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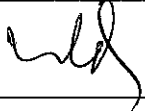
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UNIVERSITI TEKNOLOGI PETRONAS

Project Cost Contingency Estimation Modeling

Using Risk Analysis and Fuzzy Expert System

By

Mohammad Arif Rohman

A THESIS

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DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING


BANDAR SERI ISKANDAR,

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UTP or other institutions.

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ABSTRACT

Determination of the appropriate project cost contingency, especially during the tendering stage is very important to ensure a successful bidding of the project. Setting too high a cost contingency will not make the tender look competitive, while putting too low will not cover risks that may cause cost overrun during the construction. Traditionally, contractors estimate cost contingency based on subjective judgment, such as 5-10% from the base cost estimated by considering past similar project. This method is typically derived from intuition, past experience and historical data. However, such method does not have a sound basis and is difficult to justify or defend. More objective methods for estimating project cost contingency have been presented. However, most of the methods still rely on formal modeling techniques which sometimes require the user to have knowledge and familiarity with statistical techniques. This research proposes a method to estimate cost contingency using a flexible and rational approach based on risk analysis and *fuzzy expert system* concept. This method could accommodate contractors' subjective judgment and also the use of risk analysis and management concept in the analysis process. The proposed method involved the development of cost contingency model for building and infrastructure projects in Malaysia. To develop the model, a number of common risk factors were identified from the literature. Data and information from the literature were also acquired to specify *fuzzy expert system* properties, such as *membership function*, *rule base* and *fuzzy inference mechanism*. The *fuzzy expert system* was developed using scenarios to predict percentage cost contingency allocation. The scenarios were then validated using three case projects by conducting face to face interviews with the project managers. From the validation, it was found that the predictions given by the system were within 20% accuracy compared to actual cost contingencies. A computer program was also developed using MATLAB software to demonstrate the model's application in estimating tender price during the bidding stage.

Keywords: cost contingency, construction project, fuzzy expert systems, risk management

ABSTRAK

Penentuan kos luar jangka yang sesuai bagi sesebuah projek, terutamanya semasa fasa tender berlangsung adalah sangat penting untuk memastikan kejayaan dalam membida sesebuah projek. Meletakkan kos luar jangka yang terlampau tinggi tidak akan menjadikan tender mampu bersaing, manakala meletakkan kos luar jangka yang terlampau rendah tidak akan menutup risiko yang mungkin dapat menyebabkan kos meningkat semasa pembinaan. Secara tradisional, kontraktor menganggarkan kos luar jangka berdasarkan pertimbangan subjektif, seperti 5-10% daripada kos asas dianggarkan dengan mengambil kira projek yang sama pada masa lampau. Kaedah ini biasanya berasal daripada intuisi, pengalaman dan data sejarah. Namun, kaedah seperti ini tidak mempunyai asas kukuh dan sukar untuk memberikan alasan yang kuat mahupun mempertahankannya. Beberapa kaedah objektif untuk menganggarkan kos luar jangka projek juga turut dibentangkan. Namun, sebahagian besar kaedah masih lagi bergantung kepada teknik permodelan formal yang mana kadang kala ianya memerlukan pengguna yang mempunyai pengetahuan dan terbiasa dengan teknik statistikal. Penyelidikan ini mencadangkan suatu kaedah untuk menganggarkan kos luar jangka menggunakan pendekatan yang fleksibel dan rasional berasaskan kepada analisis risiko dan konsep *fuzzy expert system*. Kaedah ini dapat menyesuaikan pertimbangan subjektif kontraktor dan juga penggunaan analisis risiko dan konsep pengurusan dalam proses analisis. Dalam penyelidikan ini, kaedah yang dicadangkan melibatkan pembangunan model kos luar jangka untuk bangunan dan projek prasarana di Malaysia. Untuk membangun model, beberapa faktor risiko biasa telah dikenalpasti dari literatur. Data dan maklumat daripada literatur juga turut digunakan untuk menentukan properti *fuzzy expert system*, seperti *membership function*, *fuzzy inference mechanism*. *Fuzzy expert system* dibangunkan menggunakan beberapa senario untuk meramalkan peratusan peruntukan kos luar jangka. Senario kemudian disahkan menggunakan beberapa kes projek dengan menjalankan temu duga bersemuka dengan para pengurus projek. Daripada pengesahan, didapati bahawa ramalan yang diberikan oleh sistem berada dalam kejituan 20% dibandingkan dengan kos luar jangka sebenarnya. Suatu program komputer menggunakan perisian

MATLAB turut dibangunkan untuk membuktikan aplikasi model dalam menganggarkan harga tender semasa fasa membida berlangsung.

Kata kunci: kos luar jangka, projek pembinaan, *fuzzy expert system*, pengurusan risiko

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LIST OF ABBREVIATIONS

AS/NZS	: Australian Standard/ New Zealand Standard
AHP	: Analytical Hierarchy Process
CC	: Cost Contingency
CO	: Control Output
GUIDE	: Graphical User Interface Development Environment
H	: High
L	: Low
M	: Medium
MF	: Membership Function
MR	: Major Risk
PMI	: Project Management Institute
RL	: Risk Likelihood
RM	: Risk Magnitude
RS	: Risk Severity
VL	: Very Low
VH	: Very High

CHAPTER 1 INTRODUCTION

1.1 Background

The construction industry has a significant role in the economic development of a country, especially in developing countries. However, construction business is challenging and is categorized as a high risk business since it is always surrounded by many uncertainties which are present due to the unique and dynamic nature of the construction project itself.

Those uncertainties create many risks in almost all phases of the construction process [1]. Examples of the construction risks are natural disaster, changes in economic condition and several internal contractors' risks due to productivity problems. According to Mills [2], risk cannot be eliminated, but it can be minimized, transferred or retained.

One of the attempts to handle risks in the early stages of a project lifecycle is by representing risk in monetary value and adding to the base cost estimate, which is known as "project cost contingency". The determination of an appropriate project cost contingency is very significant for the successful management of a project. Setting high contingency value will make the tender price unattractive, while setting too low contingency may not be adequate to cater for risks that might occur during the construction process.

Traditionally, project cost contingency is simply determined by adding; say 10 percent from total project cost [2]. This method is based on the contractor's subjective judgment according to his/her experience. However, this method is arbitrary and difficult to justify or defend. It is a reason why so many projects are over budget [3].

Several methods to determine project cost contingency in the construction industry have been introduced such as Monte Carlo Simulation (MCS) [1], linear regression [4], belief network [5], and Artificial Neural Network (ANN) [6]. In general, most of these methods are based on mathematical formulas which are sometimes not easy to understand. Sometimes, these methods also require the user to have basic knowledge in statistical analysis. This becomes one of its limitations since most of the construction's project managers or construction personnel do not have any knowledge of the formalized technique to estimate cost contingency [7].

According to Dikmen et al. [8], in the construction field, often the use of expert knowledge, experience, intuitive judgment and rules of thumb that are usually ill-defined and vague cannot be avoided due to limited statistical data. The impreciseness and vagueness are usually characterized by the use of linguistic terms such as low, medium and high. Fuzzy set or fuzzy logic concept is a mathematical tool that can accommodate the use of such linguistic terms which is based on subjective judgment [9].

Previous researchers have presented the use of fuzzy sets in estimating project cost contingency method [10], [11]. However, these methods have limitation which is yet to be overcome such as the difficulty in their application [4]. The fuzzy expert system, which is developed based on fuzzy logic concept, is a technique that provides an easy method in dealing with the fuzzy set. Fuzzy logic could accommodate the human approximate reasoning, which is usually represented using IF-THEN rule. It is very useful to be used in the decision making process when statistical data is incomplete or unavailable such as in the construction field. This method is easy to be developed, understood and applied and has been widely used in many areas such as control, decision making, management, etc. [9].

The method of risk analysis has been widely used for estimating cost contingency in construction project [12]. In this research, fuzzy expert system which is capable of

accommodating subjective judgment is incorporated in risk analysis technique for estimating project cost contingency.

1.2 Problem Statement

Several methods in estimating project cost contingency have been developed by earlier researchers [1], [4], [5], [6]. However, several limitations of the previous methods still exist, particularly with regard to the difficulty of their application in practice. Most of these methods still require statistical and mathematical knowledge from the user. According to Smith and Bohn [7], contractor project managers do not have such knowledge as used in these methods. The contractor project managers are more familiar with the use of subjective judgment in estimating project cost contingency than using statistical and mathematical methods. Fuzzy set is a mathematical tool that can accommodate the use of subjective judgment. Previous researchers have introduced fuzzy set to estimate cost contingency [10], [11]. However, the limitations are still exist, particularly in the difficulty in their application [4]. Fuzzy expert system gives a more flexible way in dealing with fuzzy set. It can accommodate the use of human approximate reasoning which is represented as fuzzy IF THEN rule. Therefore, this research is intended to propose fuzzy expert system to estimate cost contingency that can accommodate subjective judgment. This can be achieved by incorporating fuzzy expert system in risk analysis technique.

1.3 Research Objectives

The research aim is to develop a method to estimate project cost contingency based on risk analysis and fuzzy expert system concept from the project contractor point of view. The research objectives are as follows:

1. To develop a model to estimate project cost contingency based on risk analysis and fuzzy expert system.
2. To demonstrate the applicability of the proposed model by developing a computer tool in estimating tender price during bidding stage.

1.4 Scope of Study

The scope of this research is divided into three areas:

1. The development of a model to estimate project cost contingency for construction project based on risk analysis and fuzzy expert system. The object is common construction, namely building and infrastructure projects. The Infrastructure project involve in this research are roads and bridges construction. Therefore, the type of risk factor specified in the model is based on these types of projects.
2. Risk factors used in the model are from contractor's perspective. These types of risk factors were obtained from literature review.
3. The collections of data or information that used to develop and to validate the model were obtained both from the literature and field interview. The interviews were conducted with the contractors under the G7 class (large contractor) registered with the Construction Industry Development Board (CIDB), Malaysia.

1.5 Thesis Outline

The thesis consists of six chapters. Chapter 1 is introduction. This chapter explains the background that motivates this research. The importance and significance of cost contingency estimation as one of the key element to ensure the success of a project is discussed.

Chapter 2 is literature review. Background theory related to cost contingency, the concept of risk analysis and the fuzzy expert system are reviewed. In order to give references to the cost contingency estimation method, the works of previous researchers who have introduced methods of estimating cost contingency are also reviewed.

Chapter 3 is research methodology. This chapter describes the steps conducted during the data collection process, model development, model validation and application.

Chapter 4 describes the development of project cost contingency model. In this chapter, every phase of the model development is presented. The model testing and tuning involved eight case projects; which is part of the model development are also presented.

Chapter 5 describes the validation and application of the model. The validation is intended to check whether the model is working according to the cost contingency model behavior. Three case projects obtained from the interview survey are used to validate the model. Finally the computer tool application, which has been developed based on the proposed model, is also presented. This computer tool is then applied to one of the case projects to estimate tender price based on risk analysis and risk management concept.

Finally, in Chapter 6, the conclusions and contributions of the research are presented. The limitations of the research are addressed and recommendations for future works are also proposed.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter presents a review related to theory and several previous works on cost contingency methods. The concepts of risk analysis and fuzzy expert system as the proposed method in this research are also discussed.

