approved project duration** refer to the approved cost and duration from the latest approved form (CRA, DRA or ERA). Project duration is calculated from CRA approval (at which point the concept is “released” and becomes a project) to the commissioning/energising date of the asset. **Business category**, **voltage category** and **job category** refer to the relevant project categories as discussed in section 4.2.

The first three input drivers will have different values at different stages in the project lifecycle. Three project lifecycle points will be considered for the purpose of this study, *i.e.* CRA approval (end of pre-project planning stage), DRA approval (end of concept stage) and ERA approval (end of definition stage). Thus three input patterns will be available per project.

Note that as some of these variables are categorical variables, **eight input nodes** will be required to represent all six input systemic risk drivers, as will be explained in subsection 9.3.1. With reference to the risk drivers proposed by Burroughs & Juntima (2004), discussed in subsection 3.4.4, *project definition level* is represented by the variable of the same name, and all of the variables save project definition level combine to describe *process complexity*. *Contracting strategy* is not added as input variable as all considered projects follow a *time and material* strategy as discussed in section 3.7. *Equipment percentage* is represented by the combination of the last three variables (similar project types are assumed to have similar equipment budgets). As none of the network asset construction projects used as input to the study were the first of their kind (standard and repeatable projects), a variable representing *use of new technology* was not included.

### 8.2.2 The output layer

The output layer of a neural network presents output data to the external environment. Each node in the output layer represents an independent output variable. For this study, **two output nodes** will be used to represent the two independent output variables:

## 8.2 Architecture of the neural network

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1. Required contingency cost percentage due to systemic risks
2. Required contingency duration percentage due to systemic risks

A similar study to determine total project cost and duration by [Pewdum \*et al.\* \(2009\)](#) utilised two individual neural networks: one predicting project cost and one predicting project duration. For their study, this choice followed from the fact that the factors influencing cost and duration to be used as inputs to the network, differed. In this study, the six input variables are all assumed to be drivers of systemic risk directly impacting both cost and schedule growth. For example, a long project duration implies high project complexity which influences both schedule and cost growth, while a large project value would be linked to stricter internal investment procedures, which could in turn lead to schedule delay. For this reason, the cost and schedule growth due to systemic risks are considered as the two output variables of a single neural network with the six chosen risk drivers as possible input variables.

### 8.2.3 The hidden layer

With regards to the hidden layer of the neural network, two choices need to be made:

1. How many hidden layers will be used
2. How many hidden nodes will be in each layer

Problems that require more than one hidden layer are rare – most practical problems require only one hidden layer. [Heaton \(2005\)](#) states that a neural network with one hidden layer “can approximate arbitrarily with any function which contains a continuous mapping from one finite space to another”. For this study, a neural network with **one hidden layer** will be used.

The selection of the number of hidden nodes in this layer is very important, as using too few nodes will result in “underfitting” – there would be too few nodes to adequately detect the signals in a complicated data set. Using too many, on the other hand, could result in “overfitting” – the training set is not sufficient to train all of the nodes in the hidden layer ([Chuang \*et al.\*, 2000](#); [Heaton, 2005](#)),

## 8.2 Architecture of the neural network

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resulting in the network overfitting itself to the available content, in turn leading to bad generalisation when the network is confronted with new input data it has not seen before. If enough training patterns exist, too many hidden nodes might still increase the training time to an extent that makes it difficult to adequately train the neural network.

Heaton (2005) suggests the following possible heuristics to assist in determining the number of hidden nodes:

- The number of hidden nodes should be larger than the number of output nodes, but less than the number of input nodes
- The number of hidden nodes should be two thirds of the number of input nodes plus the number of output nodes
- The number of hidden nodes should be less than twice the number of input nodes

As all of these heuristics indicate that **between two and 16 hidden nodes** should be used in the case of this study, the best approach will be determined by evaluating the accuracy of the model resulting from independent model runs with the number of hidden nodes ranging between two and 16. These results will be discussed in section 10.1.

Having considered the input, output and hidden layers of the neural network, the following section will focus on the selection of an appropriate activation function.

### 8.2.4 The activation function

For each neuron layer save the input layer, an activation function must be chosen. In order for the backpropagation method to be applied, the function must be continuous and differentiable. Haykin (1999) presents three often used activation function types:

- Threshold function
- Piecewise-linear function

## 8.2 Architecture of the neural network

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- Sigmoid function

The sigmoid function is by far the most frequently applied method as it exhibits a balance between linear and nonlinear behaviour (Haykin, 1999), and will therefore be the activation function type applied to the hidden and output layer nodes in the ANN model of this study.

The term **sigmoid** means curved in two directions. The sigmoid function (shown in figure 8.2) is described by

$$A(x) = \frac{1}{1 + e^{-x}} \quad (8.1)$$

where  $x$  would be substituted by the weighted sum of inputs to either the  $t^{\text{th}}$  output node or the  $l^{\text{th}}$  hidden node. An important note regarding this function is that it returns only positive numbers. If negative numbers are required as an output of the neural network, this function will not be suitable.

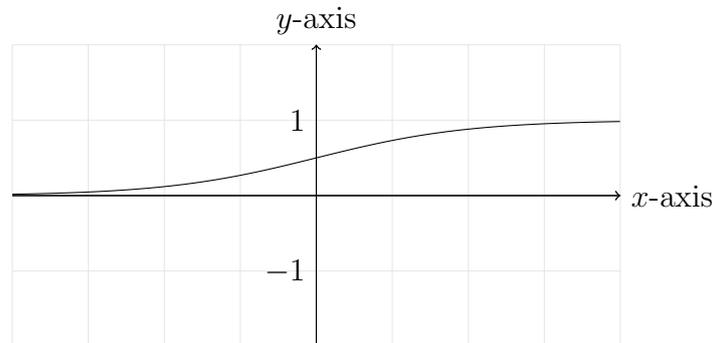


Figure 8.2: The sigmoid function.

The **hyperbolic tangent** function, as described by

$$A(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \quad (8.2)$$

and shown in figure 8.3, is a form of the sigmoid function returning both positive and negative numbers. It is therefore often used as activation function when a neural network must be able to return negative values.

The contingency cost and schedule percentages to be computed by the neural network in this study are anticipated to be positive additions to project budget

### 8.3 Training the neural network

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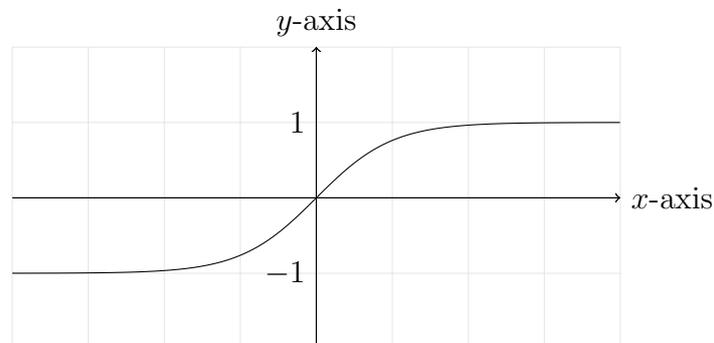


Figure 8.3: The hyperbolic tangent (tanh) function.

or schedule. However, there are cases in the training set of historical data where projects finished under budget or earlier than planned. To enable the network to approximate these negative outcomes alongside the positive outcomes, the **hyperbolic tangent function** will be applied as activation function in the hidden and output layers.

### 8.3 Training the neural network

The process of changing the connection weights in a neural network is referred to as learning/training. The initial connection weights are randomly assigned, and then changed by the network as it is presented with new data. The performance of the network is continually evaluated by the calculation of a training error, and weights are adjusted based on the outcome. Errors are calculated for each **training pattern** (set of inputs and outputs presented to the neural network), and summed when all training patterns have been considered, or one **epoch** has been completed. The process repeats itself until the training error reaches an acceptably low level, or a predetermined number of training epochs have been completed.

There are many ways in which neural networks can be trained, most of which fall into the categories of supervised, unsupervised or hybrid training methods (Heaton, 2005). *Supervised* training occurs by presenting the network with a set of input data and corresponding anticipated output data regarding an environment that is unknown to the neural network of interest (Haykin, 1999). The process

### 8.3 Training the neural network

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is portrayed in figure 8.4. The presented output data is assumed correct, and an error signal is produced to define the difference between the desired response and the actual response of the network at a given point in the training process. When the training process is completed, the anticipated output data or “teacher” can be removed, and the network can deal with inputs from the environment by itself. Supervised training can be achieved using a variety of training algorithms, including backpropagation (a commonly used method), simulated annealing and genetic algorithms (Heaton, 2005).

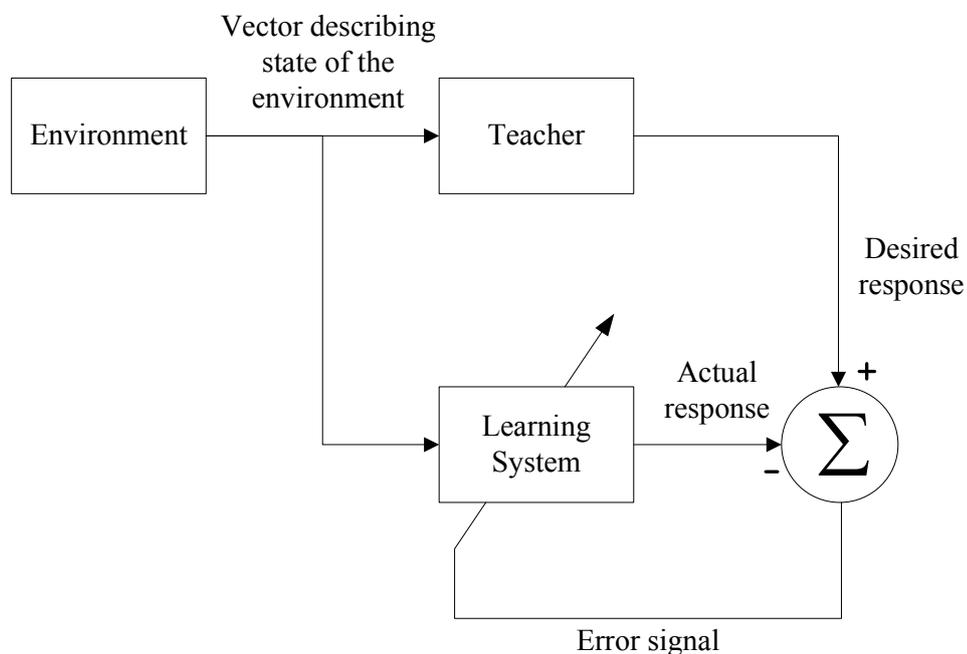


Figure 8.4: The supervised training process.

*Unsupervised* training occurs when only input data is presented to the network. This is most often applied when the desired function of the neural network is to classify inputs into several groups (Heaton, 2005).

*Hybrid* methods of supervised and unsupervised training also exist (Heaton, 2005). An example of this is training without providing anticipated output data, but while informing the network whether it is “right” or “wrong” for each output.

### 8.3 Training the neural network

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The choice of training method is influenced by the learning task that a neural network is required to perform. Haykin (1999) discusses six such learning tasks, *i.e.*:

1. Pattern association
2. Pattern recognition
3. Function approximation
4. Control
5. Filtering
6. Beamforming

These learning task types need not be discussed in depth for the purpose of this study, save for identifying **function approximation** as the learning task that the neural network will be required to perform. For this task, the purpose of the neural network design is to approximate an unknown nonlinear input-output mapping function described by  $\mathbf{y} = f(\mathbf{x})$ , where the vector  $\mathbf{x}$  is the input and vector  $\mathbf{y}$  is the output. A set of input-output mapping examples are known, and must be used to compensate for the lack of knowledge about the mapping function itself. These known examples are used to test the function  $F(.)$  approximating the input-output mapping, to ensure that  $\|F(\mathbf{x}) - f(\mathbf{x})\|$  is sufficiently small for all  $\mathbf{x}$ . This is the type of problem that is encountered in this study, and this learning task type is a perfect candidate for supervised training (Haykin, 1999).

Therefore, **supervised training** will be used by applying the desired outputs of the neural network as training values for each of the two known output variables, *i.e.*:

1. Required contingency cost percentage due to systemic risks
2. Required contingency duration percentage due to systemic risks

The selection and development of the supervised training algorithm will be discussed in the following subsections.

## 8.3 Training the neural network

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### 8.3.1 Supervised training methods

Treadgold & Gedeon (1998) state that there are two overarching training methods used to train feedforward neural networks, *i.e.* gradient descent methods and global optimisation methods, and provide various examples of training algorithms classified under each type. This section describes three of these training algorithms, *i.e.*:

1. Backpropagation algorithm, a gradient descent method
2. Simulated annealing algorithm, a global optimisation method
3. Genetic algorithm, a global optimisation method

**Backpropagation (BP)** refers to a supervised training method where the training algorithm takes a calculated error (output vs desired output) and uses it to adjust the weight of the various layers “backwards” from the output layer to the input layer. This training method utilises a gradient descent algorithm (a form of hill-climbing) that aims to minimise the error of the neural network output values. BP can be applied with any feedforward network that uses a differentiable activation function – the activation of the output nodes become differentiable functions of the input, weights and bias. If the function used to calculate the error is also differentiable, for example the “sum of square” error function, the error function is also a differentiable function of the weights. The derivative of the error can therefore be calculated using the weights, and in such a way the weights and errors required to minimise the error of the neural network can be determined. The algorithm that evaluates the derivative of the error function is called backpropagation, as it propagates the errors backward throughout the network.

The **simulated annealing (SA)** algorithm is based on the thermodynamic metallurgical process of heating up a solid material, and cooling is slowly until it crystallises. Material atoms have high energies at high temperatures, and decreasing energy as the temperature is reduced. Rapid cooling causes defects in the crystal structure. SA mimics this process by modifying a series of input values (for example, a weight matrix in a neural network) so that an arbitrary objective function (for example, the training error of a neural network) can be

### 8.3 Training the neural network

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minimised. The algorithm achieves this by beginning its search at an initial feasible solution at a high “temperature”, where newly generated solutions can assume a great range of random values – this helps prevent the algorithm from becoming “stuck” in local minima. The temperature of the simulation is allowed to fall as training progresses, which causes the probability of acceptance of “bad” solutions (also termed the transition probability (Azizi & Zolfaghari, 2004)) to decrease, and convergence is achieved.

The **genetic algorithm (GA)** simulates the principles of Darwin’s theory of evolution and natural selection, and is often applied to search large, non-linear spaces. Individual “organisms” in a GA are generally composed of single chromosomes, which are made up of different genes. Chromosomes represent possible solutions, while genes represent individual components of a solution. The “fitness level” of chromosomes are evaluated to determine whether they will survive. By manipulating genes, new chromosomes are created that have different traits. Manipulations occur through crossover (analogous to the biological process of mating and giving birth) or mutation (randomly changing the genes of some newly created offspring). Mutation is a way in which completely new information can be introduced into an existing population to prevent the population from becoming “trapped” in local minima.

Heaton (2005) compares BP, SA and GA for use as training algorithms in neural networks. Though the overwhelming majority of neural network applications employ some variation of BP (Sexton *et al.*, 1999), a fundamental flaw encountered with this training algorithm is its tendency to get trapped in local minima (Sexton *et al.*, 1999; Treadgold & Gedeon, 1998) – this being, in the case of a neural network, “a false optimal weight matrix that prevents the BP training algorithm from seeing the true solution” (Heaton, 2005). BP and other similar gradient searches typically achieve the best solution in the region of their starting point (Sexton *et al.*, 1999).

To overcome the weaknesses encountered with hill-climb / gradient descent algorithms such as BP, global search algorithms should be applied to adjust the weights in a fashion that minimises the error calculated at the end of each training epoch (*e.g.* root mean square error, sum of squared errors or sum of absolute errors). When applied in this way, SA and GA both outperform BP as training

### 8.3 Training the neural network

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algorithm by allowing the solution vector to escape local minima and seek an improved global solution (Sexton *et al.*, 1999). Note that in such an application, the values of weights are only updated at the end of each epoch, when all training patterns have been considered. This is referred to as **batch learning**, as opposed to **per-example learning** where weights are adjusted after each training pattern as with traditional backpropagation (Chuang *et al.*, 2000).

When directly compared as applied to the same problem, SA converges much faster than GA, as it finds the solution using point-by-point iterations rather than searching over an entire population of individuals (Suman & Kumar, 2006). SA also outperforms straightforward BP with respect to error levels as it is less likely to be caught up in local minima.

Ludermir *et al.* (2006) propose a method combining the advantages of SA with that of the BP method. By combining a global optimisation technique with a gradient search technique, global efficiency is obtained alongside the “fine-tuning” that the gradient method provides. The requirement of applying per-example learning at some point during the training is reiterated by Chuang *et al.* (2000), who states that batch learning methods alone cannot provide good learning performance.

Ludermir *et al.* (2006) continue that at the end of the training process using SA, the best solution “so far” is used as input for the BP algorithm, which proceeds to perform a fine-tune local search. Results from this method show that the combined approach using global optimisation and a gradient search technique provides consistently improved or equivalent error levels (when compared to the stand-alone use of global optimisation algorithms for training) for each of five experiment data sets.

There are ways to modify the BP and other gradient search algorithms for improved results that have a comparatively lower computational cost than global optimisation methods. Treadgold & Gedeon (1998) argue that because of the decreased computational cost, these gradient search methods will perform better than global optimisation methods when applied to complex networks. As the multilayer feedforward network considered in this study is relatively simple, with only one hidden layer, eight possible input nodes and two output nodes, the combination of a global optimisation method with a gradient method (BP) is

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### 8.3 Training the neural network

preferred over conducting the entire training process using a modification of the BP algorithm to decrease computational cost.

For these reasons, the **simulated annealing algorithm** will be applied alongside the **backpropagation algorithm** in the neural network model of this study in a method similar to that proposed by [Ludermir \*et al.\* \(2006\)](#). Reannealing (increase of temperature parameter in SA algorithm) will be periodically performed when the SA algorithm starts to converge to ensure that the entire solution space is searched, and a local minimum is not passed off as a global minimum ([Treadgold & Gedeon, 1998](#)). The following two subsections will discuss in more detail the BP and SA algorithms, respectively.

#### 8.3.2 Backpropagation

In the BP algorithm, the amount by which each weight must be adjusted is calculated at the end of each training pattern, and this amount is “backpropagated” through the network. During each “forward pass” through the network to determine the values of the output nodes based on current weights, the error signals for each training pattern  $tp$  (of the total number of training patterns TP) can be determined as

$$e_t(tp) = D_t(tp) - O'_t(tp) \quad (8.3)$$

where  $e_t$  denotes the error signal at output node  $t$ ,  $D_t$  denotes the desired response for node  $t$  and  $O'_t$  represents the output value of node  $t$ .