2.2 Cost Contingency

“Cost contingency” or often simply called as “contingency” is a common term used in the construction industry. Even though this term is usually used in construction practice, contractors can have a different interpretation of project cost contingency [3]. Therefore, theories to cost contingency will be reviewed which will involve its definition, cost contingency practice, and several methods to estimate cost contingency.

2.2.1 Definition

According to Oxford Dictionaries [13], contingency can have three meanings: (1) a future event or circumstance which is possible but cannot be predicted with certainty; (2) a provision for such an event or circumstance, and (3) the absence of certainty in events. Beside those definitions, contingency can also mean contingency planning that considers alternative plan with exact processes or procedures in developing an information system or program, in a disaster relief effort, or an organizational contingency plan [12].

In this research, the term “contingency” is related to provision for such an event or circumstance, which is usually represented as the amount of funds or budget that is

normally used for unpredictable event or condition. In this work, such contingency is referred to as cost contingency.

In the context of project management, Project Management Institute (PMI) [14] defines contingency as the amount of *funds, budget, or time* needed above the *estimate* to reduce the *risk* of overruns of project *objectives* to a level acceptable to the *organization*. American Association of Cost Engineer (AACE) in Cost Engineers' Notebook, as cited by Ng [12], defines contingency as the amount added to an estimate to allow for additional costs, that previous projects have shown, will likely be required. This amount may be derived either through statistical analysis of past project costs, or by applying experience gained on similar projects.

According to Boukendor [15], cost contingency allocation is intended to prevent cost overrun during the construction process. Cost contingency usually covers the costs that may result from incomplete design, unforeseen and unpredictable conditions, or uncertainties within the defined project scope. However, it does not include changes in scope or schedule or unforeseeable major events such as strikes or earthquakes.

Peurifoy and Oberlender [16] stated that cost contingency is a real and necessary component of an estimate. It is assigned based on uncertainty such as pricing, escalation, schedule, omission, and errors. In simple word, cost contingency can be interpreted as the amount of money that must be added to the base cost estimate to account for work that is difficult or impossible to identify at the time a base estimate is being prepared.

According on those definitions, in this research, cost contingency can be categorized as:

1. A fund, budget, or time above the estimate to reduce risk overruns.
2. A cost estimate element.
3. A function of uncertainty.

2.2.2 Types of Contingency

According to Gunhan and Arditi [17], there are three types of contingency, which depend on the phase of the project and the party involved. Those three contingencies are designer contingency, contractor contingency, and owner contingency. Designer contingency is included in the preliminary budget for potential cost increases during the pre-construction phase. Contractor contingency is included in the construction budget to cover unforeseen condition that may occur during the construction phase. Owner contingency is controlled by the owner and is included in the owner's budget.

Holm et al. [18] categorizes contingency in two types: owner contingency and contractor contingency. There are five categories of owner contingency as follows:

1. Design contingency, which is used as in budget estimates, because final decisions have not been made and appropriate drawings and specifications have not been prepared.
2. Document contingency, used to cover the risk associated with potential conflicts among contract documents. Any contract document discrepancies usually result in change orders.
3. Permit contingency, used to cover the risk associated with potential conflicts among contract documents.
4. Scope contingency, used to cover the cost of owner-directed changes in project scope after the drawings and specification have been completed, and construction has been initiated.
5. Unforeseen condition contingency, for covering unknown risk at site conditions.

Whereas for the contractor's contingency, there are three categories:

1. Design contingency, used to cover risks associated with elements of the design that have not been completed.
2. Escalation contingency, used early in the design process to cover the risk associated with material and labor inflation.

3. Estimating contingency, used when the estimator has not completely taken off the entire project and has not obtained material and subcontractors pricing.

With regard to this research, cost contingency is defined as the amount of money that should be allocated by the contractors in a tender price to cater risks which might happen during the construction process in order to avoid project cost overrun.

2.3 Risk and Risk Management Concept

In this section, background theories related to risk definition, risk parameters and risk management concept will be described.

2.3.1 Risk Definition

The term “risk” is often used in many areas of human life, including in construction projects. “Risk” originates from the Latin word *risicum*, which means the challenge presented by a barrier reef to a sailor [19]. Several literatures have introduced risk definition. Oxford Dictionary [13] defines risk as the chance of hazard, bad consequence, loss, etc. or the chance of negative impact. Australian Standard/New Zealand Standard (AS/NZS) [20] states risk as the chance of something happening that will have an impact on objectives.

Within the context of construction projects, risk is defined as an uncertain event or condition that, if occurs, has either a positive or negative effect on the objectives of a project [19]. Al-Bahar [1] defines risk as the exposure to the chance of occurrences of events adversely or favorably affecting project objectives as a consequence of uncertainty. PMI [14] states project risk as an uncertain event or condition that, if occurs, has either a positive or negative effect on at least one project objective, such as time, cost, scope or quality. Loosemore et al. [21] expresses risk as a potential future event which is uncertain in likelihood and consequence, and if occurs could affect company’s ability to achieve its project objectives. In these definitions, besides having a negative meaning, risk can also has a positive meaning, such as opportunity.

Sometimes, risk cannot be separated from opportunity. Risk is usually used to refer to potential events, which could adversely affect a company's objectives and opportunity is referred to potential events, which could beneficially affect company's objectives [21].

The term risk can also have different meaning for different people [1], and it is often used interchangeably with uncertainty. According to Loosemore et al. [21] and Perminova et al. [22], risk and uncertainty are two things that should be distinguished. These two phenomena are not synonymous; in fact they are better described as cause and consequence. Risk is understood as one of the implication of uncertainty and is more often stated as something that can be quantified and measured. On the other hand, uncertainty is defined as something that is less quantifiable.

Since risk is something that can be quantified, therefore its nature can be identified by characteristics in order to estimate its value. Risk characteristic that have been suggested by other researchers to measure the level of risk will be discussed in the next section.

2.3.2 Risk Related Terms

Risk can be identified by its components in order to distinguish it from uncertainty. By knowing those risk components, the measurement of risk level can be performed. Several literatures have presented those risk components as the method to identify the nature of risk such as risk factor, risk factor relationship and parameters used to quantify level of risk.

2.3.2.1 Risk Factor or Risk Event

Risk factor is an event that categorizes risk. Risk factor or event is the occurrence of a particular set of circumstances [14]. It can be meant as what might happen to the detriment or in favor of the project [1]. Risk factor is usually identifiable from the

source of risk such as client, government, nature, site, labor, equipment, material, management and so on.

2.3.2.2 Risk Relationship

Risk factors are connected to each other. Every risk factor can influence each other. Therefore, in order to quantify the level of risk, it is necessary to identify the risk relationship.

The way to identify the risk relationship can be performed by several techniques. One of the techniques is called risk breakdown structure (RBS) [19]. This technique proposes a method to identify the risk factor based on risk hierarchy from the top to the bottom levels.

2.3.2.3 Risk Parameters

Three risk parameters have been identified from literature, namely “risk probability” or likelihood, “risk impact” or risk severity or risk consequence, and “risk level” or magnitude. Risk likelihood is used as a general description of probability or frequency [20]. Probability is usually expressed as a number between 0 and 1 or 0 to 100%, which represents a judgment about the relative likelihood of some event [21]. In this case, 0 means that the event is non-existence, while 1 means that it will always happen. An event is identified as a risk if it has a probability of occurrence between 0 to 1.

Al-Bahar [1] proposed the idea of probability as a judgmental measure of personal belief. The subjective approach does not require two people to assess the same probability for a specific event provided that the assessed probabilities are coherent.

Risk severity or also known as risk consequence, is defined as the outcome of an event [20]. Ayyub [19] stated risk consequence as the degree of damage or loss from

some failure. Each failure of a system has one or more consequences which can be economic damage, environmental damage, injury or loss.

The level of risk is often stated as risk magnitude, which is measured as a combination of the consequences or risk severity and their probability or risk likelihood of an event. Al-Bahar [1] defines risk level or risk magnitude as a function of uncertainty of an event and the potential loss/gain from an event which is represented in Equation 2.1.

$$\text{Risk Magnitude} = \text{Uncertainty} \times \text{Potential loss/gain} \quad (2.1)$$

According to the definition, uncertainty and potential loss/gain are necessary condition for risk magnitude. Uncertainty is defined as how likely the event is to occur, i.e., the chance of event occurring while potential loss/gain is a consequence of the event happening.

Mills [2] stated that the risk magnitude can be measured as the likelihood of specific unwanted event and its unwanted consequence or loss, which can be expressed as Equation 2.2.

$$\text{RM} = \text{L} \times \text{C} \quad (2.2)$$

Where:

RM = risk magnitude

L = risk likelihood

C = risk consequence

AS/NZS [20] states that the level of risk is a combination of a level of likelihood and a level of consequence. In a simple form, it can be written as Equation 2.3.

$$\text{Risk Magnitude} = \text{A function of (Consequence and Likelihood)} \quad (2.3)$$

The relationships between these two variables depend on many factors that reflect the nature of the risk and the way it is perceived. When human values are applied, the relationship may well be nonlinear and even discontinues. If it is taken that the level of risk is proportional to each of its two components, the risk function is essentially a product which can be written as Equation 2.4.

$$\text{Risk Magnitude} = \text{Consequence} \times \text{Likelihood} \quad (2.4)$$

If the complicating factors such as nonlinear relationship are taken into account, the relationship can be written as Equation 2.5.

$$\text{Risk Magnitude} = (\text{C} \times \text{weighted factor})^x \times (\text{L})^y \quad (2.5)$$

The weighting factor and an exponential operator (raised to power operator, x and y) are added to achieve a required relative scale.

Loosemore et al. [21] stated that risk is normally expressed in terms of probabilities and consequences (impact on objectives). A probability is a number, between zero and one inclusive, which represents a judgment about the perceived relative likelihood of some event. A potential event having a probability of between 0 and 1 is a risk. On the other hand, consequence is a representation of the impact of risk in terms of project cost as can be written as Equation 2.6.

$$\text{Risk Magnitude} = \text{Probability of event} \times \text{Magnitude of loss/gain} \quad (2.6)$$

2.3.3 Risk Management Concept

Risk analysis is a part of the risk management concept, which usually consists of three components: risk identification, risk analysis and risk response. The concept of risk management proposed by AS/NZS [20] can be seen in Figure 2.1.