The local gradient that is used to backpropagate the required changes throughout the network based on the calculated error signal, can then be determined (for the output layer and hidden layer respectively) as ([Haykin, 1999](#))

$$\delta_t(tp) = e_t(tp) \times A' \left( \sum_{l=0}^L W'_{lt} H'_l(tp) \right) \quad (8.4)$$

and

$$\delta_l(tp) = \sum_{t=0}^T \delta_t(tp) W'_{lt} \times A' \left( \sum_{r=0}^R W_{rl} I_r(tp) \right). \quad (8.5)$$

### 8.3 Training the neural network

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Here,  $W'_{0t}$  represents the bias value connecting the hidden bias node (value +1) to the output layer nodes,  $W_{0l}$  represents the bias value connecting the input bias node (value +1) to the hidden layer nodes, and  $A'$  represents the derivative of the activation function.

When the hyperbolic tangent function is applied (as is the case in this study), these equations can be generalised (for the output and hidden layers, respectively) as (Haykin, 1999)

$$\delta_t(tp) = [e_t(tp)] \times [1 - O'_t(tp)] \times [1 + O'_t(tp)] \quad (8.6)$$

and

$$\delta_l(tp) = [1 - H'_l(tp)] \times [1 + H'_l(tp)] \times \sum_{t=0}^T \delta_t(tp) W'_{lt}. \quad (8.7)$$

From here, the required change to each weight can be determined for the output and hidden layers, respectively by (Haykin, 1999)

$$\Delta W'_{lt}(tp) = v \Delta W'_{lt}(tp - 1) + \psi \delta_t(tp) O'_t(tp) \quad (8.8)$$

and

$$\Delta W_{ri}(tp) = v \Delta W_{ri}(tp - 1) + \psi \delta_l(tp) H'_l(tp) \quad (8.9)$$

where  $v$  represents a momentum term (positive constant), and  $\psi$  represents the learning rate of the network (positive constant). The values of these constants must be selected during neural network development. A smaller network learning rate parameter  $\psi$  results in smaller changes to the synaptic weights from one iteration to the next, providing a smoother trajectory in the weight space. This is attained at the cost of a slower overall rate of learning (Haykin, 1999). A large  $\psi$  may however cause the network to become unstable. The momentum term is added to increase the rate of learning while avoiding network instability. For the purpose of this study, the values of these parameters are set to 0.001 for the learning rate, and 0.7 for the momentum term as suggested by Ludermir *et al.* (2006).

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### 8.3 Training the neural network

Having discussed the BP algorithm, SA will be considered in the following subsection.

#### 8.3.3 Simulated annealing

[Suman & Kumar \(2006\)](#) describe simulated annealing as a “compact and robust” technique which delivers exceptional solutions to both single and multi-objective functions with a noticeable decrease in required computation time when compared to other techniques. The method can be applied to problems having either continuous or discrete variables. In the case of multi-objective problems, the method is used to obtain a Pareto set of solutions.

As the simulated annealing algorithm applied in this study will aim to minimise two objective functions, *i.e.* the error function of each of the two output variables, a multi-objective simulated annealing method will be applied. Before the selection of a multi-objective simulated annealing procedure is discussed, a brief background will be given on simulated annealing for single objective optimisation.

##### 8.3.3.1 Simulated annealing for single objective optimisation

The simulated annealing algorithm differs from other, simpler local search algorithms (for example the gradient descent method) in that it attempts to avoid becoming trapped in local minima/maxima by sometimes accepting a move that would lead to a worse solution ([Suman & Kumar, 2006](#)).

SA does this by accepting “bad” moves with a certain probability – this probability is determined using an acceptance function of the form

$$p = e^{(-\Delta/\text{Temp})} \quad (8.10)$$

where Temp denotes the temperature, a control parameter corresponding to the temperature used in a physical annealing process, and  $\Delta$  is the change in the “wrong” direction (for example an increase in a minimisation problem) in the objective function value from the current to the proposed new solution. Continuing the minimisation problem example, a slight increase would be accepted with a larger probability than a large increase. Also, when the temperature is high, more “uphill” values would be accepted than when the temperature approaches

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### 8.3 Training the neural network

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zero. The steps in a single objective optimisation simulated annealing algorithm are shown in algorithm 1 (Suman & Kumar, 2006).

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**Algorithm 1** : Simulated annealing algorithm for a single objective function.

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- 1: Initialise the temperature.
  - 2: Start with a randomly generated initial solution vector,  $X$ , and evaluate the objective function  $g(X)$ .
  - 3: Give a random perturbation and generate a new solution vector,  $X_n$ , in the neighbourhood of current solution vector,  $X$ . Re-evaluate the objective function and accept the new solution vector if the value of the objective function is improved.
  - 4: If the generated solution vector is accepted, make it the current solution vector by setting  $X = X_n$ . Update the existing solution and go to Step 6.
  - 5: Else accept  $X_n$  with the probability  $p = e^{(-\Delta/\text{Temp})}$  where  $\Delta = g(X_n) - g(X)$ .
  - 6: Decrease the temperature periodically.
  - 7: Repeat Steps 2—6 until stopping criterion is met.
- 

#### 8.3.3.2 Simulated annealing for multi-objective optimisation

Simulated annealing and other heuristic algorithms are becoming increasingly popular for multi-objective optimisation (Suman & Kumar, 2006), as these methods:

1. Determine multiple solutions in a single run
2. Operate without derivatives
3. Converge to Pareto-optimal solutions with a high degree of accuracy in a short time
4. Can accommodate continuous function and combinatorial optimisation problems
5. Are less susceptible to the shape or continuity of the Pareto front than other methods

The concept of “Pareto-optimal” with respect to a multi-objective problem solution, refers to a set of alternative solutions rather than a single best solution (which does not always exist). These solutions are termed “optimal” as there

### 8.3 Training the neural network

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are no other solutions in the solution space that are superior to them when all objectives are considered – they are the “non-dominated” solutions. When a pair of non-dominated solutions are compared with regards to the objectives associated with them, each solution will be superior with respect to at least one objective. This is illustrated in figure 8.5 for the case of minimisation. The “Pareto-optimal” set is the set of non-dominated solutions to a multi-objective optimisation problem.

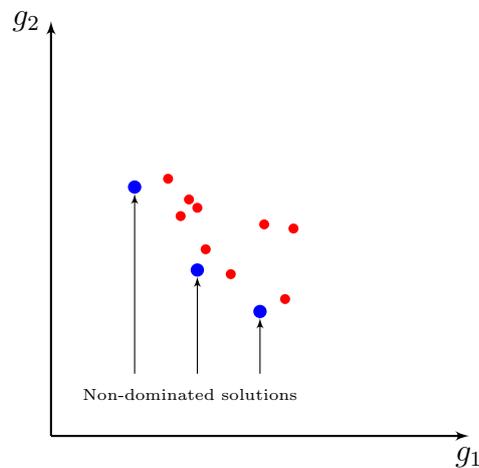


Figure 8.5: Non-dominated solutions in the Pareto-optimal set of solutions.

[Suman & Kumar \(2006\)](#) discuss several techniques that can be applied to modify the single objective simulated annealing algorithm for application on multi-objective problems. For the purpose of this study, **Multi-objective simulated annealing using Pareto-domination-based acceptance criterion (PDMOSA)** was selected.

The basic steps in the PDMOSA algorithm for a problem having  $K$  objective functions and  $k$  decision variables are summarised in algorithm 2. Note that for the purposes of this study, steps 4 and 6 have been modified to include the selection of a “best solution so far” and the periodic restart of the algorithm at this solution in particular (as opposed to any of the other Pareto-optimal solutions as proposed by [Suman & Kumar \(2006\)](#)). The modifications to the algorithm are emphasised in algorithm 2. These modifications were made because of the upfront knowledge regarding the nature of the application of model output – the model

### 8.3 Training the neural network

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must provide a single output value for each of the two output variables: cost and schedule contingency percentage due to systemic risks. The error pertaining to the model's evaluation of each of these output variables must be minimised in a way that weighs these errors equally, and does not consider a solution that provides a very low error level in one variable at the cost of a large increase in the error level of the other variable, as desirable. To achieve this, the euclidian distance from the origin to the solution vector is evaluated to determine whether the solution is the best solution so far (the solution with the shortest euclidian distance from the origin so far).

A proportional annealing schedule of the form  $\text{Temp}(i + 1) = \zeta \text{Temp}(i)$  is employed (where  $i$  refers to the number of times the temperature has been reduced in a certain annealing cycle). A constant cooling factor  $\zeta$  is used to reduce the temperature parameter. Values of  $\zeta$  normally vary between 0.80 and 0.99 as a proportional annealing schedule does not lead to equilibrium at low temperature if the cooling is too rapid (the cooling factor is too small) (Suman & Kumar, 2006). A  $\zeta$  value of 0.9 was chosen as proposed by Ludermir *et al.* (2006).

A proportional cooling schedule causes the transition probability to be high at the beginning of the search with a high chance of escaping local minima, and low at the end of the search with a low chance of escaping local minima (Azizi & Zolfaghari, 2004). This may not lead to a near optimal solution if some local minima are encountered at a relatively low temperature toward the end of the search. For this reason, reannealing (increase of temperature parameter in SA algorithm) will be periodically performed when the SA algorithm starts to converge to ensure that the entire solution space is searched, and a local minimum is not passed off as a global minimum (Treadgold & Gedeon, 1998). This is also a change to the PDMOSA algorithm, as emphasised in step seven of algorithm 2.

Having discussed both the BP and SA algorithm, the following section will provide an overview of neural network model logic, including the selection of parameter values for the BP and SA algorithms.

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### 8.3 Training the neural network

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**Algorithm 2** : Simulated annealing algorithm for a multi-objective function.

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- 1: Start with randomly generated initial solution vector,  $X$  (a  $k \times 1$  vector representing  $k$  decision variables), evaluate all objective functions and put them into a set of potentially Pareto-optimal solutions.
  - 2: Give a random perturbation and generate a new solution vector,  $X_n$ , in the neighbourhood of the current solution vector,  $X$ . Re-evaluate the objective functions.
  - 3: Compare the generated solution with all potentially Pareto-optimal solutions (feasible as well as infeasible solutions) and update the set of potentially Pareto-optimal solutions, if necessary. (This solution set is used for the fitness calculation of each potential new solution.) If the solution is potentially Pareto-optimal (non-dominated), accept it with a probability of 100% and proceed to Step 6. If the solution is not potentially Pareto-optimal, proceed to step 4.
  - 4: Accept the generated solution vector as the current solution vector with a probability given by  $p = e^{(-\Delta s' / \text{Temp})}$  where  $\Delta s' = S'_{i-1, \text{current}} - S'_{i, \text{generated}}$ , and where  $S'_{i, \text{generated}}$  is the Pareto-domination-based fitness of the generated solution at iteration number  $i$ .  $S'_{i-1, \text{current}}$  is the Pareto-domination-based fitness of current solution at iteration number  $i - 1$ . The fitness of the current solution at iteration number  $i$  is calculated as  $S'_{i, \text{current}} = 1 + \text{the number of solutions from the potentially Pareto-optimal solutions set generated so far dominating the current solution at iteration number } i$ . This means that the better solutions have lower fitness values and fitness has to be minimised. If the generated solution is accepted, take it as the current solution vector by setting  $X = X_n$ . **Evaluate whether  $X$  is the best solution so far. This is done by calculating the euclidian distance of the current solution vector  $X$  from the origin and comparing it to the previous best solution vector's euclidian distance from the origin.** If the generated solution vector is accepted, go to Step 6, else go to Step 5.
  - 5: If the generated solution vector is not accepted, retain the earlier solution vector as the current solution vector and go to Step 6.
  - 6: Periodically, restart with **the best solution so far as determined in Step 4**.
  - 7: Reduce the temperature periodically according to the annealing schedule, **and increase the temperature periodically according to the reannealing schedule**.
  - 8: Repeat Steps 2–7 until a predefined number of iterations is carried out or other stopping criteria are reached and take out a set of feasible Pareto-optimal solutions from the Pareto-optimal solution set.
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## 8.4 Overview of model logic

Having decided on the structure of the neural network architecture and the algorithm to be used during network training, a brief overview of model logic will be given. The main steps in the overall logical structure of the model, including parameters to be defined, are outlined in figure 8.6. Note that these parameters need to be set for the purpose of training the network during the study – users of the contingency estimation tool would utilise the trained network, and therefore would not need to set these parameters.

### 8.4.1 Create neural network

The neural network is created with the number of hidden nodes  $L$  specified by the developer (identified as between two and 16 for the purposes of this study – see subsection 8.2.3), number of input nodes  $R = 6$  (as will be explained in the scenario analysis of section 10.1) and number of output nodes  $T = 2$ .

The bias weights of the hidden and output layer bias connections are initialised to zero, while the weights of the remaining connections are initialised according to an interval heuristic proposed by Glorot (2010), and described by

$$W_{ij} \sim U \left[ -\frac{1}{\sqrt{u}}, \frac{1}{\sqrt{u}} \right] \quad (8.11)$$

where  $u$  is the number of nodes in the previous layer and  $U[-j, j]$  is the uniform distribution in the interval  $[-j, j]$ .

The purpose of this initialisation choice is to ensure that the initial set of weights does not cause the activation function values of hidden and output nodes to enter the asymptotic region prematurely, as this could lead to *saturation* of the network. Saturation refers to a problem that occurs if the network output is pushed towards its extremes at some point before model convergence is reached, so that the derivative is too small to make further significant weight changes in the case where the BP algorithm is applied, and in general the weights themselves take on arbitrarily large values. This causes the network to be “paralysed”, making further training improbable, and often stopping the search in an incorrect local minimum (Craven, 1997).

8.4 Overview of model logic

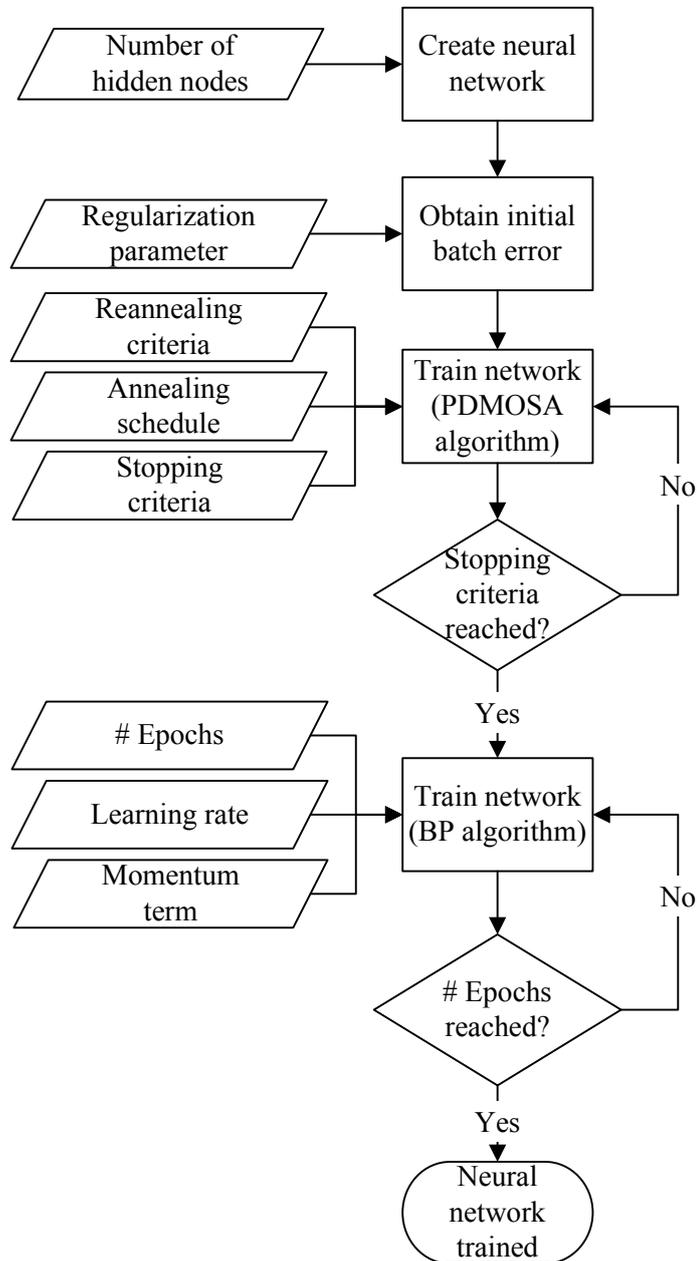


Figure 8.6: Overview of neural network model logic.

After creation of the neural network structure and initialisation of all relevant weights and bias values, the model is run through an initial epoch to obtain the

initial batch RMSP (root mean square percentage) errors as described in the following subsection.

#### 8.4.2 Run through initial epoch and obtain initial batch root mean square percentage errors

An epoch is run using the random initial weights to determine the initial batch root mean square percentage errors. In this and all other instances where the model calculates the batch root mean square percentage error or performance error  $\text{RMSP}_t$  for output node  $t$  as

$$\text{RMSP}_t = \sqrt{\frac{\left(\frac{e_t}{D_t}\right)}{\text{TP}}} \times 100 \quad (8.12)$$

the addition of a term denoting a *complexity penalty*  $E_c(\mathbf{w})$  is added as proposed by Haykin (1999) to determine the total error of the relevant output node as

$$E_t(\mathbf{w}) = \text{RMSP}_t(\mathbf{w}) + \lambda E_c(\mathbf{w}). \quad (8.13)$$

The purpose of adding this complexity penalty term is to discourage weights from assuming arbitrarily large values which lead to model saturation, and to encourage weights that do not have a large influence on the model (excess weights) to assume small values. This process, termed *complexity regularisation*, also prevents excess weights (connections) from causing the model to overfit the data to produce a slight reduction in the training error. If not avoided, this would lead to poor generalisation, where the model does not perform well with input patterns it has not seen before despite low training errors.

The performance error is dependent on the model and the input data, and is often calculated across all output nodes simultaneously (Haykin, 1999). In this study the performance error is treated as a two dimensional vector to enable the search for a multi-objective solution that does not sacrifice accuracy in one model outcome to obtain accuracy in another.

The complexity penalty is calculated as the squared norm of the weight vector,  $E_c(\mathbf{w}) = \|\mathbf{w}\|^2 = \sum_{i \in W_{total}} w_i^2$ , where  $W_{total}$  refers to all the synaptic weights in the network. This approach is proposed in the *weight-decay procedure* described

## 8.4 Overview of model logic

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by Haykin (1999). Before being added to the total error, the complexity penalty term is scaled by a regularisation parameter  $\lambda$  as indicated in (8.13), which represents the relative importance of the complexity penalty term. By comparing model behaviour when setting  $\lambda$  to 0.1, 0.01, and 0.001 respectively, 0.001 was chosen as a suitable value for the regularisation parameter that ensures complexity regularisation while keeping contributions to the total error value smaller than  $1 \times 10^{-4}$ .

Having run through the initial epoch to determine initial values for  $\text{RMSP}_1$  and  $\text{RMSP}_2$ , the network can be trained using the PDMOSA algorithm.

### 8.4.3 Train network with the PDMOSA algorithm

The network is trained using the PDMOSA algorithm as set out in algorithm 2, with the initial RMSP errors for cost ( $\text{RMSP}_1$ ) and duration ( $\text{RMSP}_2$ ) determined in the previous step as initial solution vector. A starting temperature of 10 was selected corresponding to the magnitudes of the objective function outputs being evaluated, as upon inspection of the success rate, this was found to be the temperature at which the initial average probability of acceptance is between 0.5 and 0.95 (Suman & Kumar, 2006).

Other PDMOSA parameters prescribing the movement of the model were also determined according to observations of the model. After a maximum of 10 successes or 100 attempts within a temperature, the model evaluates all parameters to decide whether it should terminate the algorithm, increase the temperature (reanneal) or decrease the temperature according to the cooling schedule.

If reannealing has occurred at least four times and *any* of the following criteria is reached, the model is stopped:

- The temperature is smaller than the lowest allowable temperature (chosen as 0.5)
- The number of consecutive rejections exceeds the allowable number of consecutive rejections (chosen as 100)
- The best solution so far is revisited 10 consecutive times at a temperature larger than or equal to 81

## 8.4 Overview of model logic

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If these stopping criteria are not met, more than 300 attempts have been made within a certain temperature, and reannealing has occurred less than 10 times, the temperature is reset to its initial value. Otherwise the temperature is reduced using a proportional cooling schedule with  $\zeta = 0.9$ .

During the generation of a new random solution vector for evaluation using the PDMOSA algorithm, each vector element addition is divided by a scaling factor used to limit the size of the changes to the weights during the relevant epoch. Model observations showed that the best results are obtained when using a small scaling factor (allowing larger movement) during initial reannealing cycles, and increasing the scaling factor for later reannealing cycles. This enables the model to initially search a wider space, and then search more thoroughly within a certain space. For this reason, the following rule is applied regarding the scaling factor,  $s$ :

- $s = 10$  during the first two reannealing cycles
- $s = 50$  for the third reannealing cycle
- $s = 100$  during all remaining reannealing cycles

The variation of the scaling factor until the third reannealing cycle is also the reason behind the rule that the algorithm cannot be terminated until the fourth reannealing cycle is reached.

### 8.4.4 Train network with the backpropagation algorithm

After completion of the PDMOSA algorithm, the best solution so far  $S_{BSF}$  for  $RMSP_1$  and  $RMSP_2$  and corresponding network weights are provided as input to the BP algorithm, which conducts a final “fine-tune” search. A standard backpropagation algorithm with calculations, learning rate and momentum term as discussed and selected in subsection 8.3.2 is applied.

Having provided an overview of model logic and chosen parameters, the application of the model to a multi-objective test problem will be briefly described.

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## 8.5 Application of model to a multi-objective test problem

### 8.5 Application of model to a multi-objective test problem

Before applying the model to actual training data, it was applied to a multi-objective test problem with three input variables ( $x_1, x_2, x_3$ ) and two objective functions ( $g_1, g_2$ ) as outlined in table 8.1.

<i>MOP2</i>	$g_1(x) = 1 - \exp(-\sum_{i=1}^3(x_i - \frac{1}{\sqrt{3}}))$	$-4 \leq x_i \leq 4$
<i>(Min)</i>	$g_2(x) = 1 - \exp(-\sum_{i=1}^3(x_i + \frac{1}{\sqrt{3}}))$	$i = 1, 2, 3$

Table 8.1: Multi-objective test problem.

Parameters were adjusted as necessary by model observation. A 1000 random values were generated for each input variable, and model outputs were compared to desired outputs as calculated using the objective functions to determine training errors. A separate validation set consisting of 100 random values for each input variable and corresponding calculated outputs for the two objective functions were used to validate the trained neural network. Calculated training (TE) and validation (VE) errors for the two objective functions are shown in table 8.2. The ability to solve a complicated multi-objective test problem to within the region of the 10% validation error margin suggested by Heaton (2005) generated confidence that the developed model was ready to be applied to real-world data.

Objective function	TE(%)	VE(%)
$g_1$	5.420	10.697
$g_2$	8.299	10.382

Table 8.2: Neural network results – Multi-objective test problem.

### 8.6 Concluding remarks on chapter 8

This chapter provided a brief introduction to neural networks and the types of problems to which they can be applied. The architecture of the neural network to be applied in this study was chosen as a multilayer feedforward network with eight

## 8.6 Concluding remarks on chapter 8

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possible input nodes, between two and sixteen hidden nodes (to be determined from model results), and two output nodes. The hyperbolic tangent function was chosen as activation function, and a supervised training approach combining a multi-objective simulated annealing algorithm and the standard backpropagation algorithm was selected for model training. An overview of model logic was given, stating the chosen values for all model parameters. Finally, the model was applied to a multi-objective test problem to confirm readiness for application to real-world data.

The next chapter will discuss the process of gathering and preparing the neural network training data through historical information on completed projects, and interviews with project managers.

## CHAPTER 9

# OBTAINING NEURAL NETWORK TRAINING DATA

To enable training of the neural network model, a set of training patterns were obtained from historical data and interviews with project managers. Each training pattern is made up of multiple input values to “feed” the corresponding input nodes of the neural network, and two output values to be compared with the values generated by the neural network’s two output nodes during training.

Data regarding model input variables could be obtained directly from historical data, whereas the impact of systemic risks on cost and schedule growth as required for the two response variables were not explicitly available. To enable the distinction of cost and duration growth due to project-specific risks from cost and duration growth due to systemic risks, interviews were conducted with project managers to obtain the relevant data surrounding projects completed in the 2010/2011 and 2011/2012 financial years.

This chapter will describe the interview process, the processing of interview data to obtain training patterns for the neural network, and the confirmation of input data integrity.

### 9.1 Conducting the interviews

Interviews were conducted on a one-on-one basis with the project managers in question. The two main reasons for the choice of an individual interview setting,

## 9.1 Conducting the interviews

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are as follows:

1. Each interview was conducted regarding a specific set of projects overseen by the project manager in question, rather than being aimed at projects in general
2. Individual interviews prevent “groupthink”

As stated in chapter 6, a problem with the current contingency estimation method is the fact that it assumes all project managers are experts, and therefore able to adequately identify and estimate the impacts of potential project issues **before they occur**. By conducting interviews on completed projects rather than projects in early stages, the ability of the project manager to “guess” what will happen based on experience does not impact this part of the process – interview outputs are based on risks that have **already been realised**.

The description of preparation for the interviews and the interviews themselves will be grouped according to five key steps set out by [Kendall & Kendall \(2011\)](#):

1. Prepare and study background material
2. Establish interviewing objectives
3. Select the interview candidates
4. Prepare the interview candidates
5. Decide on question types and structure

The first four steps will be discussed concurrently, after which the selection of question types and structure will be addressed in a separate subsection. After this, interview outputs will be discussed.

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## 9.1 Conducting the interviews

### 9.1.1 Selecting and preparing interview material and candidates

The **main objective** of the interviews was established as follows: To gather data for neural network training by uncovering causes for project cost and duration growth on completed projects, thereby enabling the distinction of systemic and project-specific risk impact in these areas. The interviews were semi-structured: their objective was fixed, but there could be some variability in meeting those objectives. This allowed interviewees to expand upon their answers and guide parts of the interview.

A list of cause categories and corresponding primary causes contributing to project cost and duration growth was compiled for use during the interview process. This list, which was derived from past projects and refined through multiple workshops with experienced project managers, can be seen (divided into different cause categories) in tables [B.1](#) to [B.10](#) of Appendix B.

It was decided to limit the projects considered for study input to asset construction projects that were completed in the last two financial years, as Eskom has undergone many organisational changes in the last few years, and using data over a larger time span might not represent the current system. To obtain the list of projects on which the interviews would be based, minutes from monthly investment committee meetings *i.e.* National Investment Committee Level One (IC L1), and Regional Investment Committees Level Two and Three (RIC L2 and RIC L3), were consulted. Minutes from the 2010/2011 and 2011/2012 financial years were used to identify projects adhering to any one of the following criteria:

- ERA cost and time revision approval obtained
- ERA cost revision approval obtained
- ERA time revision approval obtained
- FRA approval obtained

As can be seen from these criteria, the focus was initially on projects that had been completed as well as projects that had reached execution stage. The reasoning behind this was the fact that projects that had come as far as the execution stage could already exhibit noteworthy cost and schedule delays linked

## 9.1 Conducting the interviews

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to systemic risks. After studying project data, it was decided that only projects where the asset had been energised and handed over to Operations and Maintenance, would be considered as input to the neural network. The reason for this is that if a project is still in the early stages of execution, it is not known which risks may still materialise, necessitating further project time and cost revisions. Therefore, assuming that the **latest** ERA revision (which may or may not be the **last** ERA revision) gives a full view of potential systemic risk impact on a project might cause the perspective of the study to be skewed when these projects are evaluated alongside fully completed projects. Note that this does not necessarily limit the study to the projects for which FRA approval had been obtained – in cases where the project itself was completed (constructed and energised), but still awaited FRA approval, the project data was incorporated into the study.

Electrification projects were excluded from the data set due to the high level of political influence involved in these projects. The environment in which these projects are executed is also fairly isolated when compared to other network asset construction projects – they, in essence, form a system of their own.

Once the list of projects to be included in the study had been finalised, cost and schedule data was retrieved from the project workflow system. This information was **studied** to ensure a high-level understanding of each project (scope, major issues, etc.) before the interview with the relevant project manager. The relevant **interview candidates were identified** as the 25 project managers that coordinated the projects in question. Interview candidates were **prepared** for the interview by a short face-to-face or telephonic discussion of what the interview would entail, and subsequent electronic scheduling of the interview at least five working days in advance. This allowed them time to think about the interview and its purpose. Data pertaining to the CRA stage, DRA stage, ERA stage (including ERA revisions if any) and FRA stage was compiled in a single printout for each project to afford the project manager a holistic view of project cost and duration movements throughout the project lifecycle.

The chosen interview structure and question types will be discussed in the following subsection.

## 9.1 Conducting the interviews

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### 9.1.2 Question types and structure

After showing the project manager the cost and schedule data for the related project and the list of causes linked to project cost and duration growth, the following questions were posed per project:

1. Which primary/root cause contributed to project cost growth and schedule delay from CRA approval to DRA approval? If more than one, to what extent did each primary/root cause contribute?
2. Which primary/root cause contributed to project cost growth and schedule delay from DRA approval to ERA approval? If more than one, to what extent did each primary/root cause contribute?
3. Which primary/root cause contributed to project cost growth and schedule delay from ERA approval to FRA approval (with all ERA revisions taken into account)? If more than one, to what extent did each primary/root cause contribute?
4. Is there anything we haven't touched on that you feel is important regarding the project in question?

The first three questions are **closed questions**, with a finite number of possible responses limited by the list of causes. The discussion of each project is concluded with an **open question** prompting further inputs if any were overlooked during the closed questions. While most project managers responded “No” to the open question, in some cases this question served to open the “proverbial floodgates” (Kendall & Kendall, 2011), leading to much new data being presented.

The structure of closed questions followed by an open question is classified as a **pyramid interview structure** (Kendall & Kendall, 2011). This structure is recommended in instances where the interviewee needs to warm up to the topic. This was assumed to be the case for these interviews, as the causes of project cost and duration growth are not always easy for a project manager to discuss (due to the perception that these things are caused by the project manager “letting things slip”). To further ensure that the project manager felt comfortable to reply openly and honestly to the posed questions, it was reiterated (as explained

## 9.1 Conducting the interviews

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when preparing the project manager for the interview) that interview data would be used to provide an overall view of risks often encountered in network asset construction projects in the study environment, and not to pinpoint the things that went wrong on individual projects for any other purpose.

Note that interviewees did not need to contribute whether the selected causes are systemic or not – the chosen cause itself was used to indicate this, as the list of causes was studied to determine which were to be categorised as systemic, and which as project-specific. This will be discussed in more detail in section 9.2.

### 9.1.3 Interview outputs

Of the 25 identified project managers, 22 project managers were interviewed, as one had been transferred to another province and was not available during the time period when the interviews were conducted, and two had left Eskom employment. Data from these 22 interviews provided the causes for project cost and duration growth from each project stage to the next for 89 completed projects. After removing the effect of project-specific and other causes from project cost and duration growth for each phase of the project, it was assumed that all remaining project cost and duration growth could be attributed to systemic risks, even if not explicitly linked to a systemic cause during the interview.

As in the study performed by [Pewdum \*et al.\* \(2009\)](#), more than one data pattern pertaining to each project was used for model input. The data for systemic risk impact on each phase of the project was summed as shown in table 9.1 to obtain the percentage impact of systemic risks on cost and duration growth from the phase in question to project completion. The two output values (cost and duration growth due to systemic risk) for each phase were then paired with the corresponding input values for that phase of the project to make up a training pattern. In this manner, three training patterns were obtained for each project, each one linked to a different point in the project lifecycle – the end of the pre-project planning stage (CRA form), concept stage (DRA form) and definition stage (ERA form), respectively. This approach is necessary as to use neural network modelling for contingency estimation at different phases of a project, estimate computations should be based on a set of factors that are evaluated dynamically at each phase.

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## 9.2 Processing the training data

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Cost/duration growth to be calculated	Phases to be summated		
	CRA to DRA	DRA to ERA	ERA to FRA
CRA to FRA	×	×	×
DRA to FRA		×	×
ERA to FRA			×

Table 9.1: Summation of interview outputs for cost and duration growth calculation.

The next section will provide a more detailed discussion on the classification of root causes as systemic or project-specific.

## 9.2 Processing the training data

As identified earlier in the study, all training data pertaining to the required outputs of the neural network must relate to systemic risks and not project-specific risks. Causes obtained from the interviews indicated what amount of cost and duration growth were accountable to systemic risks, project specific risks, and factors that should not be included in contingency estimation, respectively. The following assumptions regarding distinctions between these three categories were made:

- Supplier issues, where these were as a result of external issues in the supplier organisation (late delivery, financial troubles, etc.), are classified as project-specific as these are not internal to the project system
- High staff turnover and resulting inexperienced internal staff is taken as a systemic risk, as lack of proper training before handover of project / ineffective project handover to the next PC is an inherent risk in the project system
- Contingency should not include escalation, scope expansion or acts of God (refer to section 3.2), therefore such events were removed from the data
- The effects of project dependency were removed to enable the use of data regarding each project as independent inputs to the model: For example, a

## 9.2 Processing the training data

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delay was only taken into account on the project where the cause directly applied, and not on other projects that were delayed due to a “domino effect”

- The effects of outage constraints due to the Soccer World Cup were removed, as the cause is no longer part of the project system
- Extreme cases of human error that lead to disciplinary action, for example an individual in the Procurement department forgetting to order a long lead time material item leading to extensive delay, were not taken into account as contingency should not account for human error (refer to section 3.2)
- In Direct Customer projects, delays due to customer acceptance or any delays linked to actions by the customer were viewed as external to the project system and not included in the systemic risk analysis
- For the management of network outages (network “down-time”) that are often required for project construction/commissioning, there are several possibilities:
  - If the delay is due to the outage approval process itself, the cause is selected as “Process complexity” and classified as systemic
  - If the delay is due to an unforeseen event that makes the planned outage unattainable, and a second outage must be awaited, it is viewed as a project-specific occurrence (this is normally due to “Exceptionally inclement weather”, but can also occur for a number of other reasons, *e.g.* illness of operator)
  - If the delay is due to a “knock-on effect” when one of a series of planned outages for a project does not occur, delaying the dates on which the others can occur, the cause is selected as “Commissioning complexity” and classified as project-specific (the risk is common across many projects, but has a unique impact on each project)
  - If the delay is a result of a lack of planning or late notification of outage requirements by the project manager, the effect is removed from the data (human error)

## 9.2 Processing the training data

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- The effects of a lack of planning for the constructability of an asset is assumed to be linked to company culture, as the constructability review is a required step in the project process, and therefore classified as systemic
- Fluctuating material prices are viewed as external effects, while fluctuating internal resource prices are internal to the project system, and therefore classified as systemic
- Scope changes that will save costs in future are sometimes allowed late in the project lifecycle: The effects of this are considered as project-specific for the purpose of this study, but is something to take note of
- In some cases, projects are fast-tracked to alleviate extreme network pressure, and then taken through the project workflow and investment approval process as a “paper exercise” – these cases were removed from the data set

Removing the effect of scope expansion avoids the classical error of comparing apples and oranges (Flyvbjerg *et al.*, 2002): only the cost and schedule growth of the work pertaining to the original scope is considered throughout the project.

Upon investigation and during initial model runs, it was found that data relating to the pre-project planning stage of the project lifecycle contained levels of noise that made model application impractical due to large changes in the project cost estimation process and flexibility regarding project scope in that part of the project lifecycle. For this reason, only data from concept, definition and execution stages were used as project input.

The exclusion of pre-project planning data from model inputs does not compromise the usability of the model, as the first point in the project lifecycle where project contingency estimation is prescribed according to the IPRM process, is during the concept phase (refer to section 12.1).

Research by Flyvbjerg *et al.* (2002) suggests that project cost estimates are often purposefully underestimated for various reasons, especially in the public sector. For the purpose of this study the assumption is made that cost and duration estimates were not purposefully inflated or deflated at any point in the project lifecycle, and represent true estimates at the relevant point in time.

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## 9.3 Preparing the data for model input

The primary cause tables outlining the classification of primary causes as systemic or project-specific for each cause category based on the assumptions as discussed, are shown in tables B.1 to B.10 of Appendix B.

Having discussed the collection and processing of interview data, the next section will outline the further preparation of data for model input.

### 9.3 Preparing the data for model input

After interview data had been gathered and processed as discussed in the previous section, further data preparation had to be performed before model training could commence. This preparation, including the scaling of variables, use of indicator variables and removal of outlier training patterns will be discussed in the following subsections.

#### 9.3.1 Non-categorical and categorical input variables

Input variables for training data inputs comprised three non-categorical variables (project definition level, project cost, and project duration) and three categorical variables (business category, voltage category and job category). **Non-categorical** refers to the fact that the variables are measured on a numerical scale (Montgomery & Runger, 2003). **Categorical** refers to a variable that denotes a decision between different categories/levels, where one level should not be seen as superior to another – they cannot be organised sequentially along a numerical scale, as this would suggest a relative importance that does not exist. As with all function-mapping techniques, ANN models cannot interpret categorical variables that cannot be put in a progressive order as single input variables (Lhee *et al.*, 2012).