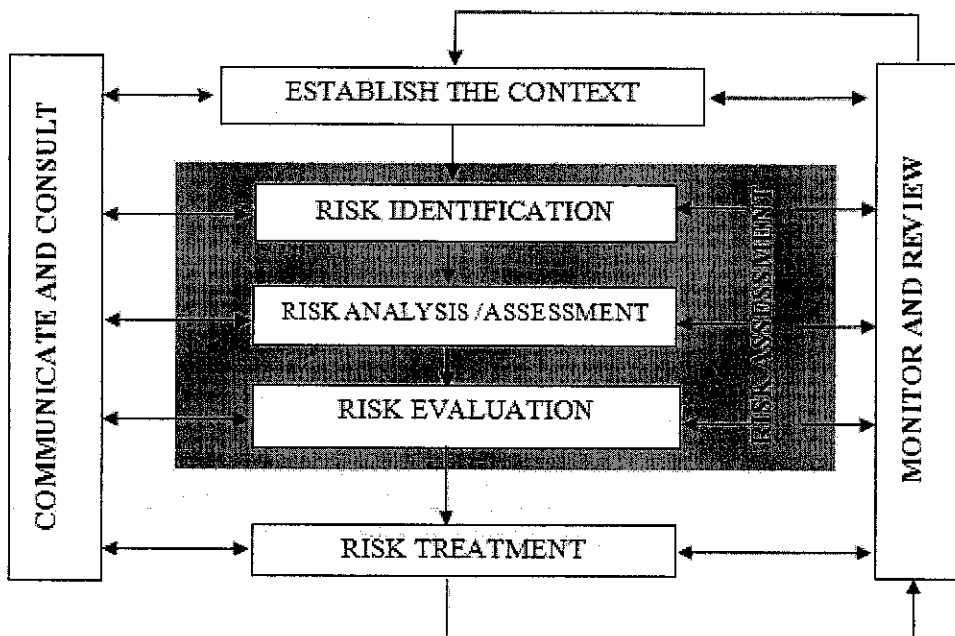


Figure 2.1 Risk Management Process-Overview [20]

In this concept, risk management is an iterative process that begins with establishing the context, followed by risk identification, risk assessment, risk evaluation, and risk treatment. In the first step, i.e. establishing the context, the basic parameters in risk must be managed. This step sets the scope for the rest of the risk management process. Secondly, risk identification is the process to identify what, where, when, why and how it can happen.

Thirdly, risk analysis or also called risk assessment, is a step of quantifying the level of risk (risk magnitude) from several risks that have been identified from the previous step. It can be performed either by qualitative or quantitative method, by combining the risk consequence and risk likelihood. Finally, risk evaluation is a decision-making

process based on the outcome of risk analysis. It is the time to decide how to treat the risk. This step involves comparing the level of risk found during the analysis with the risk criteria established at the beginning.

Other concepts of risk management are also presented by Al-Bahar and PMI. Al-Bahar [1] stated that risk management is a formal orderly process for systematically identifying, analyzing, and responding to risk events throughout the life of a project to obtain the optimum degree of risk elimination or control. PMI [14] defined project risk management as the processes concerned with conducting risk management planning, identification, analysis, responses, and monitoring and control a project, which most of these processes are updated throughout the project.

According to these several definitions, it can be concluded that the detail concept of risk management can vary from one literature to another. However, broadly speaking, risk management consists of the three steps, store-mentioned namely risk identification, risk assessment or analysis, and risk response. Therefore, these three steps are used in this research context. The three risk management steps are discussed further in the following sections.

2.3.3.1 Risk Identification

Risk identification is the first step in risk management procedure, which is aimed to identify all risks related to a construction process. This step is very important since the analysis and response to risks cannot be conducted without examining the risks that might happen.

AS/NZS [20] defined risk identification as the process of determining what, where, when, why and how something could happen. Al-Bahar [1] states that risk identification is the process of systematically and continuously identifying, classifying, and assessing the preliminary significance of risks associated with a construction project.

Based on these definitions, with regard to this research, risk identification is defined as the process of identify risk factors that could happen during the construction process. The contractor's experience from the previous project which has similar characteristic can be used for the identification of risk factor.

Several techniques have been introduced to identify risks. AS/NZS [20] suggested team-based brainstorming, structured techniques, what-if and scenario analysis, checklist and multi-level risk identification. PMI [14] proposed documentation reviews, information gathering techniques (brainstorming, Delphi technique, interviewing and root cause identification analysis), checklist analysis, assumption analysis and diagramming techniques (cause and effect diagram, system or process flowcharts, influence diagram). Loosemore et al. [21] classified the risk identification techniques into two types, namely proactive and reactive techniques.

Al-Bahar [1] proposed six steps in the identification stage: (1) recognizing the existence of uncertainty of potential risk, (2) preparing a preliminary checklist of all sources of project risks, (3) identifying all possible risk events/consequence scenarios, (4) constructing a risk mapping for every potential risk, (5) developing a formal categorization scheme of project risks, and (6) preparing a summary sheet for every risk category.

2.3.3.2 Risk Assessment

Risk assessment or also known as risk analysis is defined as a systematic process to understand the nature of and to deduce the level of risk [20]. It can also be stated as a process that incorporates uncertainty in a quantitative manner, using probability theory, to evaluate potential impact of risk [1].

Loosemore et al. [21] divided risk assessment into two stages:

- Stage one, a qualitative analysis of risks and opportunities using qualitative/descriptive scales such as high, medium and low.

- Stage two, a quantitative analysis of risks and opportunities using numerical estimates. This is normally conducted on risks and opportunities that are categorized as important from stage one, and where reliable data for analysis are available.

AS/NZS [20] divided risk assessment types into three categories, namely qualitative, semi-qualitative, and quantitative analysis. Qualitative analysis is a method that uses description rather than numerical scale to define the level of risk. It usually uses linguistic terms to represent the level of risk. In semi-quantitative analysis, a numerical scale is assigned to the linguistic terms, which have been specified earlier, to achieve a more expanded ranking scale. While quantitative analysis is a method that uses the numerical value of the risk likelihood and consequence to measure the risk level (or risk magnitude).

In terms of risk analysis method, those qualitative, semi-quantitative and quantitative assessments are conducted by assessing the probability and consequence of occurrence. It is important to consider both probability and consequence when assessing risk because although something may have a very low probability of occurring, extreme consequences can make it very high risk [21].

Qualitative analysis method is usually represented using risk matrix as can be seen in Table 2.1. In the matrix, the level of risk factor (risk magnitude) is assessed by comparing the likelihood of occurrence and its consequence. Based on these, a risk level in linguistic terms such as Low (L), Medium (M), and High (H) is assigned to the risk factor. An example of semi-quantitative analysis method can be seen in Table 2.2 . The table shows that likelihood is represented using frequency of risk factor/event occurrence per year and the consequence in terms of monetary value. The risk level itself is quantified based on the multiplication of those two parameters.

Table 2.1 Example of Qualitative Risk Analysis Method [21]

Risk Likelihood	Risk Consequence				
	Insignificant	Minor	Moderate	Major	Extraordinary
Almost Certain	L	M	H	H	H
Likely	L	M	M	H	H
Possible	L	L	M	H	H
Unlikely	L	L	L	M	M
Rare	L	L	L	M	M

Where:

L = “Low” risk level or magnitude

M = “Medium” risk level or magnitude

H = “High” risk level or magnitude

Table 2.2 Example of Semi-Quantitative Risk Analysis Method [20]

Frequency (Event/Yr)	Consequence (\$ x 1000)			
	Very Low	Low	Medium	High
	100	300	1000	3000
0.1	10	30	100	300
0.01	1	3	10	30
0.001	0.1	0.3	1	3
0.0001	0.01	0.03	0.1	0.3

In terms of the technique used, several risk assessment techniques have been proposed in the construction project area, such as Analytical Hierarchy Process (AHP) [23], Monte Carlo Simulation [1], and fuzzy set or fuzzy logic [24], [25], [8]. In general, Kangari [24] classified those types of risk assessment methods into two types, classical models (i.e. probabilistic analysis) and conceptual models (i.e. fuzzy set analysis). However, although these classical models are useful for risk analysis, they

are limited in their applicability in real construction analysis, which is usually imprecise, ill-defined, and vague in nature. This type of problem is caused by incomplete or unavailable information in the construction field. Therefore, linguistic terms are usually used to express the uncertainty related to the risk level such as low, medium, and high. In this case, the use of fuzzy set analysis can be used to overcome the limitation of the probabilistic model. The concept of fuzzy set and fuzzy expert system will be described in section 2.4.

2.3.3.3 Risk Response

After assessing and analyzing the level of risk from each risk factor that is considered significant to the project, the next step of risk management is risk response. Risk response is the action that should be conducted by the management to treat the risk in order to remove as much as possible the potential impact and to increase the control of risk.

According to Al-Bahar [1], the response to risk can be divided into five actions, namely risk avoidance, loss reduction and risk prevention, risk retention, risk transfer (non insurance or contractual transfer), and insurance. First, risk avoidance is the action where the contractor does not proceed to bid or take the project since according to their feeling, the project has high risk level. Second, loss reduction and risk prevention program is conducted by reducing the probability of risk, and reducing the financial severity of risk if it does occur. Third, risk retention is financial plan within the company, where the company may decide to absorb the potential losses. Fourth, risk transfer is the action than can be taken by the contractor to transfer the risk to other parties such as sub contractor or the owner. This risk response is usually performed by making a contractual arrangement between the contractors and other parties. And finally, insurance is the response when the contractor uses the premium insurance to cover their business.

2.4 Fuzzy Logic and Fuzzy Expert System

Fuzzy expert system is one of the most widely used applications of the fuzzy set and fuzzy logic concept [26]. It is also known as fuzzy-rule-based systems, fuzzy model, fuzzy expert system, fuzzy inference system, fuzzy logic controller and fuzzy associative memory. It is an expert system that is developed based on fuzzy set or fuzzy logic concept. An expert system is a program that behaves like an expert for some problem domain that consists of three major blocks: a knowledge base, an inference engine, and a user interface. In short, fuzzy expert system is an expert system that incorporates fuzzy set and/or fuzzy logic into its reasoning process and/or knowledge representation scheme [9].

Kasabov [9] stated that fuzzy expert system consists of five components: fuzzy rule and the membership functions as the system knowledge base, fuzzy inference machine that activates all the fired rules at every cycle, fuzzification and defuzzification, interface unit, and an explanation module. In general, the concept of fuzzy expert system can be depicted in a block diagram as presented in Figure 2.2 . All of these components will be described in more detail in section 2.4.2.

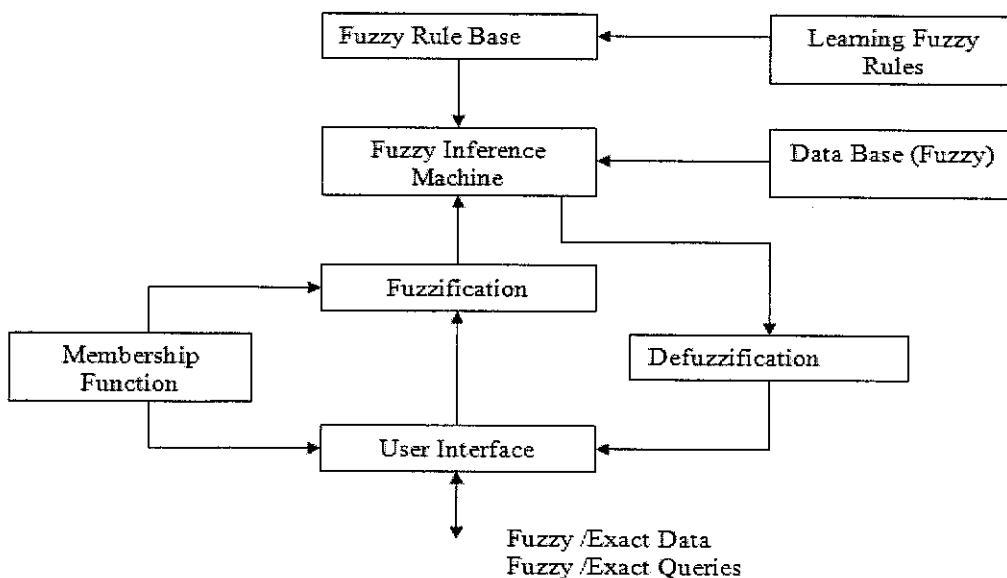


Figure 2.2 Fuzzy Expert System Block Diagram [9]

According to Jang et al. [26], the basic structure of a fuzzy expert system consists of three conceptual components: a rule base, which contains a selection of fuzzy rules; a data base (or dictionary) which defines the membership functions used in the fuzzy rules; and reasoning mechanism, which performs the inference procedure upon the rules and given fact to derive a reasonable output or conclusion. In order to know the concept of the fuzzy expert system, the basic theory of the fuzzy set and fuzzy logic theory will be presented in the following section.

2.4.1 Fuzzy Set and Fuzzy Logic Theory

Fuzzy set can be simply stated as a set with fuzzy boundaries. This is the concept of a set that is used to represent the fuzziness and imprecision. The basic idea of the fuzzy set comes from the condition that there are phenomena that cannot be represented perfectly using conventional set concept (Boolean set).

Fuzzy set is different from Boolean (or also known as crisp) set. In fuzzy set, the degree of belief of every fuzzy subset from “belong to set” to “not belong to set” is represented in a gradual transition which is known as a membership function. The membership function represents the degree of belief of every subset in the universe of discourse by a number between 0-1.

The differences between Boolean and fuzzy set can be described using Figure 2.3 and Figure 2.4 For example, in the case of defining the element of a set or a subset, a linguistic term set is used to represent the risk level such as low, medium and high. By using Boolean concept, a subset is separated sharply as a member of a set or not a member of a set. If it is a member, it is represented as 1 and not a member as 0.

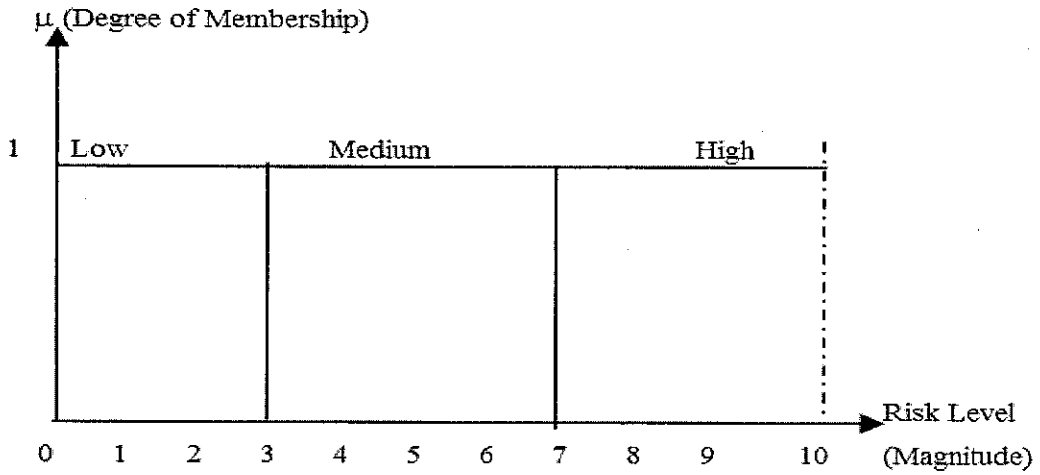


Figure 2.3 Risk Level (Risk Magnitude) in Boolean Set

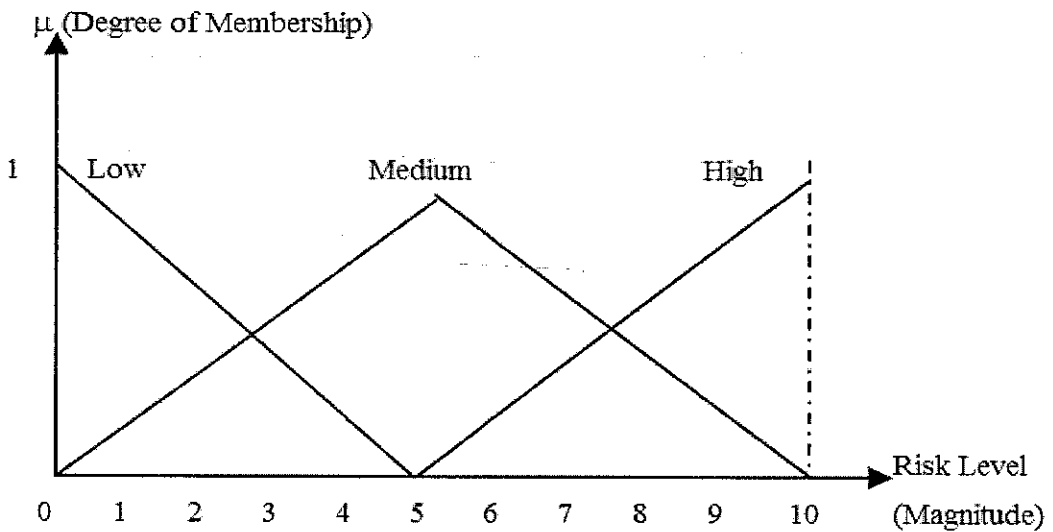


Figure 2.4 Risk Level (Risk Magnitude) in Fuzzy Set

However, in the real condition, to determine the subset of each linguistic term set is not easy since the boundary between each linguistic term is vague. In fuzzy set, this vagueness is represented by the overlapping area between each set as illustrated in Figure 2.4 .

Fuzzy logic is a mathematical tool that is used to model a problem usually surrounded by ambiguity and impreciseness (fuzziness). Fuzzy logic or multi-valued logic was

first introduced in 1930 by Jan Lukasiewicz, a Polish logician and philosopher [27], [28]. In 1965, Lotfi Zadeh rediscovered fuzziness, identified and explored and promoted this concept into a formal system of mathematical logic, which is called fuzzy logic.

2.4.2 Development of Fuzzy Expert System

In general, fuzzy expert system consists of three components, namely membership function, rule base and inference mechanism. Every step involved in developing fuzzy expert system will be described in each of the following sub-sections.

2.4.2.1 Fuzzy Membership Function

Membership function represents the degree of belief of the member of linguistic terms set used in the fuzzy set. Several techniques of developing the fuzzy membership have been proposed by other researchers. Kasabov [9] classified the methods into three types: expert interview, designer's imagination, and using the method of machine learning such as neural network and genetic algorithm. In the expert interview technique, an expert is expected to define the shape of membership function, and the number of labels used. However, this method is sometimes difficult to be applied since human expert is usually unfamiliar with fuzzy set or fuzzy logic. By using the imagination of the designer, the system designer has to imagine the physical behavior of the real system and think about the physical meaning in natural and technical language. While by using the methods of machine learning, a neural network and genetic algorithm are used to learn fuzzy rules from data.

Sivanandam et al. [29] classified the method to assign membership function into seven types, i.e., intuition, inference, rank ordering, angular fuzzy sets, neural networks, genetic algorithm, and inductive reasoning. Intuition is a method that is based on human intelligence and understanding to develop the membership function. This technique requires a person with knowledge of the problem and linguistic variables.

Inference is a method that requires knowledge to perform deductive reasoning. The membership function is formed from known facts and knowledge of the intended area. Rank ordering is a polling concept that assigns membership values by a rank ordering process. In this case, preferences are determined by the use of pair wise comparisons. The result of the rank ordering will then be used to construct the membership function. The angular fuzzy set is a method that is different from the standard fuzzy set in the coordinate description. This set is defined by the universe of angles.

Using the neural network method, the fuzzy membership function is created based on input data set. In this method, the process can be divided into two steps, i.e., training and testing of data set. In the genetic algorithm method, the concept of Darwin's theory of evolution which involves reproduction, crossover, and mutation is applied. Preliminary fuzzy membership function types are assumed in the beginning. In the process, the fitness function is applied to evaluate and choose the fittest membership function. Finally, in the inductive reasoning method, the fuzzy membership function is developed by performing the entropy minimization principle. This method requires a well-defined database for the input-output relationship.

Several important considerations during the construction of the fuzzy membership function are the type of membership function, the model of membership function (linguistic value used and its subset), and also the method used to construct the membership function. The type of membership function can be classified as single valued or singleton, triangular, trapezoidal, sigmoid, Z function and Bell function [9].

There is no specific guidance to determine the number of fuzzy set based on linguistic terms. More importantly, the term used actual field condition [9]. The more fuzzy sets used are better since it will increase the precision of the result, but sometimes it is difficult for the expert to determine its membership function subset. The trial and error method can be used to determine the suitable member of fuzzy sets. The result of analysis can be compared between the actual condition and the output of the

system. The number of fuzzy set can be adjusted during testing and tuning of the system.

2.4.2.2 Fuzzy Rule Base

Fuzzy rule base is the basis or backbone of the fuzzy expert system. Fuzzy rule is also known as fuzzy “IF – THEN” rule, “fuzzy implication” or “fuzzy conditional statement” [26]. It is used as the basis of the composition or reasoning process of the fuzzy expert system model. Fuzzy rule base provides a foundation for approximate reasoning with an imprecise proposition using fuzzy set theory. This concept gives a possibility to model a complex problem by imitating human approximate reasoning that is usually present in IF (antecedent) THEN (consequent) rules. It is represented as a conditional statement in the form of “IF x is A THEN y is B”. Here x and y are linguistic variables, while A and B are linguistic values determined by fuzzy sets in the universe of discourse X and Y, respectively. Examples of linguistic variables are risk level, depth, height and so on. While examples of linguistic value are very low, medium, and high. In the case, “x is A” is called as antecedent or premise part, while “y is B” is called as consequence or conclusion part.

Examples of the fuzzy IF-THEN rules are:

- IF pressure is high, THEN volume is small
- IF the speed is high, THEN apply the brake a little

If there are more than one antecedent (multiple parts) used in the fuzzy rule, the AND or OR fuzzy operator can be used to connect those antecedents part. Example of the fuzzy rule base that uses more than one antecedent part is as follows.

- IF the demand is high AND the supply is low THEN the production is high.

2.4.2.3 Fuzzy Inference Mechanism

Inference mechanism is a process of mapping an input value to the fuzzy expert system for obtaining the output from the system. This process is generated by the use of fuzzy IF-THEN rule that has been embedded into the system.

There are three inference mechanisms that are usually used namely Mamdani, Sugeno and Tsukamoto [26]. However, Mamdani inference mechanism is the most commonly used or applied, especially in fuzzy expert systems [27], [29].

The Mamdani inference mechanism can be divided into five steps, i.e., fuzzification, rule evaluation, implication, aggregation and defuzzification [27]. These five steps can be described graphically as in Figure 2.5 and Figure 2.6 for crisp input and fuzzy input, respectively. In general, the process of fuzzy inference mechanism from these two inputs is the same. The only difference between these two inference mechanisms is in the fuzzification process.

Fuzzification is a process of converting an input into fuzzy data by specifying the input into appropriate fuzzy membership function. In Figure 2.5, the inference mechanism uses a crisp input. In that figure, there are two input variables and one output variable. The input for the variable A “is x_1 ” (a number within the universe of discourse X) and the input for variable B “is y_1 ” (a number within the universe of discourse Y).