For non-categorical input variables, values were scaled between  $-1$  and  $1$  as described in (3.13) (refer to subsection 3.4.4.2). Categorical input variables were incorporated through **indicator variables**, where a categorical variable with  $h$  levels can be modelled by  $h - 1$  indicator variables as illustrated in table 9.2 for the voltage category example.  $I_{5i}$  denotes the  $i^{th}$  indicator variable representing the  $5^{th}$  neural network input risk driver (voltage category).

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### 9.3 Preparing the data for model input

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$I_{51}$	$I_{52}$	Represented voltage category
1	0	Subtransmission
0	1	Distribution
0	0	Reticulation

Table 9.2: Values of indicator variables representing different voltage categories.

As Electrification projects were excluded from the study, the remaining three business categories, three voltage categories and two job categories require two, two and one indicator variable(s), respectively. When added to the three non-categorical input variables, this accounts for **eight possible input variables** with which to train the neural network.

#### 9.3.2 Removal of outlier training patterns

Before model training could proceed, outlier data points needed to be removed (Hollmann *et al.*, 2009). Outlier analysis was not performed based on data pertaining to model input variables, as doing so would limit model relevance to, for example, projects below a certain cost. Training patterns corresponding to outlier data points in output variable data were removed to ensure that projects exhibiting systemic cost/duration growth that is “out of the ordinary” did not skew the neural network training process.

The respective data sets for cost and duration were analysed to determine the first, second and third quartiles for each data set. The first quartile,  $q1$ , represents a value that has approximately 25% of observations below it and 75% of observations above it. The second quartile,  $q2$ , is equal to the median, and has roughly 50% of the observations below its value. Finally, the third or upper quartile  $q3$  has approximately 75% of the observation below its value (Montgomery & Runger, 2003). These values for the cost and duration data sets are shown in table 9.3 and contained by “boxes” in the box plots of figure 9.1.

Outliers, depicted as “crosses” in figure 9.1, were determined as values larger than  $q3 + 1.5IQR$  or smaller than  $q1 - 1.5IQR$  as shown in table 9.3 and illustrated by the “whiskers” in figure 9.1, where IQR denotes the interquartile range calculated as  $IQR = q3 - q1$ .

9.3 Preparing the data for model input

Quartile	Systemic cost growth training patterns	Systemic duration growth training patterns
$q1 - 1.5IQR$	-0.17693	-0.33901
$q1$	0.00000	0.00453
$q2$	0.05213	0.09048
$q3$	0.11795	0.23356
$q3 + 1.5IQR$	0.29489	0.57710

Table 9.3: Cost and duration quartiles – Identification of outlier data patterns.

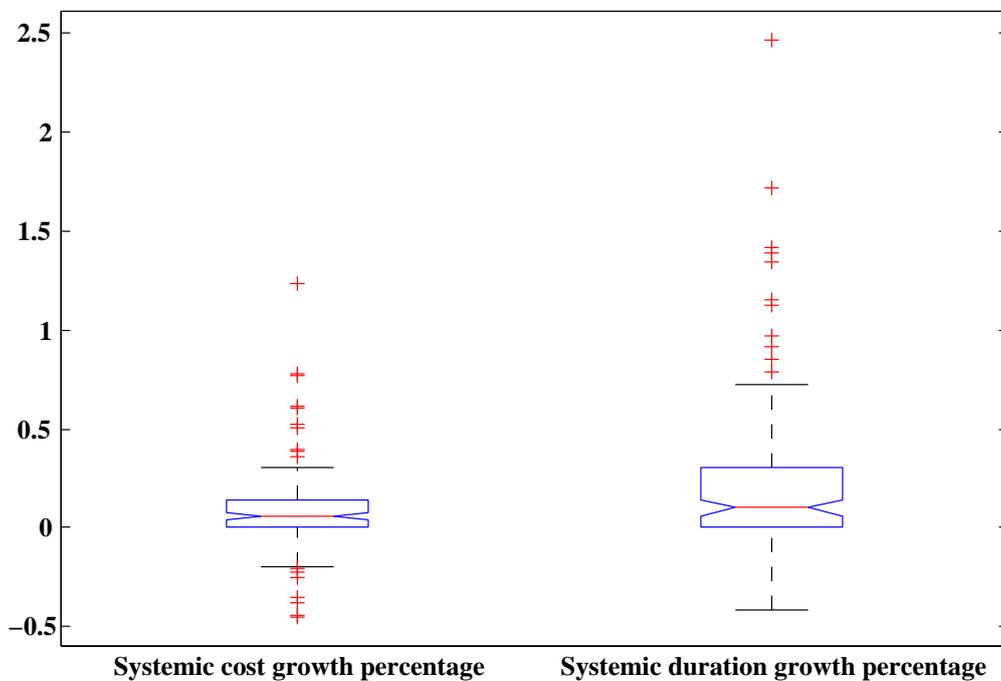


Figure 9.1: Box plots of output node training patterns.

After removing these outliers, 138 training patterns pertaining to 85 projects remained. These patterns were randomly divided into three groups (for training, validation and testing) using an 80:10:10 ratio. The first group is the training data set, which is used to train the neural network during the development phase. The second group is the validation data set, which is used to evaluate the performance of the ANN model during development, and to inform the selection of the best

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## 9.4 Benford analysis of training data

model between a number of competing models. The last group is the testing data set, which is used to conduct a “blind test” to enable a final assessment of the performance of the chosen model. This process will be discussed in more detail in the next chapter (chapter 10).

Having obtained, processed and further prepared training data, the neural network could be trained. However, before commencing training, a further analysis was conducted on data gathered through the interview process in the form of the application of Benford’s Law to ensure data integrity, as will be discussed in the following subsection.

### 9.4 Benford analysis of training data

A nonzero base-ten integer starts with some digit other than zero (a digit from one to nine). It might be expected that for a random data set it would be equally probable that a data element’s leading digit would be one as that it would be five, or any other number. This would amount to an equal probability of roughly 11% of a given data element starting with any one of the possible nine leading digits. Benford’s Law states that this is not the case, and that in a random data set, about 30% of the random numbers would start with a one, 18% of the numbers would begin with a two, and so forth, down to less than 5% of numbers starting with nine (Tichenor & Davis, 2008). This relationship is formalised with

$$p = \frac{1 + \frac{1}{ld}}{BF} \quad (9.1)$$

where  $p$  denotes the probability of a number having the leading digit  $ld$  in a data set of size  $BF$ . This law can be practically applied to test whether data provided by human input is truly random, or whether the data is intentionally skewed towards “seemingly average” values that are perceived to “sound good” (in which case, for example, a large percentage of numbers with five as leading digit could be expected).

As data surrounding percentage project cost and duration growth due to systemic risks were obtained through human input (interviews), the frequency of different leading digits for all nonzero entries in these data sets were compared

### 9.4 Benford analysis of training data

to Benford's Law to confirm data admissibility. As illustrated in figure 9.2, frequencies of leading digits correspond strongly with that expected according to Benford's Law, providing confidence in data integrity.

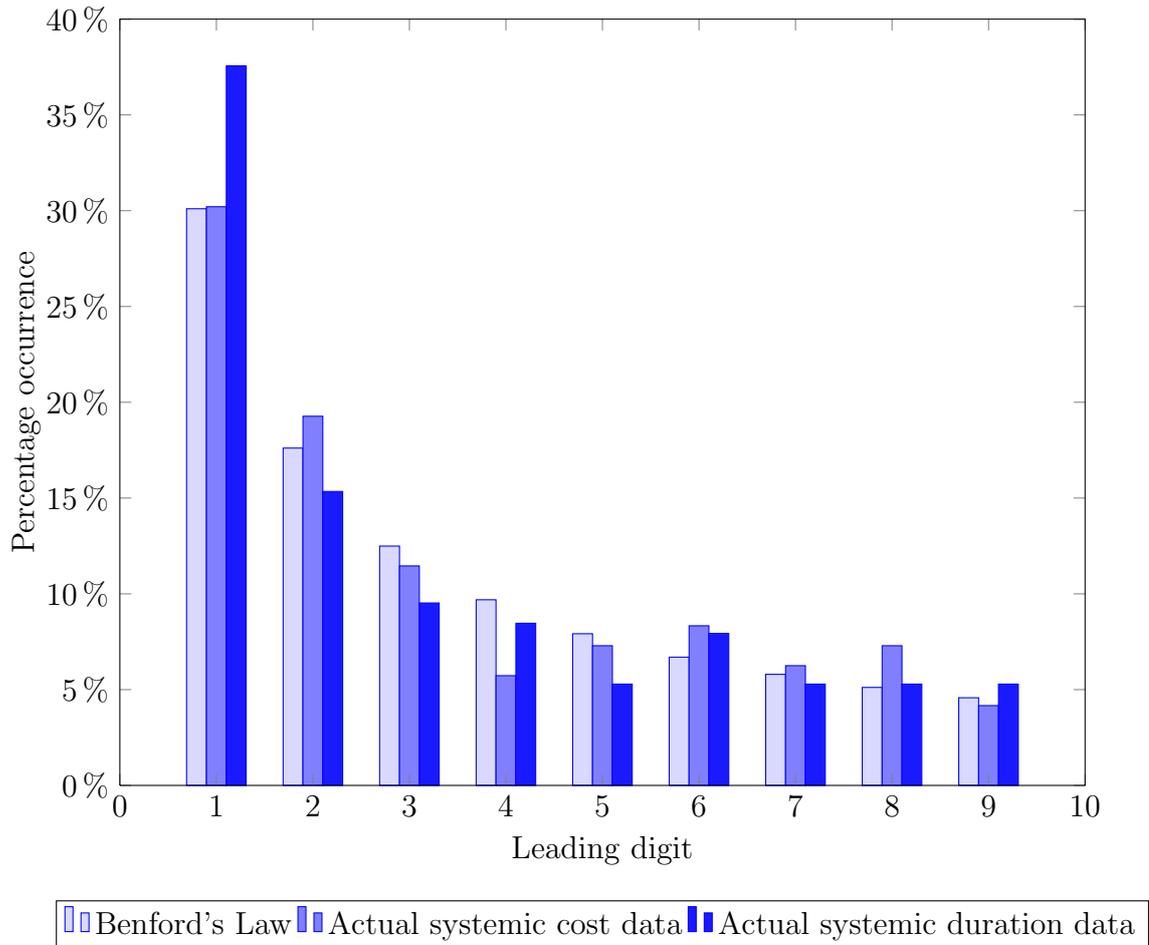


Figure 9.2: Leading digits of interview outputs for project cost and duration growth due to systemic risks.

To ascertain the goodness of fit of leading digit frequencies for cost and duration data with the distribution of leading digit frequencies according to Benford's Law, a chi-squared goodness-of-fit test was performed on the data. The null hypothesis statement  $H_0$  and alternative hypothesis statement  $H_1$  can be defined as follows:

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## 9.5 Concluding remarks on chapter 9

- $H_0$ : The form of the leading digit frequency distribution for interview data follows the Benford's Law frequency distribution
- $H_1$ : The form of the leading digit frequency distribution for interview data does not follow the Benford's Law frequency distribution

The value of the chi-squared test statistic was determined by

$$\chi_0^2 = \sum_{i=1}^h \frac{(\text{FO}_i - \text{FE}_i)^2}{\text{FE}_i} \quad (9.2)$$

where  $h$  is the number of bins or class intervals in the frequency histogram that BF observations are arranged in,  $\text{FO}_i$  is the observed frequency of the  $i^{\text{th}}$  class interval, and  $\text{FE}_i$  is the expected frequency of the  $i^{\text{th}}$  class interval (Montgomery & Runger, 2003). For calculations regarding the test statistic, the frequency count for each of the nine bins (leading digit 1 to 9) in cost and duration data was used rather than the frequency percentages as illustrated in figure 9.2, as a minimum value of five is suggested for expected frequencies. This serves to ensure that the test statistic reflects the departure of observed frequencies from expected frequencies rather than being skewed by the small magnitude of the expected frequencies themselves. To obtain values for  $\text{FE}_i$ , the calculated frequency percentages as per Benford's Law were multiplied by the total number of observations  $BF$ .

In this way, the values of the test statistic  $\chi_0^2$  were calculated as 6.51 and 8.06 for cost and duration data sets, respectively. The hypothesis  $H_0$  that the leading digits in the data sets follow Benford's frequency distribution cannot be rejected as the calculated test statistics are below  $\chi_{\alpha, h-\text{par}-1} = \chi_{0.05, 8} = 15.51$ , where  $\text{par}$  represents the number of parameters of the hypothesised distribution estimated from the data set (equal to zero in this case), and  $\alpha$  is the level of significance (chosen as 0.05).

## 9.5 Concluding remarks on chapter 9

As data regarding the impact of systemic risks on cost and schedule growth as required for the two response variables of the ANN model were not explicitly available, interviews were conducted to separate systemic risk impacts from

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## 9.5 Concluding remarks on chapter 9

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project-specific and other impacts. Interview preparation, the selection of interview questions and a pyramid interview structure were discussed. Outputs from 22 interviews provided three data patterns for each of 89 completed Refurbishment, Strengthening and Direct Customer projects. After interview data had been gathered and processed to remove project-specific and other impacts, further data preparation had to be performed before model training could commence. These preparation steps, including the scaling of non-categorical variables, use of indicator variables to represent categorical variables, and removal of outlier training patterns were discussed. Having obtained, processed and further prepared training data, the neural network could now be trained. However, before commencing training, further analysis was conducted on data gathered through the interview process in the form of the application of Benford's Law to ensure data integrity. Leading digit frequencies corresponded strongly to values expected according to Benford's Law for a random data set as confirmed through a chi-squared goodness-of-fit test, providing confidence that training could proceed with the gathered input data.

The following chapter will discuss neural network training results.

## CHAPTER 10

# NEURAL NETWORK RESULTS

A total of 267 neural network training data patterns were collected from project data and related interviews regarding 89 network asset construction projects completed in the 2010/2011 and 2011/2012 financial years. Through analysis and processing of available input data as described in chapter 9, a final input data set was identified containing 135 training patterns relating to 85 projects. This data set was divided into three groups: training, validation and testing.

The construction and comparison of model scenarios regarding possible combinations of model input variables and number of hidden nodes, will be discussed. A scenario will be selected based on training and validation errors. The chosen scenario for model input will then be evaluated by considering the testing errors, the repeatability of the model over ten independent runs, and residual analysis of expected model outputs vs actual model outputs for the validation data set. Finally, the chosen model will be compared to a multiple linear regression model.

### 10.1 Choosing the best scenario

As discussed in subsection 9.3.1, there are eight possible input variables representing the six chosen risk drivers. More input variables require more training examples to reach a given accuracy (subsection 3.4.4.2). To ensure that the model is not unnecessarily complex, different scenarios using varying combinations of the

## 10.1 Choosing the best scenario

Definition level	Cost	Duration	Business category	Voltage category	Job category
×	×	×	×	×	×
×	×	×	×	×	
×	×	×		×	×
×	×	×	×		×
×	×	×			

Table 10.1: Possible systemic risk driver combinations.

Risk driver excluded	Input nodes	Evaluated number of hidden nodes			
Business category	6	12	9	6	2
Voltage category	6	12	9	6	2
Job category	7	14	10	6	2
All categorical	3	6	4	2	-
No exclusion	8	16	12	8	2

Table 10.2: Evaluation of number of hidden nodes for different risk driver scenarios.

six risk drivers for model input, were tested as shown in table 10.1. Definition level, project cost and project duration were identified as **key risk drivers** that would be present in all scenarios. Five scenarios were identified: one in which all risk drivers are present, one in which only the key risk drivers are present, and three in which each of the non-key risk drivers are left out in turn.

For each of the five scenarios, the varying number of input variables  $R$  presented to the model require a correspondingly varied number of hidden nodes,  $L$ , to be considered. Recalling the heuristics discussed in subsection 8.2.3, each scenario was evaluated at three to four “levels” of hidden nodes, as shown in table 10.2.

By comparing within each risk driver input scenario the results obtained for different numbers of hidden nodes, the best output for each scenario could be

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## 10.1 Choosing the best scenario

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obtained as displayed in table 10.3 with the corresponding number of hidden nodes for each scenario.

<b>Risk driver excluded</b>	<b>Hidden nodes</b>	$TE_{cost}$ (%)	$TE_{time}$ (%)	$VE_{cost}$ (%)	$VE_{time}$ (%)	<b>Accepted solutions</b>
Business category	9	7.6	14.2	6.2	13.9	2380
Voltage category	12	9.1	13.8	6.3	13.9	559
Job category	14	9.2	15.4	6.2	13.9	771
All categorical	6	8.3	15.2	6.3	13.9	790
No exclusion	12	7.9	13.0	7.8	15.8	2031

Table 10.3: Neural network results – Best output for each scenario.

The neural network scenario models were trained using 99 patterns relating to 67 projects, and applied to a validation data set including 9 projects composed of 18 data patterns. The validation set results were used to compare different model scenarios, and the chosen model was tested using the testing data set (18 patterns relating to 9 projects). This was modelled on the approach taken by [Pewdum \*et al.\* \(2009\)](#), who used data regarding two projects (and the 24 patterns pertaining to those projects) to validate a neural network trained using 49 projects (998 patterns).

The most suitable number of hidden nodes for each scenario was chosen based on validation error levels. In general, the results shown in table 10.3 were read at the point in the error curve where the average of the validation errors ( $VE_{cost}$  and  $VE_{time}$ ) were at a minimum. An unexpected side-effect of the use of a global optimisation method with varying step size in the first three reannealing cycles, was that error values were very erratic until the scaling factor  $s$  had reached its final value (see subsection 8.4.3). For all scenarios, the training algorithm step size and relative corresponding smoothing of the error curve was observed after approximately 450 accepted solutions, at which point the scaling factor is at its final value. For this reason, results were taken at the number of accepted solutions corresponding to the minimum validation error *after* the point at which 450 solutions had been accepted, had passed.

Figure 10.1 illustrates the training and validation errors of a scenario with seven input variables (job category excluded) and 14 hidden nodes. Erratic

## 10.1 Choosing the best scenario

movement of error levels is apparent until approximately 450 solutions have been accepted. Also, the “overfitting” phenomenon discussed in subsection 8.2.3 becomes apparent here, with validation errors steadily increasing as training errors continue to reduce – the improved fit of the model to training data occurs at the expense of the ability to respond well to new data (the validation set). A similar effect was seen with many of the scenarios at the maximum evaluated number of hidden nodes – low validation error levels are obtained early in the model run, when training errors are still high, and as training errors reduce, the validation errors increase. A lower number of hidden nodes caused the network to find the minimum validation error later in the model run, with lower corresponding training errors providing a better overall solution. However, when the number of hidden nodes are reduced too far, the model starts to “underfit”, exhibiting increased error levels as the number of hidden nodes is not sufficient to represent the level of complexity in the input-output relationships of the data set.