The fuzzification process is performed by mapping the input values, x_1 and y_1 in the fuzzy set A_1 and B_1 for the first rule, and fuzzy set A_2 and B_2 for the second rule. The fuzzification result is obtained by getting the intersection between the inputs with the fuzzy membership function curves.

The intersection is obtained by drawing a vertical line from the input to the membership function. The number of intersection can be more than one. The intersection of the vertical line with the fuzzy membership function can be obtained in the value of the membership degree (μ) which is known as “the strength of fire” (α). In the example, since two rules are fired, therefore two strength of fires are produced (α_1 and α_2). This “ α ” value is then used as the basis in the next process which is called implication.

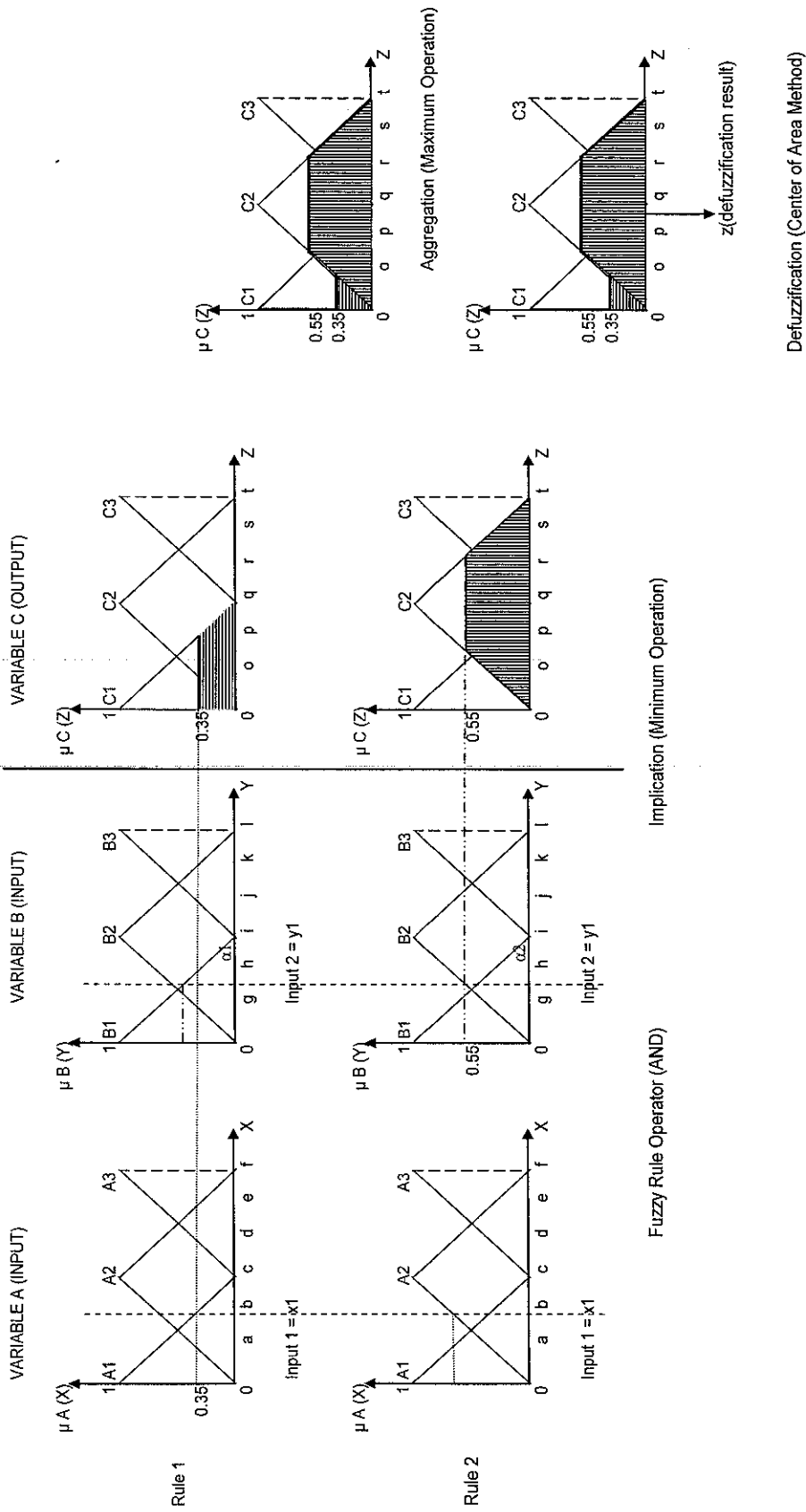


Figure 2.5 Example of Fuzzy Inference Mechanism Process using Crisp Input

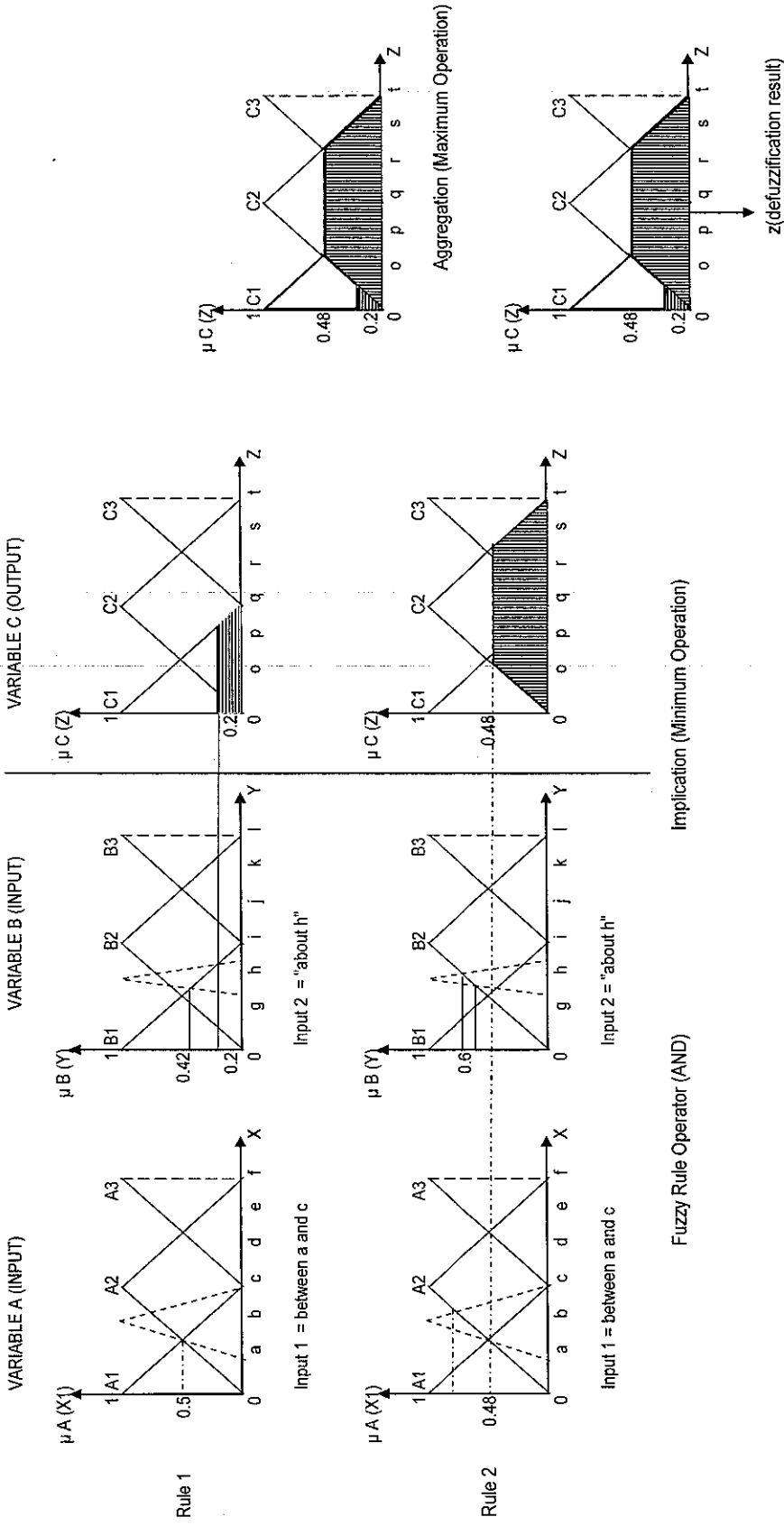


Figure 2.6 Example of Fuzzy Inference Mechanism Process using Fuzzy Input

While for fuzzification using fuzzy input, the input value is represented as a shape constructed from the concept of fuzzy number. It can be represented either in a trapezoidal or triangular form. The example of fuzzy input in Figure 2.6 is the triangular form (dashed line) with the values “between a and c” (a range of number between a and c in the universe of discourse X) and “about h” (a number within the universe of discourse Y). The fuzzification result is obtained from the intersection between the fuzzy number and the fuzzy membership function, which is also called the strength of fire (α).

Implication is the process of mapping the antecedent part from IF-THEN rule into the consequence part. This step is performed by mapping the strength of fire (α) obtained from the fuzzification process to the fuzzy membership of consequence variable (C1 and C2). If there is more than one antecedent part, there must be a fuzzy operator that connects both antecedent parts. There are two fuzzy operators that can be used to connect the antecedent parts, namely the AND and OR operators. An ‘AND’ operator is used for evaluating the conjunction of the rule antecedents, while ‘OR’ operator is used for disjunction of rule antecedents [27]. In both Figure 2.5 and Figure 2.6, ‘AND’ fuzzy operator is used to connect the antecedents parts. The use of ‘AND’ fuzzy operator means the ‘MIN’ function will be used to combine the antecedent parts. Consequently, the minimum value of strength of fire (α) will be used to map the antecedent parts (fuzzy set A and B) to the consequence part (fuzzy set C).

Aggregation is the process of combining or unifying all outputs from the implication process. The number of combined implication depends on the number of fuzzy rules fired at the same time. In the case when the number of rules fired is two, aggregation is conducted from the result of the first and the second rules. However, the result of this aggregation process is a fuzzy set. In order to obtain the crisp number (in this case represented as Z_1), the defuzzification process has to be performed on the aggregation results.

Defuzzification is the process to convert the aggregation result into a crisp value. According to Sivanandam et al. [29], there are seven types of defuzzification method i.e. max-membership principle, centroid method, weighted average method, mean-max membership, centre of sums, centre of largest area, and first of maxima or last of maxima. In MATLAB Fuzzy Logic Toolbox, the defuzzification type can be classified into five, namely, “centroid”, “bisector”, largest of maximum (LOM), middle of maximum (MOM), and smallest of maximum (SOM).

“Centroid” is also called as “center of area” (COA) or “center of gravity” (COG) and is the most widely used method. It uses the center of gravity as the defuzzification result. The bisector method is used by bisecting the area under the curve of the aggregate output set, while “LOM”, “MOM”, and “SOM” use the largest value, mean value and the smallest value, respectively.

2.5 Cost Contingency Practice

Cost contingency has been practiced for a long time in the construction industry. Smith and Bohn [7] interviewed 12 small to medium contractors in the scope of Pennsylvania State University, US. The interviews were intended to identify the risk models and factors that were most frequently considered by contractors in common size projects. According to the results, only 1 out of 12 contractors had used cost contingency in their work. The other 11 contractors did not use contingency since using contingency allowance will most likely make their bids less competitive. The interview also discovered that contractors considered contingency and markup changes separately. It also showed that none of the contractors interviewed had any knowledge of the mathematical models used to formulate contingency, and they did not have any formalized technique for estimating contingency. The interview also revealed that contingency was primarily considered as line item in estimate based on percentage of the total project cost.