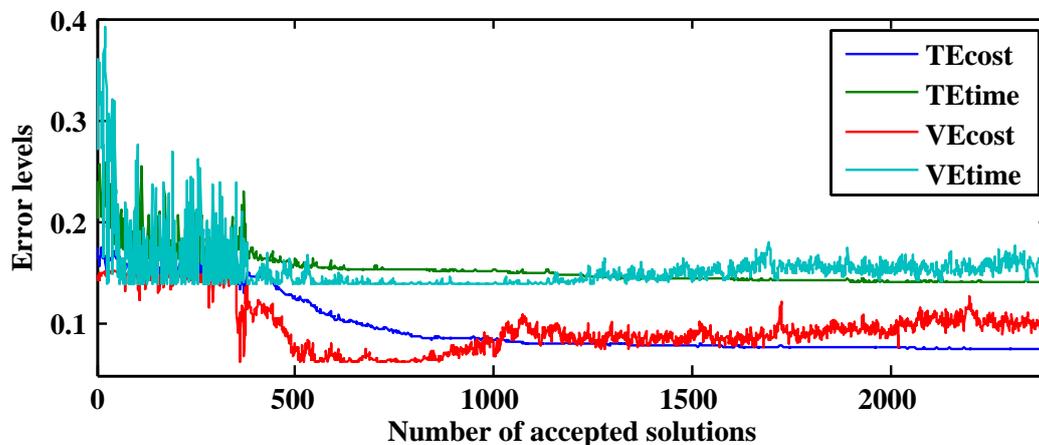


Figure 10.1: Example of validation error increase due to overfitting.

The **exclusion of the business category** risk driver and corresponding two indicator input variables (use of six input nodes representing five input risk drivers) with the use of **nine hidden nodes** was identified to be the best scenario from table 10.3. Validation error levels are rivalled by only one other scenario

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### 10.1 Choosing the best scenario

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<b>Hidden Nodes</b>	$TE_{\text{cost}}$ (%)	$TE_{\text{time}}$ (%)	$VE_{\text{cost}}$ (%)	$VE_{\text{time}}$ (%)
8	7.9	14.2	6.2	13.9
9	7.6	14.2	6.2	13.9
10	7.8	14.2	6.2	13.9

Table 10.4: Results for differing number of hidden nodes in the chosen scenario.

(exclusion of job category), and the training error levels were used as a “tie-breaker” to motivate the scenario choice. Similar model runs excluding business category as model input were subsequently performed with the number of hidden nodes as eight and ten, respectively, to ensure that nine is indeed the best number of hidden nodes to apply. Resulting outcomes as presented in table 10.4 are similar save for  $TE_{\text{cost}}$ , which is the lowest at nine hidden nodes. This confirms that the best performance is observed using nine hidden nodes.

The validation errors of the chosen scenario are considered reasonably acceptable, as the average validation error across the two output nodes is 10.1%, and an average batch validation error level of below 10% across all output nodes is generally considered good during network validation (Heaton, 2005). Also, error levels are comparable to those of similar studies in the project management field – the accuracy is not as high as in other fields of application due to high variability inherent in data related to the management of projects. The corresponding variance of the error for the chosen scenario was determined as  $8.296 \times 10^{-3}$  and  $2.103 \times 10^{-2}$  for cost and duration, and the corresponding testing errors were determined as 6.0% and 11.1% for cost and duration.

The result of the exclusion of business category as best scenario could point to the possibility that the business category input variable is correlated to one or more other input variables without representing much new information (as discussed in subsection 3.4.4.2).

Another possible way to analyse the relative contribution of input variables would be to conduct a **sensitivity analysis** where all the input training patterns of a certain input variable are either increased or decreased, and repeating this process for each input variable or different combinations of input variables.

## 10.1 Choosing the best scenario

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This would serve as means to determine the extent to which (and manner in which) each input variable influences model outputs. This is linked to the field of **variable importance** in neural networks, which pertains to measurements that indicate which input variables are closely associated with a chosen response variable (Auret, 2010).

In this study, the number of input variables on which a sensitivity analysis can be performed reduces to two due to the fixed nature of feasible values for project definition level and the three categorical input variables. Due to the limited nature that a sensitivity analysis would have in this study, and the fact that there is no reason to believe that either project cost or duration outweighs the other in terms of importance, the scenario analysis as described in section 10.1 will be used as primary indication of input variable effect on model output.

It should be noted that for the scenario in table 10.3 in which all of the categorical inputs were excluded (the network viewed all project types as similar), the error levels were still reasonable. This was not the case in a similar study conducted by Lhee *et al.* (2012), where categorical variables were not included as neural network input, but rather used as means to split data into groups – a separate network was trained for each project type. Chen & Hartman (2000) also report improved results of contingency estimation using a neural network when project data is grouped into two or more disjunct sets based on, for example, project cost range, and each set is used with a separate neural network. This difference in results could be attributed to the fact that while Lhee *et al.* (2012) and Chen & Hartman (2000) were searching for networks to model all project risks and estimate total contingency, the model in this study aims to approximate only the impact of systemic risks, which are more likely to follow a constant pattern throughout all project types as they apply to all projects within the system.

By considering the errors linked to training the network on all training sets simultaneously (as seen in table 10.3) as opposed to the error levels obtained when the network was trained using only data pertaining to Subtransmission projects, it was confirmed that the network was better able to approximate the input-output mapping relationship when presented with all the data at once. This could also be due to the fact that the advantage obtained by having a larger number of input training patterns outweighs that of considering data related to

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## 10.2 Evaluating the chosen scenario

different categorical variables, independently. Once again, this would seem to be the case when considering the relatively low impact of the model not being provided with categorical information at all.

The next section will evaluate the chosen input scenario in terms of repeatability and residual analysis.

### 10.2 Evaluating the chosen scenario

The **repeatability** of the model was confirmed by running the chosen model ten times with the same training and validation data. Error levels over the ten model runs are shown in figure 10.2, and the model seems to show sufficient repeatability – validation error results are fairly constant, and training error results, though not as fixed as validation error results, do not vary significantly. In eight out of the ten repetitions, average training error was below the average training error calculated at eight and ten hidden nodes (average of training error values shown in table 10.4), respectively.

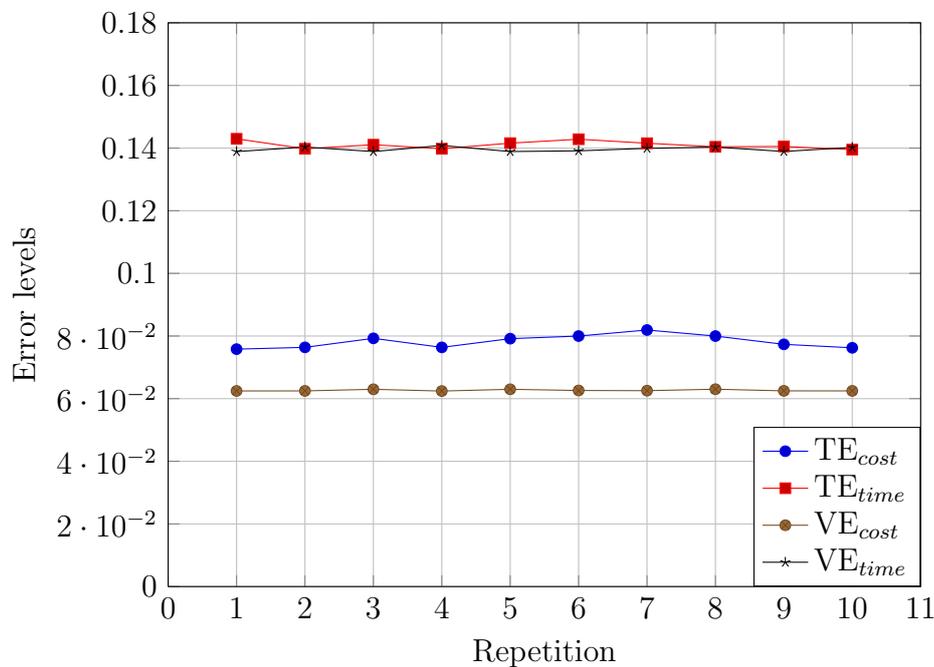


Figure 10.2: Model repeatability over ten independent runs for chosen scenario.

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## 10.2 Evaluating the chosen scenario

**Residual analysis**, which was performed on the **validation data set**, refers to any technique that uses the residuals to investigate the adequacy of an applied model (Montgomery & Runger, 2003). A residual is calculated as the difference between desired and actual model output (referred to as  $e_t(tp)$  in subsection 8.3.2 for output node  $t$  and training pattern  $tp$ ). Two widely used methods are applied to the validation set of the chosen scenario, *i.e.* a plot of the predicted vs desired values and plots of the residual values for cost and duration growth due to systemic risks vs different input variables.

The predicted vs desired values as shown in figure 10.3 correlate to the low calculated  $R^2$  values (0.222 for cost and 0.135 for duration) as will be discussed in more detail in section 10.3.

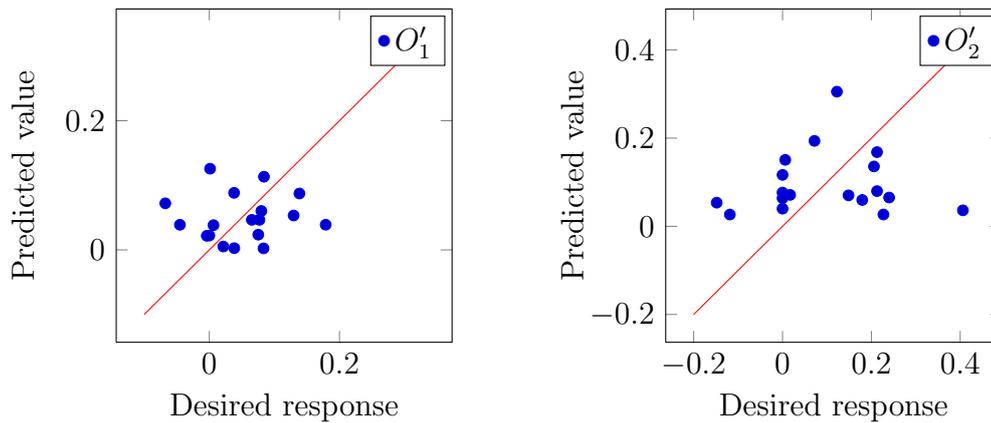


Figure 10.3: Predicted values vs desired response (cost and duration) for validation set of chosen model.

Plots depicting the relationship between input variables and residuals are shown for the **cost growth due to systemic risks** output variable in figure 10.4 and the **duration growth due to systemic risks** output variable in figure 10.5. Only the cost and duration input variables were analysed using this approach, as project definition level and the categorical input variables have certain predefined feasible values, limiting their display in this format to vertical scatter patterns that cannot be meaningfully interpreted as being homoscedastic or heteroscedastic.

10.2 Evaluating the chosen scenario

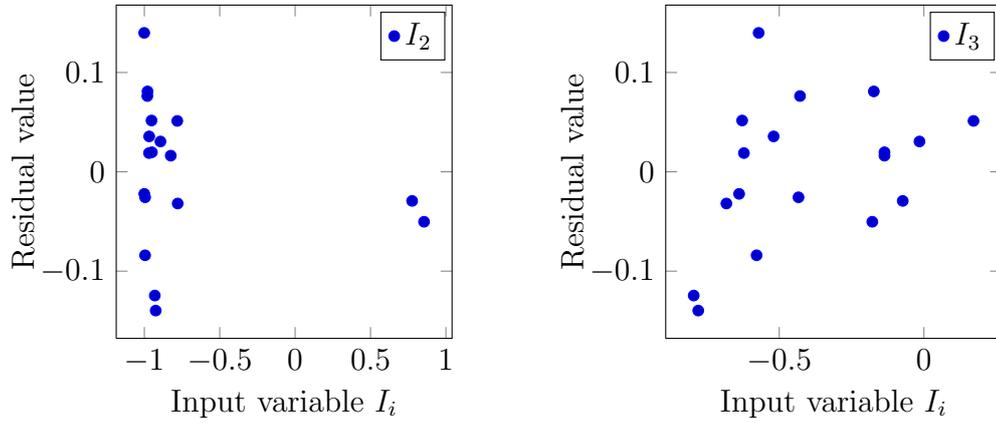


Figure 10.4: Cost residuals vs input variables for validation set of chosen model.

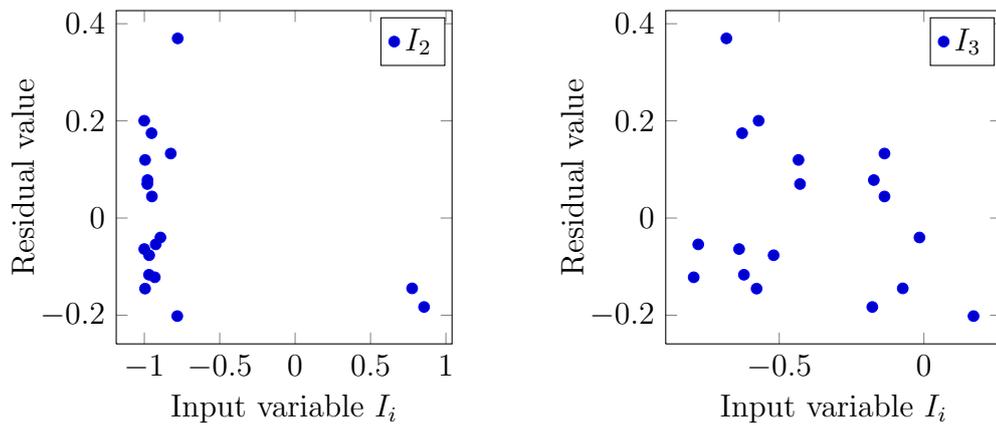


Figure 10.5: Duration residuals vs input variables for validation set of chosen model.

### 10.3 Comparison of chosen scenario to multiple linear regression

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**Homoscedasticity** refers to an equal variance of errors across all levels of the input variable, and **heteroscedasticity** refers to the case where the variance of errors differs at different values of the input variable (Osborne & Waters, 2002). Homoscedasticity implies that the model has fully exploited the relationship between a certain input and response variable – no relationship “remains” to be modelled.

Both residual plots with cost ( $I_2$ ) as input variable show a cluster of points to the left due to the fact that single large projects caused the scaled values (between  $-1$  and  $1$ ) of the majority of project cost inputs to be negative, making it more difficult to interpret results. The left-hand cluster in these graphs does exhibit properties of homoscedasticity. Where duration ( $I_3$ ) is the analysed input variable, both residual plots seem to indicate a lack of remaining relationships in the data, and therefore homoscedasticity.

Having evaluated the chosen scenario in terms of repeatability and residual analysis, the next section will focus on the comparison of the chosen scenario with multiple linear regression.

### 10.3 Comparison of chosen scenario to multiple linear regression

To enable the neural network to be objectively evaluated against a competing method, its performance was compared to that of a multiple linear regression (MLR) model using the chosen scenario (exclusion of business category as model input with nine hidden nodes). Table 10.5 summarises MLR coefficients for the intercept and model input variables, where the coefficients Voltage category 1 and Voltage category 2 correspond to the indicator variables of the categorical variable in question.

As with the ANN, the MLR model was trained using the training set, and then applied to the validation set. The corresponding results for both the ANN and the MLR model are presented in table 10.6.

The values predicted by the ANN show improved validation error levels and “fit” ( $R^2$ ) when compared to that of the MLR, as can be seen from the increased  $R^2$  values and the reduced error levels. However, the difference (especially with

## 10.4 Concluding remarks on chapter 10

Coefficients	Project cost growth	Project duration growth
Intercept	-0.00342	0.15382
Definition level	-0.02079	-0.03148
Cost	-0.04428	0.04142
Duration	0.00206	0.01716
Voltage category 1	0.03417	0.10441
Voltage category 2	0.04264	-0.08073
Job category	-0.00680	-0.03225

Table 10.5: Multiple linear regression (MLR) coefficients.

Method	$R^2_{\text{cost}}$	$R^2_{\text{time}}$	$VE_{\text{cost}}$	$VE_{\text{time}}$
MLR	0.189	0.126	8.3%	16.4%
ANN	0.222	0.135	6.2%	13.9%

Table 10.6: Comparison of ANN and MLR.

respect to  $R^2$ ) is not as significant as was anticipated. This could be attributed to the fact that the neural network does not yet have enough training patterns to address all possible scenarios, and results are expected to further outperform that of MLR as additional training patterns become available. Also, as [Chen & Hartman \(2000\)](#) and [Lhee \*et al.\* \(2012\)](#) report  $R^2$  values between 0.23 and 0.55 for similar neural network applications estimating total project contingency, the results are not seen as abnormally low.

## 10.4 Concluding remarks on chapter 10

The results of the neural network were presented for different scenarios regarding possible combinations of model input variables and number of hidden nodes to minimise training and validation errors. The chosen model scenario (exclusion of business category indicator variables with nine hidden nodes) was then evaluated by considering the repeatability of the model over ten independent runs, and residual analysis of expected model outputs vs actual model outputs for the validation data set. Finally, the chosen scenario was used to compare the ANN with a multiple linear regression approach to enable the objective evaluation of the neural network against a competing method. Findings showed that the ANN

#### 10.4 Concluding remarks on chapter 10

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outperforms the MLR approach. It is expected that ANN performance will be further improved as additional training patterns become available.

The following chapter will explain the integration of the project-specific and systemic contingency evaluation methods into a consolidated contingency estimation tool.

## CHAPTER 11

# INTEGRATION OF CONTINGENCY ESTIMATION METHODS: SYSTEMIC AND PROJECT-SPECIFIC

After the neural network had been trained, it could be applied to new projects to estimate contingency due to systemic risks alongside an estimation of contingency due to project-specific risks. This chapter will briefly provide a summary of the overall proposed approach. Thereafter, the project-specific contingency estimation method and the role of interview outputs regarding project-specific causes for cost and duration growth in this method, will be discussed. The practical integration of the two methods will be outlined alongside a description of model inputs, outputs and advantages. Finally, the research importance of the proposed integrated method will be briefly outlined.

### 11.1 Summary of proposed approach

The proposed integration of the two contingency estimation methods can be summarised as follows from discussion in chapter 7:

- To be able to address both systemic and project-specific risks, a **hybrid method** in line with that suggested by [Hollmann \(2010\)](#) is proposed, incorporating both a **neural network** and an **expected value analysis** tool

## 11.2 Project-specific contingency estimation

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- The logic behind the approach is as follows:
  - Neural network modelling is used on data from past projects to evaluate the impact of systemic risks that are not readily quantifiable by traditional risk analysis
  - The expected value method is used to evaluate the impact of project-specific risks that are suitable for traditional risk analysis
  - The simultaneous use of the two methods leverages their strengths
- The expected value method is preferred to range analysis as
  - It does not require that the team change its basic risk quantification methods between decision analysis and risk screening/control
  - It can provide a contingency estimate without using Monte-Carlo simulation
- The expected value analysis is performed in Microsoft Excel, and the neural network is programmed in Visual Basic to enable automated interaction between the two contingency estimation methods

With reference to this overview, the following sections will discuss project-specific contingency estimation and the integration of the two methods.

### 11.2 Project-specific contingency estimation

This section will describe the application of the expected value analysis method to determine project contingency pertaining to project-specific risks. Though the method does not make use of probability distributions describing each risk, expected value analysis is classified as a quantitative risk analysis method by the PMBOK (PMI®, 2008).

The following two subsections will describe the role of the risk register and interview results for project-specific risks in the estimation of project contingency linked to project-specific risks.

## 11.2 Project-specific contingency estimation

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### 11.2.1 The risk register

A Microsoft Excel-based risk register acts as departure point for the expected value analysis to estimate project contingency for project-specific risks. The fields (and corresponding terminology) of the risk register were chosen to align to the Eskom IRM methodology and IPRM process for standard and repeatable projects (and also align with PMBOK minimum requirements for the risk register as outlined in subsection 2.3.1.2), and include the following:

- Risk description
- Cause category
- Primary cause
- Delay
- Cost
- Likelihood (three-point estimate: most likely, pessimistic, optimistic)
- Treatment
- Treatment owner
- Treatment timing (immediacy)
- Treatment plan assurance
- Treatment plan assurance owner
- Linked to critical path (Y/N)
- Project risk score

A unique ID is assigned to each risk based on the populated work breakdown structure number and the position of the risk in the risk register (for example 2313A.1). The risk description format is standardised as per the IRM methodology in the following format: “[*Something occurs*], *Leading to...*”, with “*caused by*” and “*controlled by*” contained in separate fields. The register allows for the

## 11.2 Project-specific contingency estimation

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analysis of pre-mitigation and post-mitigation risks to assist cost-benefit analysis of proposed mitigation strategies, but contingency values are determined based on post-mitigation values. For each risk, information regarding mitigation activities must be provided as per the list of fields above.

The cause category and primary cause are selected per risk from drop-down lists, after which anticipated **pre-mitigation and post-mitigation** delay, cost, and likelihood are populated. A three-point estimate is allowed for likelihood even though this is not necessary in applications of the expected value method where Monte-Carlo simulation is not performed (refer to subsection 3.4.3.3). The purpose of this is to aid the project manager (facilitator) in a risk workshop setting where participants are hesitant to agree to a single value regarding risk probability, as probability is more difficult to assess than impact. The PERT equation,  $\frac{\text{optimistic}+4\times\text{mostlikely}+\text{pessimistic}}{6}$ , is used to determine the expected value of the three-point likelihood before expected value analysis calculations proceed.

The pre-mitigation and post-mitigation project risk scores are determined as per the IPRM likelihood and consequence criteria shown in table 5.1, and the risks are populated in both a pre-mitigation and post-mitigation risk matrix. An example of a populated pre-mitigation risk matrix is shown in figure 11.1, where each risk is identified by its unique ID as mentioned earlier.

Hereafter, the expected value contingency amount is determined as the sum of the expected values ( $probability \times impact$ ) for all risks. To ensure that the project-specific contingency value estimated in this fashion is not overly conservative, the method proposed by [Khamooshi & Cioffi \(2009\)](#) is applied, using the binomial distribution to estimate how many of the risks will occur. In the contingency estimation tool, this calculation is triggered by pressing a button labeled “Calculate contingency linked to expected number of risks”. The calculation steps performed by the tool to determine Contingency<sub>PS</sub> (contingency due to project-specific risks) are as follows:

1. Determine binomial distribution parameters
  - $p$  (probability of “success” in each trial) calculated as the average post-mitigation probability of risk occurrence
  - $n$  (number of trials) equal to the number of identified risks

11.2 Project-specific contingency estimation

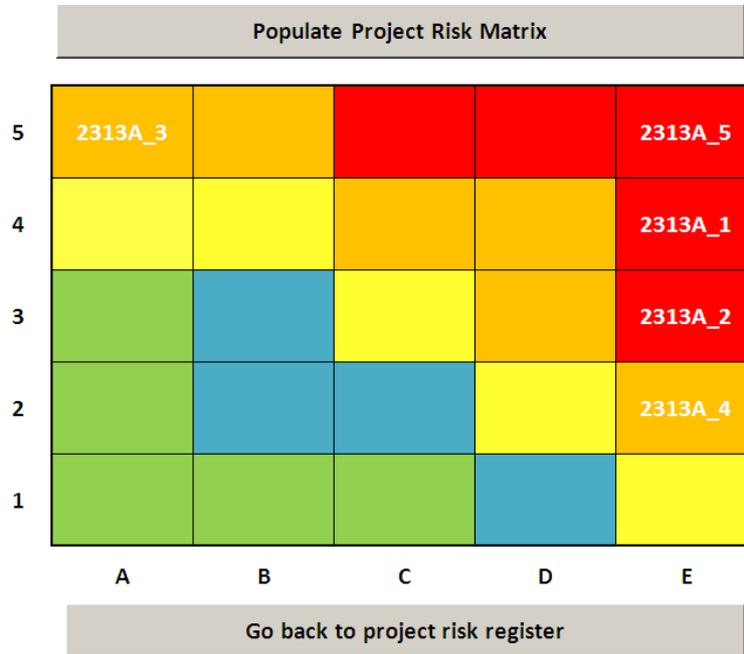


Figure 11.1: Pre-mitigation project risk matrix.

2. Determine the number of risks that the contingency budget/duration must account for – an integer value  $a$  is determined
3. Sort risks according to risk rating (largest to smallest)
4. Contingency<sub>PS</sub> =  $\sum_{i=1}^a \text{probability} \times \text{impact}$  for both cost and duration

Note that in the Excel-based tool, the integer quantity  $a$  is determined using (3.19) as provided by Khamooshi & Cioffi (2009) for the case where 20 or more risks are being considered at a 99% confidence level (the probabilistic maximum number of risks  $a$  will be exceeded only 1% of the time). The assumption is therefore that 20 or more risks will be identified for each project, which holds in project risk workshop sessions that have been attended by the author. Where less than 20 risks are identified, the equation will cause a larger number of anticipated risks  $a$  to be reflected than would have been read directly from the corresponding cumulative probability distribution at a 99% confidence level. This is a desirable effect, as the identification of a small number of risks might indicate that the

## 11.2 Project-specific contingency estimation

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project team in question is inexperienced with regards to risk identification, and therefore a more conservative reflection of the contingency amount makes sense.

The following subsection will explain how interview results regarding project-specific risks can be applied to aid in project-specific contingency estimation.

### 11.2.2 Interview results: Project-specific risks

Though the main objective of the interviews discussed in chapter 9 was to gather neural network training data regarding systemic risks, the format of the interviews enabled the distinction of systemic and project-specific risk impact on cost and schedule growth of completed projects. Another output of the interviews was therefore the frequency of identified project-specific causes on the 89 interview projects as shown in figure 11.2, as well as the extent to which the project was impacted by these risks.

To ensure that the knowledge obtained during these interviews does not go to waste, results regarding project-specific risks on previously completed projects will be populated in a Microsoft Access “lessons learned database”. This aligns with requirements of the PMBOK risk monitoring and control process (PMI®, 2008). The database is newly developed, and does not as yet contain any data. Database input fields include standard project information available for all interview projects. Further required fields align strongly to the information gathered during interviews, *i.e.* the cause of an issue on a project and the corresponding cost and schedule impact. The list of causes available for selection during population aligns to the list used during the interview process of this study.

The database also requires the input of a “corrective action” linked to the cause of each issue, which was not part of the interview scope. The corrective action field will therefore be left blank during population of the database using interview data, and filled out for projects completed in future. This should not interfere with the use of the database as a referencing tool accumulating causes and impacts that have affected similar past projects. By making this data available and enabling it to be continuously and easily updated, project-specific risk analysis and contingency estimation on new projects will become a more informed process.

## 11.2 Project-specific contingency estimation

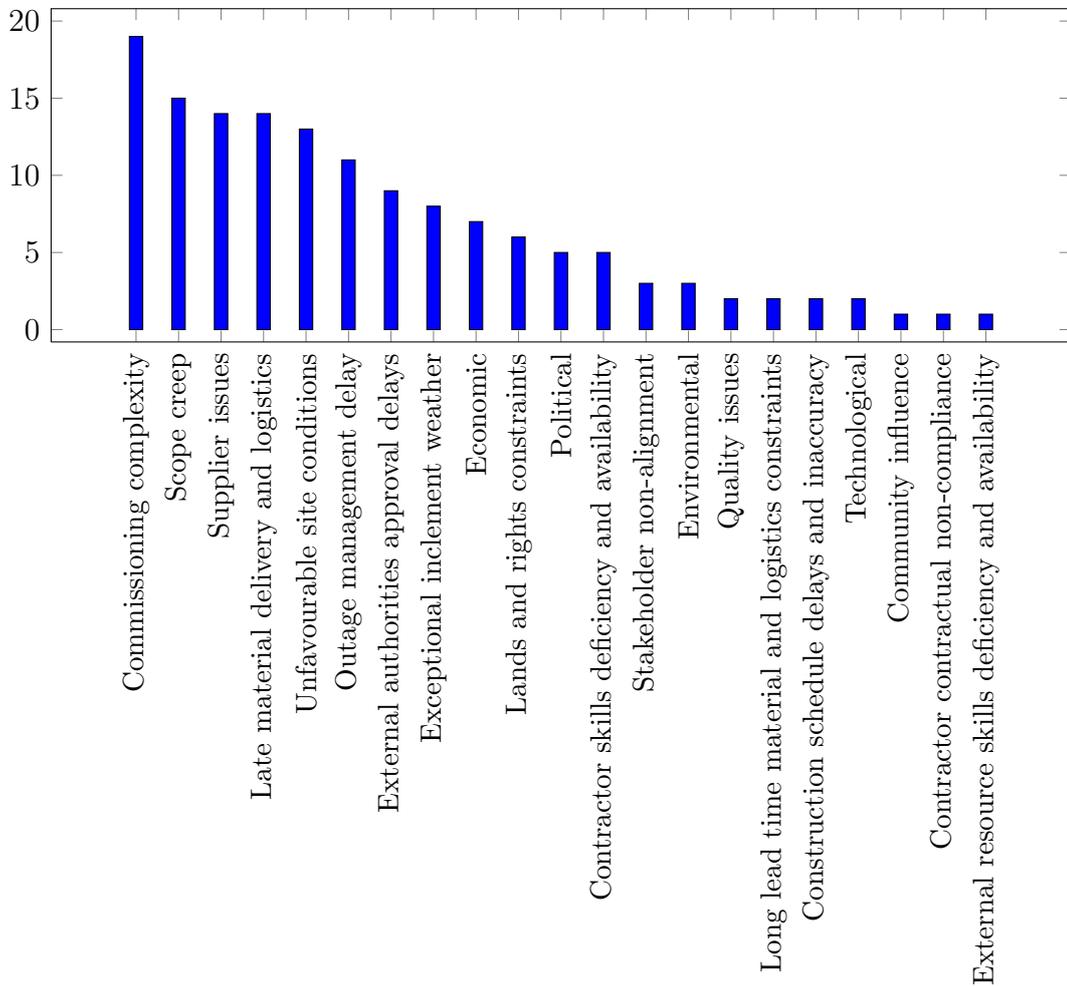


Figure 11.2: Interview data – Frequency of project-specific causes.

It should be noted that though the first-run population of the lessons learned database will consider only project-specific risk interview data, future population will prompt feedback on the impact of both systemic and project-specific causes on projects as they are completed. This will enable neural network model training data updates to be obtained directly from the database rather than by repeating the interview process. This staggered approach is preferred as if the impact of systemic causes were also initially populated in the lessons learned database, it may cause confusion regarding the absence of systemic risk causes in the root cause “drop-down” field of the risk register (this absence is discussed in section

### 11.3 Practical integration of the two methods

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11.3). Allowing the database to contain only project-specific information at first should enable users to become accustomed to the difference between systemic and project-specific causes and their applications with respect to the contingency estimation tool before being asked to populate systemic and project-specific cause information in the lessons learned database for future model input.

Having discussed the method used to determine contingency due to project-specific risks, the following subsection will discuss how the Excel-based risk register is integrated with the trained neural network to estimate the total contingency values for cost and schedule.

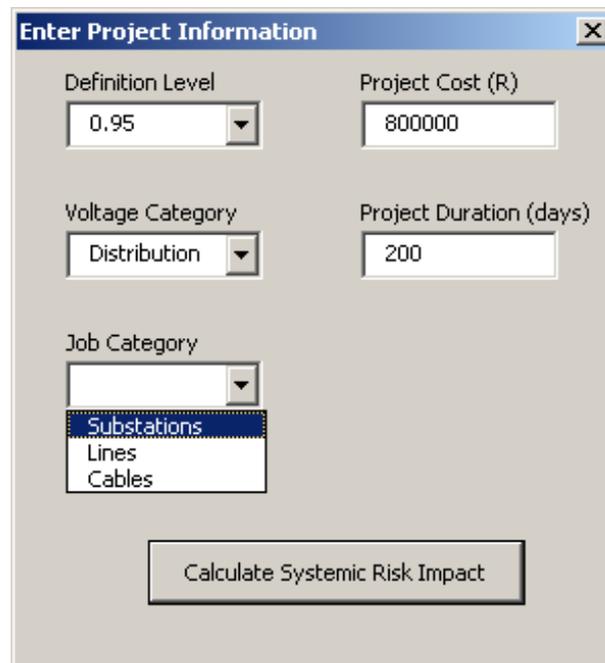
### 11.3 Practical integration of the two methods

While the neural network is trained, the set of connection weights linked to the lowest training and validation errors is stored for application in the contingency estimation tool. Upon opening the contingency estimation tool, the following steps are followed/executed:

1. User enters/selects values for input variables (definition level, cost, duration, voltage category, job category) in a userform as shown in figure 11.3
2. These values are sent as input to the trained neural network, which returns contingency cost and duration percentages representing systemic risk impact
3. Generated percentages are multiplied with project cost and duration (as per user input) respectively to obtain Rand-value of cost impact, and duration impact in days (converted to months in tool display)
4. Contingency<sub>SY</sub> (contingency due to systemic risks) cost and duration values are automatically entered as a “one-liner” (representing systemic risks) with 100% probability in the risk register
5. Contingency<sub>T</sub> (total contingency) is determined as follows: Contingency<sub>T</sub> = Contingency<sub>PS</sub> + Contingency<sub>SY</sub> for both cost and duration

### 11.3 Practical integration of the two methods

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The screenshot shows a dialog box titled "Enter Project Information" with a close button in the top right corner. The dialog contains the following fields:

- Definition Level:** A dropdown menu with the value "0.95".
- Project Cost (R):** A text input field containing "800000".
- Voltage Category:** A dropdown menu with the value "Distribution".
- Project Duration (days):** A text input field containing "200".
- Job Category:** A dropdown menu with a list of options: "Substations", "Lines", and "Cables". "Substations" is currently selected.

At the bottom center of the dialog is a button labeled "Calculate Systemic Risk Impact".

Figure 11.3: Userform – Populating project information.

Systemic risk causes are not available for selection during project-specific risk analysis. This serves to further reinforce the awareness that these risks should not be analysed, as they are already incorporated through neural network model output. However, project-specific cause categories and primary causes as determined in preparation for data interviews are available for selection. This aids a structured approach during risk identification and subsequently enables the identification of common causes across projects when risks are communicated to program and portfolio level as will be discussed in section 12.2.

The contingency estimation tool does not integrate automatically with the project schedule – the user must consult the project schedule to determine whether or not the identified risk affects the critical path, and indicate this by choosing “Yes” or “No” in the required field. The tool uses this as an indication whether or not the identified delay due to a certain risk should form part of the calculated overall duration contingency. The disadvantage remains that cost/schedule integration for time dependent costs are not explicit, and must be manually updated between the risk register and the project schedule. For this reason, a total

### 11.3 Practical integration of the two methods

duration distribution is not provided.

Finally, the total cost distribution is approximated by the assumption of a normal distribution with a standard deviation equal to the contingency value as proposed by Rothwell (2005). The budgeted project cost plus the estimated contingency amount for systemic and project-specific risks represents the mean total project cost, which for normally distributed data is equivalent to the median value (the point at which project cost overrun or underrun is equally likely) (Hollmann *et al.*, 2009). An example of the generated total cumulative cost distribution for a project with a R1,200,000.00 budget and proposed contingency value of R148,060.63 (as calculated by the tool) is shown in figure 11.4. The calculated contingency is reflected as the contingency cost leading to an equal probability of budget overrun and underrun.

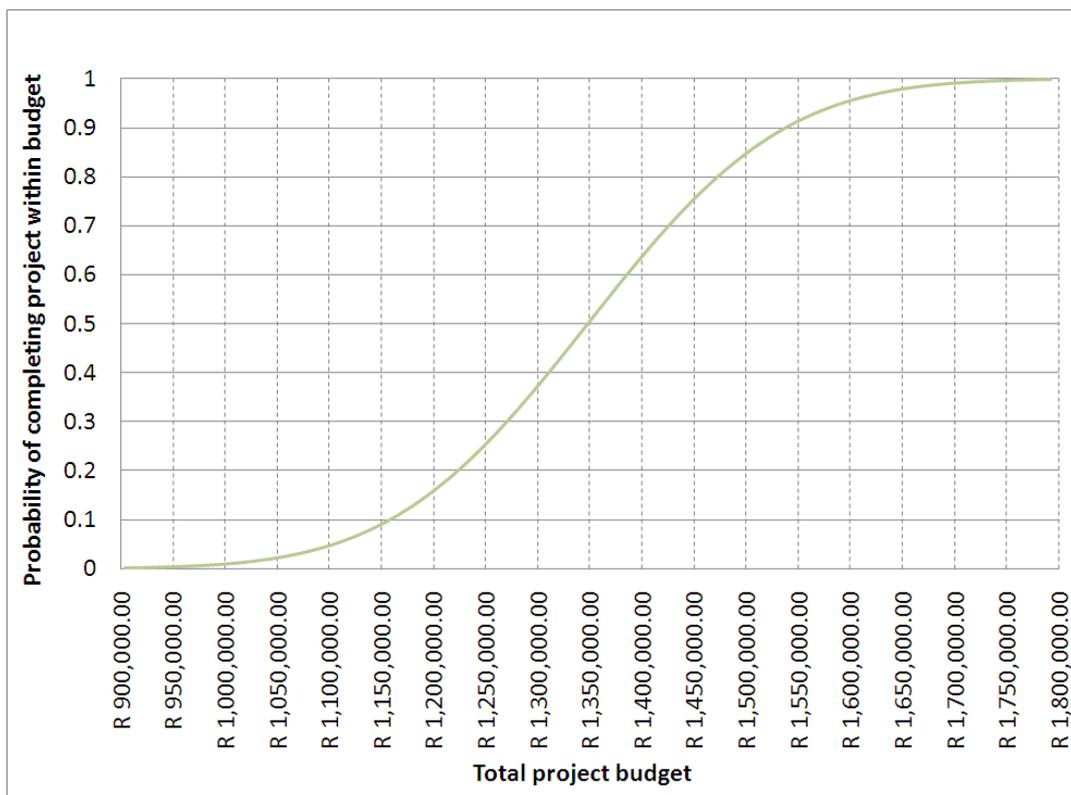


Figure 11.4: Total cumulative cost distribution.