In practice, the most common approach for estimating project cost contingency is traditional estimate [3]. This method is mainly based on contractor's intuition and experience. For example, if in the previous project the contractor had been successful by allocating 5% cost contingency to the base cost estimate of the project. Then, in the next tender bidding process the same amount of cost contingency, which is around 5%, will be added again to the base estimate.

However, this is a subjective method based on intuition. Therefore, it has several weaknesses such as danger of being overly simplistic and heavily dependent on the estimators' faith in their own experiences [30]. To overcome this condition, several methods of estimating cost contingency for the construction industry have been proposed by several researchers.

2.6 Methods of Estimating Cost Contingency

According to Burrough and Juntima [31] as cited by Ng [12], in general, the cost contingency method can be classified into four types, namely predetermined percentage, expert judgment, risk analysis and regression analysis.

Predetermined percentage is determined by the owner and project management team by allocating a cost contingency of 5 to 10 percent of base cost estimate. This method is easy to use, but it removes the specificity of the project characteristic. Whereas, expert judgment uses the educated judgment of experts, which involves skilled estimators and project team members to assist in setting the contingency level. This method considers specific risk factors and base estimate competitiveness. The advantage is if the experts are very knowledgeable and objective in their estimate, this method will result in good estimation and vice versa.

Risk analysis examines the risk factors in a structured way by applying quantitative method of translating risks into cost contingency values. Monte Carlo Simulation (MCS) is most commonly applied in this method. A probability distribution is assigned to each line item and randomly simulated to select a possible outcome for

each line item's distribution and aggregates the item outcomes into a total expected project cost outcome. The advantage of this method is that it allows for confidence level to be explicitly considered. The limitation is difficulty in assigning probability distribution to each line item.

Regression analysis is a statistical technique that relates explanatory variables with cost contingency value. The explanatory variables in the regression model are quantified risk drivers based on past projects. The advantage of this method is that it is probabilistic in nature and allows for a statistical confidence level of cost outcomes to be considered. A disadvantage of this method is that sometimes estimate may be based on incomplete data sets.

Previous researchers have presented cost contingency estimation methods. Al-Bahar [1] proposed the use of Monte Carlo Simulation (MCS) to estimate project cost contingency during the tendering stage and construction process. These techniques were incorporated in the risk analysis concept, which consists of risk identification and risk assessment. In this proposed method, the types of risk factors were identified. The relationship between risk factors was modeled by influence diagram technique. Al-Bahar finally proposed the MCS method to estimate the amount of project cost contingency. However, as previously described, the limitation of MCS method is difficulty in assigning probability distribution to each line item and how to interpret the analysis result.

Artificial Neural Network (ANN) has been proposed by Chen and Hartman [6] as a method to estimate cost contingency. This method was proposed for predicting the cost contingency and time allowance at the earliest stage of project development. However, the limitation of this method is that there is no rational explanation to describe and analyze the relationship between inputs and outputs because ANNs are essentially black-box methods. Data go in and predictions come out but there is no understanding of what happens in between [6].

Khalafallah et al. [5] proposed Belief Network as the method to estimate residential project cost contingency in Egypt. Factors that affect the level of risk and uncertainty of a project and, consequently affecting the contractor's estimation of contingency were identified. It was conducted through literature review and unstructured interviews with experts in the domain of residential building construction. In this research, 22 risk factors were identified and ranked based on their relative significance index score (RSIS). A causal belief network is introduced to assess and predict the level of risk and uncertainty associated with a project based on the identified factors. This method involves four steps, which are variable definition, variable relationship, variable state and defining probabilities. However, this method is considered static [5].

Mak and Picken [32] reported the use of Estimating using Risk Analysis (ERA) method that was introduced by the Hong Kong Government. This method implements the use of risk analysis to estimate project cost contingency by identifying and costing risk event or risk factors associated with the project. The starting point of ERA process is a base cost estimate, which is an estimate of the known scope and is risk free. This base estimate is then added to the cost contingencies to determine the project cost. The risk factor types are categorized as fixed and variable risks by the project team. Fixed risk events are those that happen either in total or not at all. If the event happens, a maximum cost will be incurred, if not, then no cost will be incurred. The maximum risk cost is calculated based on the risk probability and maximum risk allowance. Meanwhile, variable risk events are those events that will occur, but the extent to which they will occur is uncertain. All risk events that have been identified are then summed up to obtain the project cost contingency.

Sonmez et al. [4] proposed the method to estimate cost contingency for international construction project during bidding stage. The factors impacting cost contingency were identified. In order to determine the project risk factor, questionnaires were sent to international Turkish contractors. Then, correlation and regression analysis techniques were used to determine the factors included in the model.

Mostly, the works of previous researchers as described in the literature review have been applied within the concept of risk analysis. They were applied by examining risk factors in a structured way and translating them into cost contingency value. The use of risk analysis in the process of identification and assessment of risk gives level of confidence since it is practiced by carefully examining the risk factor types one by one [12]. However, several limitations of the previous methods still exist such as difficulty of application by construction personnel since it still requires statistical knowledge from the user. The summary of the previous methods in estimating cost contingency can be seen in Table 2.3.

According to Kangari [24], the assessment of risk in a construction project is still subjective since it involves the use of linguistic terms such as low, medium and high. The use of linguistic terms is unavoidable due to the incomplete history of data of a construction project. Fuzzy set has been proposed as a method to quantify such linguistic terms in the risk analysis process.

The uses of fuzzy set in estimating cost contingency have been investigated. Paek et al. [10] proposed fuzzy set method in estimating cost contingency. This concept consists of risk elements identification, quantification of risk-associated consequences under uncertainty, development of alternative risk-management strategies, and reassessment of risk-associated consequences. However, one of the limitations of this method is the difficulty in its application [7]. Besides, this method still could not accommodate the use of linguistic terms that are usually used by construction personnels as the basis to express their subjective judgment in the risk assessment process.

Table 2.3 Cost Contingency Estimation Methods

No	Researchers / Methods	Advantage	Disadvantage
1.	Al-Bahar (1988), Monte Carlo Simulation (MCS).	Can address the limitation of the single value estimation. Give an accurate analysis since it is run by a simulation with probabilistic model.	<ul style="list-style-type: none"> o Difficult in assigning probability density function (limitation of historical data and model complexity). o Difficult to understand the analysis result (represented as cumulative density function curve).
2.	Chen and Hartman (2000), Artificial Neural Network (ANN)	Can accommodate a nonlinear relationship between cost contingency variable.	<ul style="list-style-type: none"> o Limitation of historical data. o Cannot accommodate subjective judgment.
3.	Khalafallah et al., Belief Network.	It has abilities for dealing with uncertainties and incomplete data, to assist in the estimation of cost contingency.	<ul style="list-style-type: none"> o The belief network's knowledge is considered static. o Cannot accommodate subjective judgment.
4.	Mak and Picken (2000), Estimate using Risk Analysis (ERA).	Its ability to retain the traditional method of presenting a project cost estimate in the form of a base estimate plus a cost contingency.	<ul style="list-style-type: none"> o Difficulty into determine probability of occurrence of risk items and cost associated with these items due to a lack of data and records. o Cannot accommodate subjective judgment.
5.	Sonmez et al. (2007), Linear Regression.	Can be understood and analyzed in detail, and easy to explain and implement.	<ul style="list-style-type: none"> o Cannot accommodate a nonlinear relationship between each variable. o Limitation of historical data. o Cannot accommodate subjective judgment.

Another fuzzy set method has been proposed by Tah et al. [11]. They presented the use of fuzzy set operation in estimating project cost contingency. In this concept, linguistic terms that are usually used to represent the level of risk such as low, medium and high are accommodated to estimate the level of risk in order to determine the project cost contingency. However, a limitation is still found in this method since the output of the analysis result is still in linguistic terms. Besides, cost contingency value has to be determined based on numerical value. In this case, the analysis output must be converted to a numerical value in order to be used in the bidding stage.

In an attempt to overcome the limitation of the previous methods, this research is intended to investigate and explore the use of fuzzy logic in estimating cost contingency using a fuzzy expert system. The fuzzy expert system is one of the most widely used applications of fuzzy set and fuzzy logic [27]. This research uses the fuzzy expert system to estimate cost contingency for the construction project while accommodating contractor's subjective judgment. This is achieved by incorporating fuzzy expert system in risk analysis technique, which is one of the general methods for estimating project cost contingency. The methodology for the research is explained in the next chapter.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter gives a general overview of the methodology involved in developing and validating the cost contingency estimation model. The whole model development process and its application in a computer tool will be dealt with in greater detail in chapter 4 and 5 respectively.

The research steps involves the development of a conceptual model of cost contingency estimation, data collection, determination of risk factors for use in the model, development of a preliminary fuzzy expert system, composition of preliminary fuzzy expert system scenario, model testing and tuning, validation, and development of a computer tool to demonstrate the application of the proposed method in actual practice. A flowchart for the methodology is presented in Figure 3.1 for guidance.

3.2 Development a Conceptual Model for Project Cost Contingency

The conceptual model forms the basis for the computer model that will be developed based on risk analysis and fuzzy expert system. Prior to developing the computer model, a conceptual model based on cost contingency system behavior will be developed by considering previous models that have been proposed by Al-Bahar [1] and Tah et al. [11].

According to these authors, the factor that influence the project cost contingency is the magnitude of the risk factor. This was also agreed by Sonmez et al. [4] and Mak and Picken [32]. Therefore, the conceptual model of cost contingency will be developed based on the relationship between risk factor and cost contingency.

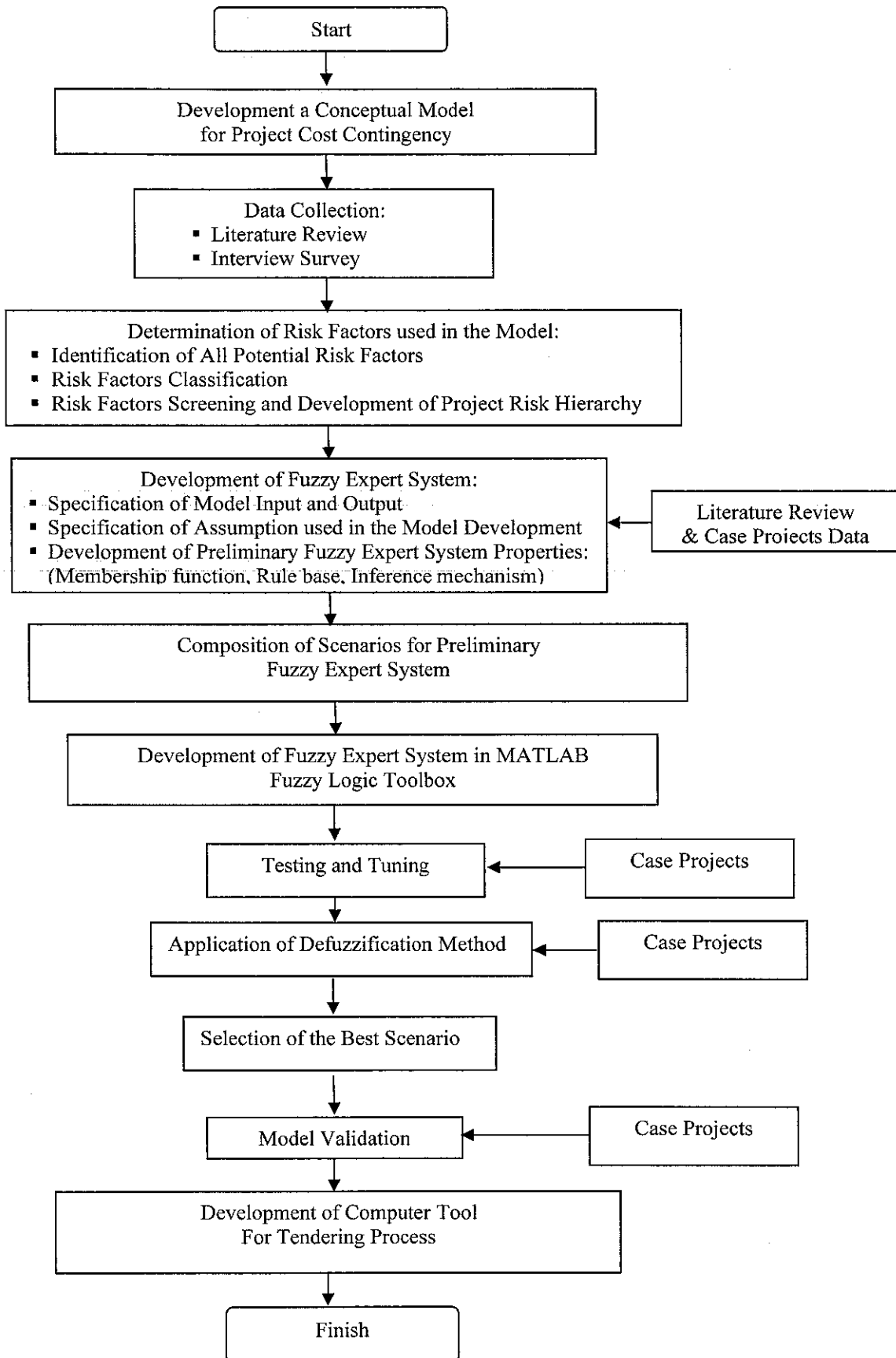


Figure 3.1 Flowchart of Research Methodology

3.3 Data Collection

The data collection process is intended to obtain data that will be used to develop and validate the model. The data needed can be divided into three types, namely risk factors that are significant to building and infrastructure works, fuzzy expert system properties such as fuzzy membership function, rule base and fuzzy inference mechanism, and project data. The data were obtained from literature as well as from field survey.

3.3.1 Data Collection from Literature

A review was conducted by collecting published papers and books that relate to cost contingency model behavior. This contingency behavior will be used as the basis for model development. The type of risk factors might vary from one project to another and between each contractor. However, in this research context, only common risk factors that are usually faced by contractors during the construction process will be used in the model.

Risk factors that are considered significant by contractors for building and infrastructure works are identified through the literature review. The risk factor types obtained from the literature survey are then used to develop a conceptual model, which is the basis for the implementation of the fuzzy expert system.

During the literature review, information regarding the fuzzy expert system properties for each variable in the cost contingency model was also reviewed. Among the information is the universe of discourse in the fuzzy set membership function, the fuzzy inference mechanism procedure consisting of components such as fuzzification procedure, fuzzy rule evaluation, implication process, and defuzzification method.

3.3.1.1 Determination of Risk Factor used in The Model

The step to determine the type of risk factor used in the model is adapted from the method proposed by Wiguna [33]. This method was used since it proposes a technique on how to determine risk factor used in the model by utilizing risk factors from literatures. Several risk factors in construction project can be easily found from literatures [34], [1], [11], [35], [7], [36]. The step can be divided into three parts, namely, identification of all risk factors in the building and infrastructure work, risk factor classification, and risk screening and developing the risk factor relationship.

In the identification step, all risk factors that are related to common construction projects such as building and infrastructure work are identified through the literature review. In the risk classification step, the identified risk factors are then classified according to the characteristic. Similar risk factors that belong to the same classification are combined.

For the risk screening step, the combined risk factors above are further reviewed and reduced to make it easier for the interview respondent during the interview session (Section 3.3.2). Risk factors that are usually not considered by contractors, either because they can be shared or transferred to other parties are removed in order to reduce the number of risk factors.

Finally, the risk factor types that have been reduced are then used to produce the project risk hierarchy. An event tree diagram can be used to compose the project risk hierarchy. Alternatively, an influence diagram can also be used to relate each risk factor and the total project risk. In this research an event tree diagram has been used.

3.3.2 Data Collection from Interview Survey

Survey has been chosen as the method for collecting project data to capture the expert's knowledge regarding the cost contingency behavior. According to

Denscombe [37], interview is used as a technique to obtain an insight and in depth information into the topic. In this study, detailed information on cost contingency practices from the construction experts can be obtained through the interview.

The interviews were conducted selectively with eight contractors in the G7 class (large contractors) of Construction Industry Development Board (CIDB) who are located in Selangor, Penang and Perak, Malaysia. In this research, the tender price estimation is assumed as independent of the contractor's location since in the Malaysian system, all G7 contractors are allowed to operate outside their locations. This means that their practice should be the same anywhere in Malaysia.

The experts who have been chosen as the interviewees are project managers mostly having more than 10 years of working experience in the construction industry. The choice on project managers was made because they usually have a more comprehensive understanding of the project rather than the lower-ranking construction personnel such as estimators or work superintendents.

The projects selected for the surveys are those completed projects, which did not face cost overruns. In other words, the actual cost contingency of the project was just the right amount which is usually between 1 to 10% [38].

Experts in the construction industry have been interviewed to obtain project cost contingency data based on their previous project experiences. The project cost contingency values together with the risk factors that are significant to the project and their risk parameter values are then subjected to the construction expert's evaluation.

The interview form consists of two sections, respondent information and case project for cost contingency estimation. The first section is mainly intended to obtain information regarding the interviewees' experiences in construction projects. The second section is intended to obtain information related to the project and the expert's estimation for cost contingency. Expert judgments in terms of risk likelihood (RL)

and risk severity (RS) are required for those risk factors that are significant to their project.

3.4 Fuzzy Expert System Development

The development of fuzzy expert system can be described based on several parts, namely; specification of model input and output, assumptions used in fuzzy expert system design, data used to develop the model, development of preliminary fuzzy expert system properties, composition of scenarios of preliminary fuzzy expert system, model testing and tuning.

3.4.1 Specification of Model Input and Output

The model input and output was specified based on the project risk hierarchy that has been developed in the previous step. The model input and output is used as the guidance to specify the type of fuzzy expert system properties, i.e. membership function, rule base and inference mechanism.

3.4.2 Assumptions used in Fuzzy Expert System Design

Several assumptions were specified to develop fuzzy expert system for cost contingency estimation model. These assumptions were determined by considering the cost contingency behaviour. The information that can be obtained from literature was used to specify these assumptions.

3.4.3 Data used to Develop the Model

The data used can be classified into two types: data to develop preliminary fuzzy expert system and the actual project cost contingency data to test and validate the model. The data or information required to develop the preliminary model were obtained from literature.

3.4.4 Development of Preliminary Fuzzy Expert System Properties

In this research, a fuzzy expert system has been developed as the preliminary model, which has been tested and validated at a later stage using eleven case projects. The information obtained from the literature and interview surveys were combined to justify the assumption used to develop the preliminary fuzzy expert system properties.

Development of the preliminary fuzzy expert system consists of three stages, namely construction of membership function, development of rule base, and specification of the fuzzy inference mechanism.

3.4.4.1 Construction of Membership Function

Membership function represents the degree of belief of the member of linguistic terms set used in the fuzzy expert system. In this case, there are three membership functions for risk factor parameter, i.e. risk likelihood (RL), risk severity (RS) and risk magnitude (RM).

The membership functions are developed based on information from the literature. The type of membership function shape can be specified based on the information from literature, while the alternative value of the universe of discourse is assigned based on the information from the survey. Based on the cost contingency behaviour, possible alternatives of the fuzzy membership function are specified at this stage.

3.4.4.2 Development of Fuzzy Rule Base

Fuzzy rule base is usually represented using IF (antecedent) and THEN (consequent). The fuzzy rule represents the relationship between three risk parameters, RL, RS and RM. In this case, RL and RS are specified as antecedent part while RM is the consequent part.

The fuzzy rule base is developed by specifying a number of alternatives. In this research, previous rule base proposed in the literature, i.e. by Tah and Carr [25] and An et al. [39] are adapted with some modifications. The modifications were performed in the specification of the RM values, which were determined from the combination of the RL and RS values. In this research, the determination of the RM values was conducted by considering the cost contingency behaviour. This fuzzy rule base can be represented by using a risk matrix.

3.4.4.3 Specification of Fuzzy Inference Mechanism

The fuzzy inference mechanism that involves fuzzification, rule evaluation, implication, aggregation and defuzzification process is specified by observing the project cost contingency system behavior. The fuzzy logic application from previous studies have been adapted to specify the inference mechanism such as the use of fuzzy operator to connect the “antecedent” into “consequence” part in the IF-THEN fuzzy rule base, the implication and aggregation type, and also defuzzification method.

3.4.5 Composition of Scenarios of Preliminary Fuzzy Expert System

Alternatives of the fuzzy expert system properties, such as membership function type and rule base that have been specified earlier are then composed as scenarios. A scenario is a combination of the possible alternatives of the fuzzy expert system properties. The number of scenarios developed depends on the possible combinations of the alternatives developed. These scenarios will be used as the basis in the testing, tuning and validation of the model.

3.4.6 Model Testing and Tuning

After developing the scenarios for the preliminary fuzzy expert system, the next step is to test those models. The purpose of the testing is to choose the best model from the possible scenarios of the preliminary fuzzy expert system that have been developed

earlier. The testing is followed by tuning process, which is aimed at improving the model performance by revising the fuzzy expert system properties such as membership function.

Testing is performed using data from eight projects obtained from the interview sessions. The model testing is performed by inputting a set of input and output from the case projects. The input values are RL and RS values from significant risk factor variables and the output is cost contingency value prediction.

The results of the model testing for all scenarios are then compared to the actual cost contingency (CC). The best scenario is then chosen as the final model for the system. Error parameter is used as the basis for choosing the best scenario [40], [41]. The error represents the difference between the model prediction and the actual cost contingency value. The actual cost contingency is the total amount of contingency that has been spent by the contractor at the end of the project and can be different from the planned CC allocated to the project during tendering. This is necessary for this research as the model has to be developed, tested and tuned to actual CC value at the end of the project.

The error is calculated by using Equation 3.1.

$$\text{Error} = \frac{(\text{Predicted CC} - \text{Actual CC})}{\text{Actual CC}} \times 100\% \quad (3.1)$$

In this research, the model has been tested using data from more than one project, which generated several error values depending on the project. Therefore, the average error which is known as the Mean Absolute Error (MAE) is used [4]. MAE is calculated using Equation 3.2.

$$\text{MAE} = \frac{\sum_{i=1}^n |\text{Predicted CC} - \text{Actual CC}|}{n} \quad (3.2)$$

Where n is the number of data.