### 11.3 Practical integration of the two methods

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It is proposed that all project cost contingencies be estimated at this 50/50 point (the median), as choosing additional allowance amounts corresponding to higher levels of certainty of completing the individual project within budget may lead to overallocation of funds on a program/portfolio level. In other words, an additional allowance value to further decrease the probability of budget overrun should only be added to the 50/50 contingency value in extreme circumstances. This does not correspond to a high risk appetite in the study environment, but rather to a simultaneous consideration of the risk of underspend on a portfolio level, and an accountability towards the proper management of public money.

The contingency estimation tool does not incorporate the method proposed by [Touran \(2007\)](#) for the management of contingency costs on portfolio level considered in chapter 7, as the assumption that the project budget will always be overrun (never underrun) was disproved during the data gathering interviews. Also, the main aim of the method proposed by [Touran \(2007\)](#) is to provide the confidence level at which the contingency should be read from the total project cost distribution, which is not necessary if the assumption is made that for all projects comprising the portfolio, contingency will be determined at the median point of the total cost distribution (equal probability of budget overrun and underrun).

Though the assignment of contingency to each project-specific risk is transparent, the same cannot be said for the assignment of contingency for systemic risks using the neural network. Neural networks are essentially “black boxes”, and their output cannot be explained. However, in the proposed tool the neural network is only applied to address risks which, by their nature, are hard to relate to specific budget/schedule items, and therefore difficult to describe in a risk register format. The disadvantage is therefore not seen as an impediment to the successful application of the tool.

For contingency fund/duration management purposes, project cost/duration growth can be covered by the systemic contingency amount/duration if linked to a systemic primary cause. In the case of project-specific risks, the contingency amount/duration as explicitly linked to the risk in question can be used to manage the application of contingency fund/duration. As discussed, the systemic contingency amount/duration is based on the level of project definition provided

## 11.4 Summary of tool inputs and outputs

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as model input, and is therefore dynamically evaluated at different points in the project lifecycle. The contingency fund/duration set aside for project-specific risks should also be updated as the project lifecycle progresses – some risks will no longer be applicable as the activities they are linked to are completed. Risks should not be deleted from the project risk register, but their probability should be set to zero if they are no longer a threat.

It should be noted that for larger projects where the necessary risk practitioner expertise is available, the output from the systemic risk model could be used as a one-liner input to a Monte-Carlo based project-specific risk analysis in a commercial software package (for example Primavera or @Risk). In Eskom, Primavera is currently applied for project risk management and contingency estimation on mega projects, so the procurement of licenses for the application of Primavera to larger standard projects (*e.g.* IC L1 projects, where the project value is larger than 35 million rands) is a possibility.

Having discussed the integration of the two methods, the following (and final) section of this chapter will summarise tool inputs and outputs.

### 11.4 Summary of tool inputs and outputs

A summary of contingency estimation tool inputs and outputs is provided in figure 11.5. Clear advantages of this method include the fact that the input drivers for systemic contingency estimation do not leave room for subjectivity, as is the case in some other neural network modelling applications for the estimation of project contingency. Also, by allowing the trained neural network to estimate contingency cost and duration due to systemic risks separately from the expected value analysis of project-specific risks, there is no need for the project team to attempt to analyse systemic risks, which due to their stochastic nature are not easy to predict or understand. By following this approach, systemic and project-specific risks are contained in a single tool providing contingency cost and duration output.

Another advantage of the proposed model vs a model where the contingency is calculated as direct output and the user does not analyse any risks, is that the necessity of user involvement prompts a thinking and debating process that

## 11.4 Summary of tool inputs and outputs

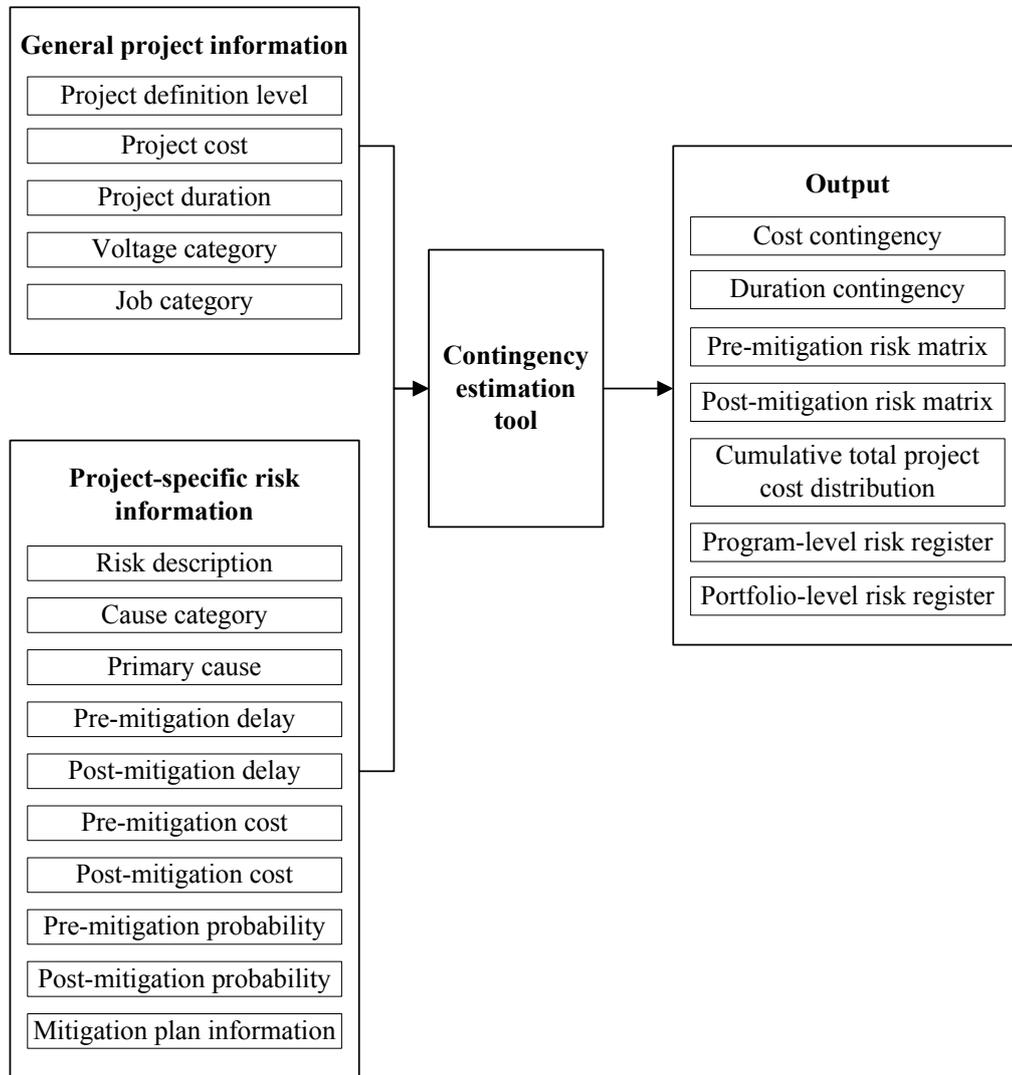


Figure 11.5: Inputs and outputs of the contingency estimation tool.

will be more likely to provide a full view of possible risks on a project. The phenomenon described as “when models turn on, brains turn off” is avoided.

Though the development of the tool focused on contingency estimation, the project risk management approach as defined in the IPRM process (Theron & Van Niekerk, 2012) was considered to ensure that:

- The contingency estimation tool aligns with requirements of the IPRM process

## 11.5 Research importance

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- The IPRM process includes points in the PLCM at which contingency estimation should be performed, and enforces the population of risk information in the “lessons learned database” on project completion (as will be discussed in section [12.1](#))

For this reason, inputs and outputs not directly aligned to the numerical calculation of contingency (such as *Mitigation information*, *Pre-mitigation and post-mitigation risk matrix* and *Program-level and portfolio-level risk registers* shown in figure [11.5](#)) were included in the contingency estimation tool.

### 11.5 Research importance

As stated by [Hollmann \(2010\)](#), no commercial contingency estimation tool incorporating a hybrid neural network model for systemic risk analysis and expected value model for project-specific risk analysis, currently exists. This was confirmed through further correspondence with [Hollmann \(2012\)](#) on the subject, and it was also learned that though he has developed models of this nature for private clients (of which the details remain confidential and unpublished), to his knowledge, no academic paper had been published on the development of such a tool.

The documentation of this study therefore fills a gap in the sphere of academic research that has not yet been addressed.

### 11.6 Concluding remarks on chapter 11

After a summary of the overall proposed approach addressing systemic and project-specific risks was given, the project-specific contingency estimation method was discussed, and the way in which interview outputs will be used to assist this approach was described. The practical integration of the two methods was discussed alongside a description of model inputs, outputs and advantages. Finally, the research importance of the proposed integrated method was briefly outlined.

The next chapter will focus on the integration of the contingency estimation tool with the Eskom PLCM and enterprise risk management process as per the IRM methodology.

## CHAPTER 12

# INTEGRATING THE CONTINGENCY ESTIMATION TOOL WITH THE PROJECT LIFECYCLE MODEL AND ENTERPRISE RISK MANAGEMENT

This chapter will examine the integration of the developed contingency estimation tool with two important structures in the Eskom environment: the project lifecycle model (PLCM) and the enterprise risk management process. Points in the PLCM at which the contingency estimation tool should be applied, are prescribed, alongside an explanation of why such a prescription is necessary. After this, the way in which contingency estimation tool outputs become reporting inputs to the enterprise risk management system, is described.

### **12.1 Timing of contingency estimation tool application within the project lifecycle model**

In the identification and analysis of risks, subjectivity should be reduced as far as possible. During the literature review of this study, it was found that the timing of the contingency estimation workshop, if not prescribed, is in itself a subjective decision which can significantly impact the outputs of the session

## 12.1 Timing of contingency estimation tool application within the project lifecycle model

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(section 2.5). For this reason, it was proposed that guidelines be set up as part of the IPRM process regarding the minimum points in the project lifecycle at which the proposed tool should be employed for contingency estimation in a project team workshop setting. These can be summarised as follows for the concept, definition and execution stages:

- **Concept stage**
  - After concept release approval: During the job planning meeting
  - Reviewed after technical evaluation of concept design
  
- **Definition stage**
  - After design release approval: During the detailed design planning meeting
  - Reviewed after completion of the detailed design, before execution release approval
  
- **Execution stage**
  - Monitor and review (monthly)

To further reduce the subjective decisions by the project manager that affect workshop outcomes, suggested workshop participants are outlined in the IPRM process. The latest version of the risk register and supporting documentation clarifying its contents (if necessary) should be circulated to all workshop participants a week in advance of the contingency estimation session to ensure that everyone has a chance to prepare for the session. Risks pertaining to project stages that have passed that have not realised, are not deleted from the risk register, but their probability is set to zero. In this way, the contingency estimation is only updated based on residual risks and newly identified (emergent) risks.

If necessary, the contingency values requested during the concept stage can be amended during the definition stage. The estimation of required contingency values should occur alongside monitoring of project budget and schedule contingencies that have already been expended (realised risks), if any, and presented to the relevant investment committee in this fashion. Once the execution stage is reached, focus should shift to monitoring expended contingency vs requested

## 12.1 Timing of contingency estimation tool application within the project lifecycle model

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contingency, as revision of the contingency values during this project stage is not advised.

These contingency estimation points in the project lifecycle are applicable to all standard and repeatable projects, and are included in each project's risk management plan, which should be drawn up at project initiation. Note that the structure and application of the risk management plan will not be discussed here as it is outside the scope of this study. The risk management plan structure as outlined in the Eskom PCM (Process Control Manual) for project risk management (Booth, 2012) (of which the IPRM process forms a supporting document) will be applied alongside the risk register.

An additional requirement was added to the IPRM process following this study to ensure that project risk information is populated in the lessons learned database during the finalisation stage of the project, to be employed during application of the contingency estimation tool as described in section 11.2.2. Data regarding the systemic risks of completed projects will also be used to update the neural network model semi-annually. In this way, the reference data used for both the estimation of systemic and project-specific contingency continues to increase.

From a macro level planning perspective (rolling and business plans), the current approach is that cost contingencies not be phased with the planned monthly/annual values per cost element, but rather linked to the project root element. However, current practice promotes the consideration of schedule contingencies during the phasing of costs in these macro level plans. This is not a consistent approach, and the recommendation is that project-specific cost contingencies, which are linked to individual risks, should indeed be phased according to a rough estimation of when they are expected to occur (at the "front end" of the activity to which the risk is linked). This reinforces the fact that planned contingency values are associated to specific identified risks, and are not funds/durations that can be completely expended in the course of the project, no matter what happens. As contingency costs linked to systemic risks cannot be easily phased in this way, it is proposed that they be planned on the project root element. Also, some project-specific risks are not linked to specific activities and could occur with

## 12.2 Integrating the contingency estimation tool with the enterprise risk management system

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equal probability at any point in the project – these should be treated similarly to systemic risks with respect to macro level planning.

Having considered the points in the project lifecycle at which the contingency estimation tool should be applied, the following section will consider the integration of the tool with the enterprise risk management system (CURA).

## 12.2 Integrating the contingency estimation tool with the enterprise risk management system

As discussed in chapter 5, enterprise risk management in Eskom Holdings SOC Ltd. is performed according to the IRM process. This process specifies that enterprise risks must be populated in the national enterprise risk management system, *i.e.* CURA. This system is not suited to the analysis of project risks for reasons stated in subsection 5.1.5.

On project level, risks are evaluated in Microsoft Excel using the proposed tool. The Excel tool will be available in SAP PPM (Portfolio and Project Management) as a downloadable template, and the latest version of the populated Excel-based risk register should be uploaded as an attachment into the relevant phase of the PLCM in SAP PPM .

Outside SAP PPM, risks are “rolled up” to program and portfolio level. The integration of the project risk register with program-level and portfolio-level risk registers was automated as part of the IPRM process for standard and repeatable projects. This aligns to guidelines regarding risk responsibilities as outlined by PRINCE2 (discussed in subsection 2.3.2). In these higher-level risk registers, risk ratings are calculated using more sensitive consequence criteria based on the impact of the risk in question on the program/portfolio as a whole. A summary view is provided of cost and duration at risk on each project, and frequency of risk causes throughout the entire program/portfolio. In addition to utilising the bottom-up communication of risks in this fashion, the program/portfolio manager is also responsible for the top-down identification of risks pertaining to program/portfolio level that were not identified on project level. Risks identified in a top-down fashion should be communicated to the relevant level (program/project).

## 12.2 Integrating the contingency estimation tool with the enterprise risk management system

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The IPRM process requires that the portfolio manager re-evaluate all risks that are deemed relevant on portfolio level using the IRM enterprise-level likelihood and consequence criteria shown in table 5.2 and Appendix A. If the portfolio manager evaluates a risk as being at a level I, II or III according to the IRM enterprise-level criteria, the risk should be communicated to the relevant body most affected by it and consequently logged in the applicable risk register on CURA. This reporting sequence is illustrated in figure 12.1. Typically, the risk would be communicated to one of three recipients:

1. Group Capital (National Project Management Office – PMO)
2. Provincial Risk Committee
3. Another Division (for example, Generation)

All of these recipients are responsible for maintaining their own CURA-based risk registers of enterprise-level risks, and providing feedback on a national level regarding these risks. In this way, the link between results of the regional contingency estimation tool and the national enterprise risk management system is connected.

To ensure the smooth integration of the different levels in this process, project managers, program managers and portfolio managers of Distribution Western Cape Operating Unit will receive training on the contingency estimation tool itself, how the tool practically integrates with the IPRM and IRM processes, and the use of the lessons learned database. This training will be conducted per program (groups of smaller than 10) to help ensure that sessions remain interactive and focused. The portfolio managers will be trained in a separate session prior to the other training sessions to ensure that they are familiar with all aspects of the tool before it is rolled out.

For tool maintenance and update purposes, an additional “super-user” will be identified to be trained not only on the use of the tool, but the way in which it was developed, and the manner in which it should be updated when additional training patterns become available. The VBA code linked to the tool is also furnished with detailed comments to ensure clarity for future update purposes.

## 12.2 Integrating the contingency estimation tool with the enterprise risk management system

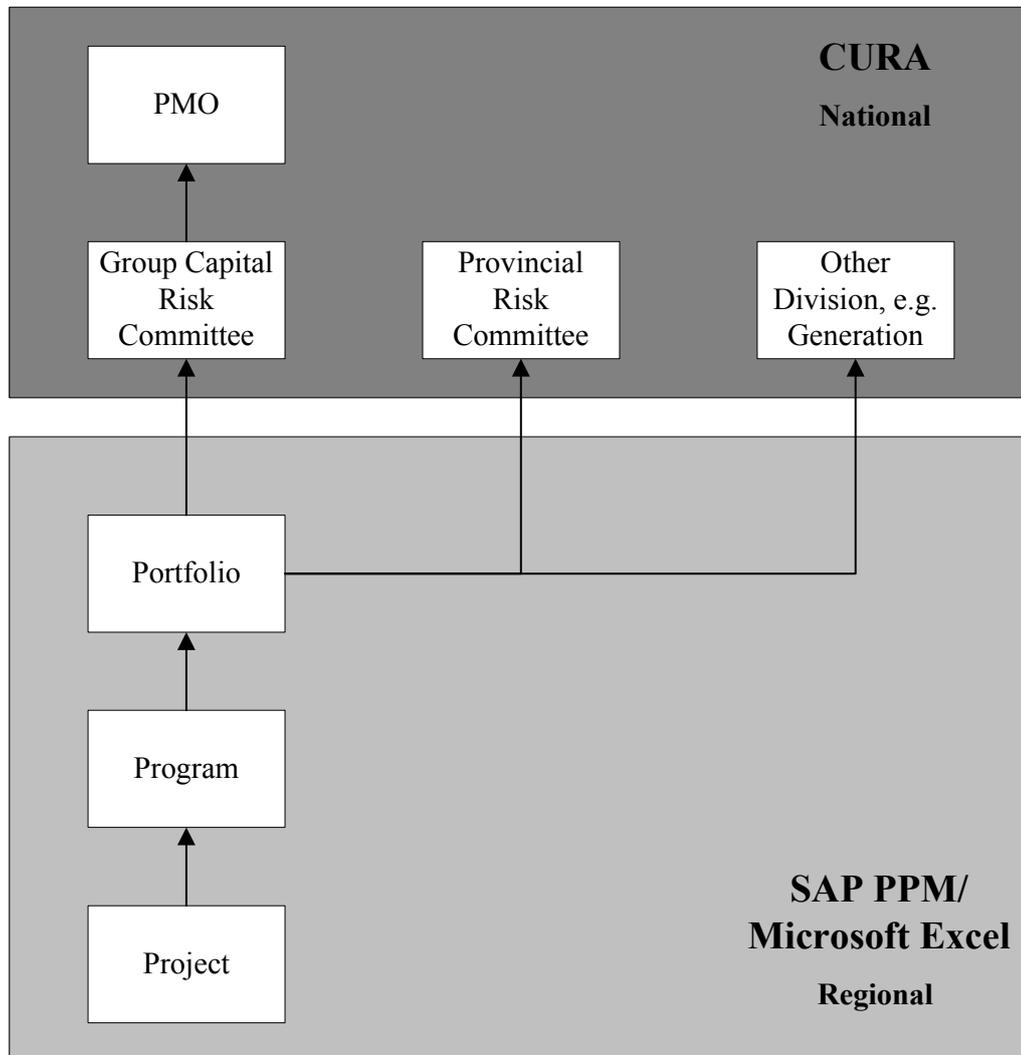


Figure 12.1: Integration with enterprise risk management system (CURA).

The semi-annual update of the neural network model using additional training data will be the shared responsibility of the author and the identified super-user.

Unless otherwise required by the program manager in question, it will be proposed that the tool not be arbitrarily applied to all projects that are already in progress. To ensure that the model not be populated with irrelevant information without consultation with project team members for the sake of “getting it done”, it is proposed that the tool be applied on:

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### 12.3 Concluding remarks on chapter 12

- New projects
- Existing projects as they reach a point in the PLCM at which the tool should be applied (according to the IPRM process)

### 12.3 Concluding remarks on chapter 12

This chapter reviewed the integration of the developed contingency estimation tool with two importance structures in the Eskom environment: the project life-cycle model (PLCM) and the enterprise risk management process. Points in the PLCM at which the contingency estimation tool should be applied, were prescribed, alongside an explanation of why such a prescription is necessary. After this, the way in which the contingency estimation tool outputs become reporting inputs to the enterprise risk management system, were described.

The next and final chapter will outline the project summary and conclusions, and describe possible future research.

## CHAPTER 13

# RESEARCH SUMMARY AND CONCLUSIONS

The research project is summarised in this chapter, and research conclusions are presented alongside suggestions for further research.

### 13.1 Project summary and conclusions

The purpose of the study was to develop a contingency estimation tool to decrease the influence of subjectivity on contingency estimation methods throughout the project lifecycle so as to enable consistent project risk reflection on a portfolio level in the capital program management department of Eskom Distribution Western Cape Operating Unit. To achieve this, a hybrid tool incorporating neural network analysis of systemic risks and expected value analysis of project-specific risks, was developed.

The objectives of this study were defined as follows:

- Determining the **most suitable method(s)** to be included in the contingency estimation tool to enable integrated cost-schedule contingency estimation
- Developing a **contingency estimation tool** that
  - Can be easily applied by a project manager without statistical knowledge or experience as a risk practitioner
  - Is applicable to all levels of project definition

### 13.1 Project summary and conclusions

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- Addresses systemic and project-specific risks
- Determines the following when provided with suitable risk driver information:
  - \* The cumulative probability distribution of total project cost
  - \* A breakdown of contingency amounts (cost and duration) assigned to project-specific risks
  - \* The level of project risk at portfolio level
- Providing standard guidelines regarding the points in the project lifecycle at which the contingency estimation tool should be applied

Neural network analysis and expected value analysis **were identified as contingency estimation techniques** due to their respective suitability to address systemic and project-specific risks, and the **relatively low level of risk practitioner expertise / statistical knowledge required to apply these methods**. For neural networks, expertise is involved during model development rather than model application.

The tool **is applicable to all levels of project definition save the pre-project planning stage**. This is not seen as an extreme disadvantage as the IPRM process for standard and repeatable projects does not require the estimation of contingency before the concept stage is reached. It is however possible to apply the expected value portion of the model in isolation during the pre-project planning stage if a rough indication of required contingency is deemed necessary.

Interviews were conducted with project managers to distinguish cost and duration growth due to systemic risk from cost and duration growth due to project-specific risk and other reasons. Outputs from 22 interviews provided three data patterns for each of 89 completed network asset construction projects. Leading digit frequencies corresponded strongly to values expected according to Benford's Law for a random data set as confirmed through a chi-squared goodness-of-fit test, providing confidence that training could proceed with the gathered input data. After interview data had been processed to remove project-specific and other impacts, 138 training patterns pertaining to 85 projects remained for model training, validation and testing.

### 13.1 Project summary and conclusions

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Six possible input variables (systemic risk drivers) to the neural network were selected as project definition level, project cost, project duration, business category, voltage category and job category. A multilayer feedforward neural network was trained using a supervised training approach combining a multi-objective simulated annealing algorithm with the standard backpropagation algorithm.

The results of the neural network were considered for different scenarios regarding possible combinations of model input variables and number of hidden nodes to minimise training and validation errors. The validation errors of the chosen scenario are considered reasonably acceptable, as the average validation error across the two output nodes is 10.1%. Error levels are comparable to those of similar studies in the project management field – the accuracy is not as high as in other fields of application due to high variability inherent in data related to the management of projects. The corresponding variance of the error for the chosen scenario was determined as  $8.296 \times 10^{-3}$  and  $2.103 \times 10^{-2}$  for cost and duration, and the corresponding testing errors were determined as 6.0% and 11.1% for cost and duration. The chosen scenario (exclusion of business category indicator variables with nine hidden nodes) was compared with a multiple linear regression approach, and findings showed that the neural network outperforms the multiple linear regression approach. However, calculated  $R^2$  values were lower than anticipated for the ANN. It is expected that neural network performance will be further improved as additional training patterns become available.

The trained neural network was combined with an expected value analysis tool (risk register format) to be applied to projects to **estimate contingency due to systemic risks alongside an estimation of contingency due to project-specific risks**. The **expected value (contingency) linked to each project-specific risk is visible** in this format. The project-specific expected value method was modified by basing the contingency estimation on the number of risks that are expected to occur according to a binomial scenario. A **total cost distribution** was included in model outputs by assuming the contingency cost equal to the standard deviation of the cost estimate. Other risk register inputs and outputs were included to align to the Integrated Project Risk Management process, including a function to allow risk “roll-up to program/portfolio level” and thereby **display the level of risk at portfolio level**.

### 13.1 Project summary and conclusions

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To ensure business integration of the developed contingency estimation tool, study outputs included the **points in the project lifecycle model at which the contingency estimation tool should be applied**, and the manner in which contingency estimation tool outputs become reporting inputs to the enterprise risk management system.

The developed tool is a clear improvement on the subjective expert opinion approach currently applied in contingency estimation in the study environment. Timing of contingency estimation workshops has also been defined, which was not previously the case. Also, the individual assignment of contingency values to project-specific risks rather than the estimation of an overall contingency value, enables the management of contingency funds and durations with respect to the risks they were requested for. By the population of the lessons learned database using interview data, and the planned continual update of said database using data from completed projects as part of the IPRM process, the first step is taken towards the maintenance of a data repository that can be used for future project-specific risk identification / systemic risk analysis.

Another advantage of the proposed model vs a model where the contingency is calculated as direct output and the user does not analyse any risks, is that the necessity of user involvement prompts a thinking and debating process that will be more likely to provide a full view of possible risks on a project. The phenomenon described as “when models turn on, brains turn off” is avoided.

Though the assignment of contingency to each project-specific risk is transparent, the same cannot be said for the assignment of contingency for systemic risks using the neural network. Neural networks are essentially “black boxes”, and their output cannot be explained. However, in the proposed tool the neural network is only applied to address risks which, by their nature, are hard to relate to specific budget/schedule items, and therefore difficult to describe in a risk register format. The disadvantage is therefore not seen as an impediment to successful application of the tool.

A presentation of the study ([Van Niekerk & Bekker, 2012](#)) was given at the 2012 International Conference on Computers and Industrial Engineering (CAIE) in Cape Town, South Africa. The presentation was positively received by the

international community (from academic and practical backgrounds) represented at this conference.

### **13.2 Future research**

Though the ANN developed in this study was shown to outperform MLR, it was not compared to any other regression function types, *e.g.* polynomial or exponential due to the lack of information on the input-output mapping function, if a defined mathematical form exists at all. If an appropriate regression function were to be found for the data set by conducting a more exhaustive search on possible function formats, this approach would be advantaged by the transparency of the input-output mapping relationship. If regression were to be applied, a new regression function might have to be found when new data becomes available (just as the neural network model parameters could require adjustment when new data is presented). This could be a possible topic for future research.

A basic version of the developed expected value risk register (excluding expected number of risks to occur and total cost distribution) is being rolled out nationally on Eskom standard and repeatable projects as risk analysis and contingency estimation tool. This roll-out forms part of the project focused on implementing the newly developed IPRM process. The improved hybrid tool that was the final output of this study is currently only applicable to the Distribution Western Cape Operating Unit due to the boundaries of the development data set. It has been proposed that data from other Operating Units be gathered using questionnaires to determine whether expanding the neural network training data set in this way would make the developed contingency estimation tool applicable for use on all standard and repeatable projects.

“It seems to be a law of nature, inflexible and inexorable,  
that those who will not risk cannot win.”

John Paul Jones

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APPENDIX A

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LESKOM IRM ENTERPRISE-LEVEL CONSEQUENCE  
CRITERIA

Rating	Financial impact (Net profit)	People effects	Environment	Brand and Reputation	Legal and Compliance	Continuity of supply
6	R150b+ loss or gain	<ul style="list-style-type: none"> <li>- More than 10 fatalities</li> <li>- Many 10's of people subjected to irreversible effects</li> </ul>	<ul style="list-style-type: none"> <li>- Irreversible long term environmental harm</li> <li>- Community outrage (potential large scale class action)</li> <li>- Public inquiry by Government agency</li> <li>- Environmental licence revoked</li> <li>- Potential for significant legal sanctions against Eskom</li> </ul>	<ul style="list-style-type: none"> <li>- Critical event that the organisation would be forced to undergo significant change; for example chief executive departs and Board is restructured</li> <li>- Sustained adverse international / national press reporting over several weeks</li> <li>- Prolonged loss of Government confidence and community support</li> </ul>	<ul style="list-style-type: none"> <li>- Major litigation or prosecution with damages of R100m+ plus significant costs</li> <li>- Custodial sentence for company Executive</li> <li>- Prolonged closure of operations by authorities</li> </ul>	<ul style="list-style-type: none"> <li>- National blackout with enormous impact on country from image, economic, point of view</li> <li>- National load shedding &gt; six months</li> </ul>

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Table A.1 – continued from previous page

Rating	Financial impact (Net profit)	People effects	Environment	Brand and Reputation	Legal and Compliance	Continuity of supply
5	R999m–R1.5b loss or gain	- Multiple fatalities - Significant irreversible effects to 10's of people	- Prolonged environmental impact - High-profile community concerns raised requiring significant rectification measures - Government agency inquiry - Environmental licence revoked and directives issued	- Significant event that would require ongoing management and brings the organisation into the national spotlight - Sustained adverse national press reporting over several days - Sustained impact on the reputation of Eskom - Loss of Government support - Executive management restructure	- Major litigation costing R10m+ - Investigation by regulatory body resulting in long term interruption to operations - Possibility of custodial sentence	- Unexpected regional blackout lasting <6hrs - Unexpected under-frequency event resulting in voluntary and mandatory load shedding - Expected national load shedding <4weeks - Expected loss of critical supply to critical customers (deep level mines, smelters etc.)

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Table A.1 – continued from previous page

Rating	Financial impact (Net profit)	People effects	Environment	Brand and Reputation	Legal and Compliance	Continuity of supply
4	R99m–R999m loss or gain	<ul style="list-style-type: none"> <li>- Single fatality and/or</li> <li>- Severe irreversible disability to one or more persons</li> </ul>	<ul style="list-style-type: none"> <li>- Measurable environmental harm – medium term recovery</li> <li>- High potential for complaints from stakeholders and community</li> <li>- Environmental directives issued by authorities</li> </ul>	<ul style="list-style-type: none"> <li>- Major event that causes adverse local press reporting – over several days</li> <li>- Manager may be asked to leave</li> <li>- Minister raises concerns</li> </ul>	<ul style="list-style-type: none"> <li>- Major breach of regulation with punitive fine</li> <li>- Significant litigation involving many weeks of senior management time</li> </ul>	<ul style="list-style-type: none"> <li>- Regional blackout lasting &lt;6hrs</li> <li>- National load shedding &lt;2weeks</li> <li>- Loss of supply to major centre of customer for &gt;12hrs</li> </ul>
3	R1m–R99m loss or gain	<ul style="list-style-type: none"> <li>- Extensive injuries or irreversible disability or impairment to one or more persons</li> </ul>	<ul style="list-style-type: none"> <li>- Medium term recovery, immaterial effect on environment/community</li> <li>- Required to inform Government agency (e.g. noise or dust)</li> </ul>	<ul style="list-style-type: none"> <li>- Serious event that can be readily managed but management effort is still required to minimise impact locally</li> <li>- Adverse local press reporting</li> <li>- Disciplinary action likely</li> </ul>	<ul style="list-style-type: none"> <li>- Breach of regulation with investigation or report to authority or report to authority with prosecution and/or moderate fine possible</li> </ul>	<ul style="list-style-type: none"> <li>- Local loss of supply affecting 10,000 customers (&gt;50MW) for &gt;12hrs</li> </ul>

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Table A.1 – continued from previous page

<b>Rating</b>	<b>Financial impact (Net profit)</b>	<b>People effects</b>	<b>Environment</b>	<b>Brand and Reputation</b>	<b>Legal and Compliance</b>	<b>Continuity of supply</b>
2	- R100k–R1m loss or gain	- Medium term largely reversible disability to one or more persons - Significant medical treatment, disabling or lost time injury < 2 weeks	- Short term transient environmental or community impact – some clean-up costs	- Event that site management can readily manage internally - No press reporting or external interest - Disciplinary action may be taken	- Minor legal issues, non-compliances and breaches of regulation	- Loss of supply to large customers or affecting >10,000 customers for >4hrs
1	- <R100k loss or gain	- First aid treatment or minor medical treatment	- Negligible impact on the environment, little to no ecological effect and no measurable impact on human health	- Entirely an internal issue - Attention is confined to site	- No breach	- Loss of supply to some customers (normal interruption) affects 3,000 customers for <4hrs

Table A.1: IRM consequence criteria – Enterprise-level.

APPENDIX B

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RISK CAUSE CATEGORIES AND PRIMARY/ROOT  
CAUSES

<b>CRA phase cause category</b>	
Systemic causes	Project-specific causes
CRA approval delays	Stakeholder non-alignment
Ineffective Resource Planning Meeting	
Unclear project definition	

Table B.1: CRA phase cause category – Systemic vs project-specific causes.

<b>DRA phase cause category</b>	
Systemic causes	Project-specific causes
Conceptual design inaccuracy	Environmental constraints
DRA approval delays	External resources unavailability
Internal resources unavailability	Lands and rights constraints
Material requirements inaccuracy	
Site investigation incompleteness	
Technical Evaluation Forum approval delays	
Unrealistic project scheduling	

Table B.2: DRA phase cause category – Systemic vs project-specific causes.

<b>ERA phase cause category</b>	
Systemic causes	Project-specific causes
Internal resources skills deficiency and availability	External resource skills deficiency and availability
ERA approval delays	External authorities approval delays
Final design late	Lands and rights constraints
Final design inaccuracy / incompleteness	Long lead time material and logistics constraints
Lack of constructability plan	
Material requirements inaccuracy	
Poorly defined scope	
Procurement process constraints	
Unrealistic project scheduling	

Table B.3: ERA phase cause category – Systemic vs project-specific causes.

<b>Execution phase cause category</b>	
Systemic causes	Project-specific causes
Internal resources skills deficiency and availability	Contractor skills deficiency and availability
Contractor appointment delay	Contractor contractual non-compliance
Ineffective site handover	Material availability
Ineffective asset handover	Late material delivery and logistics
	Construction schedule delays and inaccuracy
	Poor construction methodology
	Pre-energising testing delays
	Quality issues
	Resource performance inefficiencies
	Scope creep
	Unfavourable site conditions
	Supplier issues
	Project dependencies
	Outage management delay
	Commissioning complexity

Table B.4: Execution phase cause category – Systemic vs project-specific causes.

<b>FRA phase cause category</b>	
Systemic causes	Project-specific causes
Lack of control over internal costs	Project close-out delays

Table B.5: FRA phase cause category – Systemic vs project-specific causes.

<b>Governance cause category</b>	
Systemic causes	Project-specific causes
Availability of governance committees - Investment committee	Complexities of managing emerging contractors
Availability of governance committees - Tender board	

Table B.6: Governance cause category – Systemic vs project-specific causes.

<b>Process challenges cause category</b>	
Systemic causes	Project-specific causes
Ineffective processes	Process non-compliance
Process complexity	
Process changes	
Procurement process (ERA before tender)	

Table B.7: Process challenges cause category – Systemic vs project-specific causes.

<b>Organisational challenges cause category</b>	
Systemic causes	Project-specific causes
Conflicting project priorities	
Inter-departmental politics and silos	
Lack of sponsorship	
Management resistance	

Table B.8: Organisational challenges cause category – Systemic vs project-specific causes.

<b>External constraints cause category</b>	
Systemic causes	Project-specific causes
	Community influence
	Economic
	Environmental
	Legal
	Political
	Protest action
	Social
	Technological

Table B.9: External constraints cause category – Systemic vs project-specific causes.

<b>General cause category</b>	
Systemic causes	Project-specific causes
High staff turnover	Exceptional inclement weather
Inaccurate reporting systems	
Inadequate communication	
Lack of accountability	
Lack of training and skills	

Table B.10: General cause category – Systemic vs project-specific causes.