The scenario that produces minimum MAE is chosen as the “best scenario”. In order to improve the model accuracy, tuning process is performed on the best scenario. Tuning was conducted by changing the fuzzy expert system properties such as membership function. Every tuning process is followed by testing, based on actual case projects using the same procedure that has been described earlier. In addition, the application of several defuzzification methods is also performed to improve the model accuracy. The same testing procedure is repeated for this step.

3.5 Model Validation

Validation is performed to ensure that the model prediction is comparable with the real world within an acceptable level of accuracy. The validation procedure is same as the testing procedure that is by comparing the output of the optimum model to the actual cost contingency. However, the case projects used in the validation process are different from the case projects that have been used in the model testing and tuning during the model development process. Three case projects were used for this validation process.

3.6 Development of a Computer Tool for Estimating Tender Price

In order to demonstrate the applicability of the cost contingency model in estimating contractor’s tender price, a computer tool has also been developed. This computer tool is designed to accommodate the contractor’s judgment. By entering three values into the system, which are base cost estimate, RL and RS values, a contractor can obtain recommended tender price from the system. The contractor can also use the trial method to estimate an appropriate tender price and cost contingency value by modifying the RL and RS variable values. In this case, the contractor will be guided to estimate a competitive bidding price in a flexible and rational way by applying the risk management concept.

CHAPTER 4

DEVELOPMENT OF COST CONTINGENCY MODEL

4.1 Introduction

This chapter describes in detail the process of developing the project cost contingency model based on risk analysis and fuzzy expert system. The model is applied for building and infrastructure works. The development of the cost contingency model consists of three main steps: development of a conceptual model for cost contingency, determination of type of risks factors used in the model and development of the fuzzy expert system.

4.2 Development of a Conceptual Model for Project Cost Contingency

A conceptual model forms the basis for implementing the fuzzy expert system. The conceptual model is used to show the relationship between the dependent and independent variables in the cost contingency system. In this context, project cost contingency can be assumed as the dependent variable while the number and type of risk factors as the independent variables.

The conceptual model of cost contingency can be specified by reviewing previous models. Cost contingency (CC) is a summation of the risk magnitude of risk factor (RM) that is considered significant to a project [1], [11], [32]. Mathematically, the relation between CC and the RM of each risk factor can be expressed in Equation 4.1.

$$CC = RM_1 + RM_2 + RM_3 + \dots + RM_n \quad (4.1)$$

where

CC = cost contingency value

RM = risk magnitude for each risk factor

1,2,3,..n = the number of risk factor

RM is proposed to be measured based on two risk variables, known as risk likelihood (RL) and risk severity (RS). According to Mak and Picken [32] the relationship between RL, RS and RM can be stated as a multiplication function. However, sometimes it is better represented as a nonlinear relationship as suggested by AS/NZS [20]. Therefore, in this research, the relationship between RM, RL and RS is stated as in Equation 4.2 below.

$$RM_i = f(RL_i, RS_i) \quad (4.2)$$

where

RM = risk magnitude

f = function

RL = risk likelihood

RS = risk severity

i = number of risk factor

In conclusion, the cost contingency (CC) value is a function of risk factor magnitude (RM) of all risk factors. Therefore, it is necessary to specify the relationship between RM for all risk factors with the CC value. The process of specifying of this relationship was conducted through the identification of possible cost contingency models.

4.2.1 Possible Cost Contingency Models

Two alternatives have been identified to relate risk factors with cost contingency. First alternative is applying influence diagram to relate each risk factor as proposed by Al-Bahar [1]. Second one is representing the risk factor relationship using event tree diagram as proposed by Tah et al. [11].

4.2.1.1 Influence Diagram Model

Every risk factor in the influence diagram model is assumed to be related to each other. However, if the numbers of risk factors that must be included in the model are too many, it is difficult to accommodate the relationship in one influence diagram. In order to simplify the relationship between each factor, a classification of risk factors based on major risk (MR) is used. Consequently, two influence diagram models need to be developed. First, the influence diagram which is used to relate RM to other RM and their MR. Second, the influence diagram that is used to relate MR to the CC.

The influence diagram model to relate the RM with other RM and to their MR is given in Figure 4.1. In this model, every RM that influences other RM or MR is illustrated by using an arrow. For example, RM_{1A} (risk factor 1 within major risk A) influences RM_{2A} , RM_{4A} , RM_{5A} and MR_A . Therefore, the relationship is given by drawing an arrow from this RM_{1A} to the other factor influenced by it. The MR is the summation of the entire RM of all risk factors. The influence diagram model is also used to relate the MR with the CC value as can be seen in Figure 4.2.

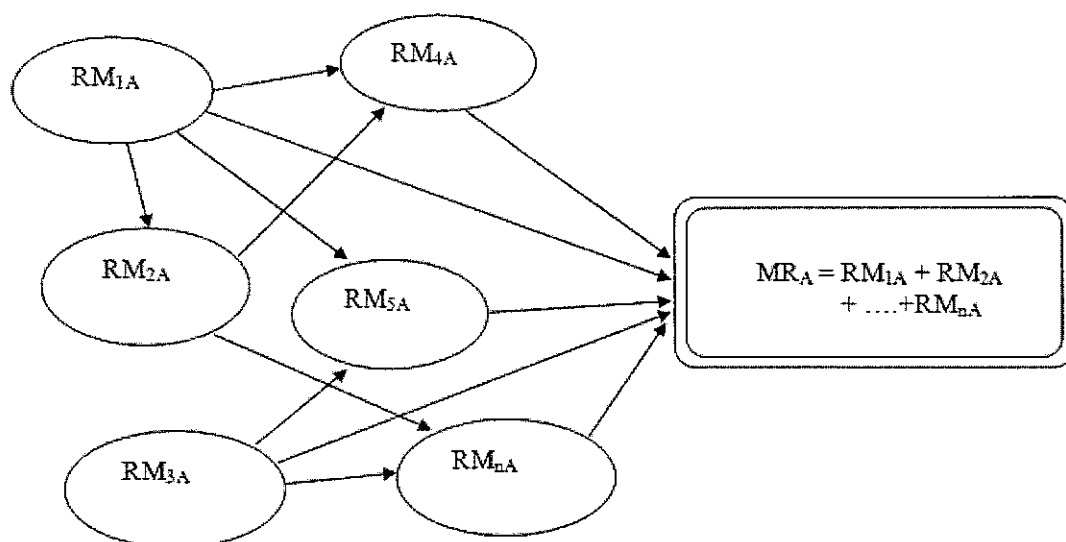


Figure 4.1 First Project Cost Contingency Model: Relationship of Risk Magnitude of Risk Factor (RM) with Major Risk (MR)

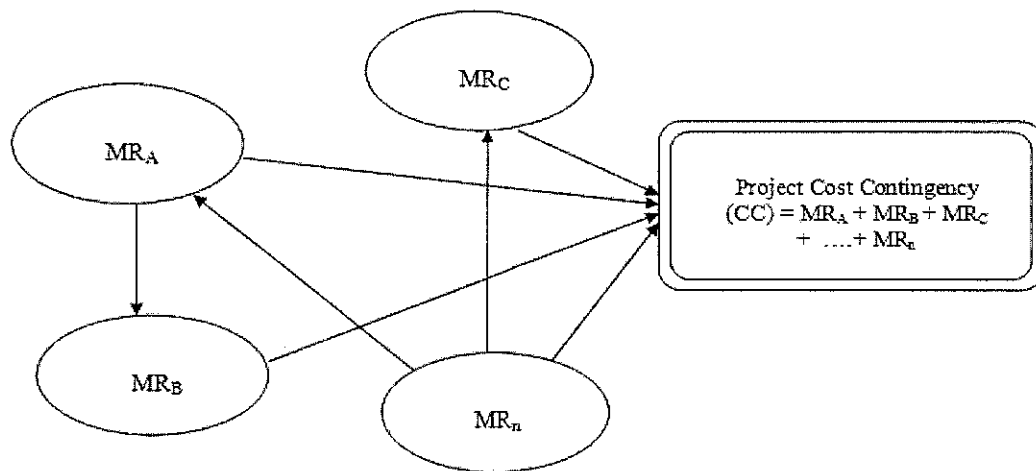


Figure 4.2 First Project Cost Contingency Model:
Relationship of Major Risk (MR) with Project Cost Contingency (CC)

4.2.1.2 Event Tree Diagram Model

The second alternative is to represent the risk factor relationship using event tree diagram as illustrated in Figure 4.3. The figure shows three level of project risk hierarchy. Level 1 indicates the project cost contingency, which is equal to total project risk. Level 2 denotes the type of major risk which is constructed by risk magnitude of risk factors in Level 3. This level (Level 3) is the lowest part of the project risk hierarchy.

In this concept, every RM is assumed as not influencing each other. Every RM is assumed to only influence their MR in their upper level. On the other hand, CC is influenced by the MR. However, to use this second alternative; the risk factor types that will be selected in the model must not have a relationship between each other.

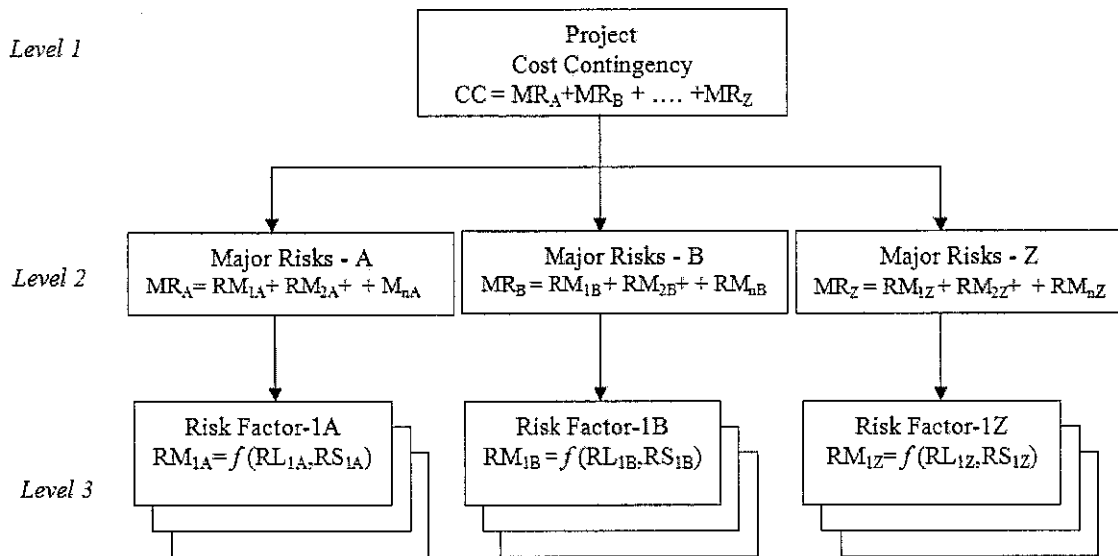


Figure 4.3 Second Project Cost Contingency Model using Event Tree Diagram

From these two alternatives, the second model was chosen for this research. The use of influence diagram will cause complexities in the modeling process using fuzzy expert system. It is difficult to model the RM relationship because every risk factor is related to each other. Therefore, the RM relationship is simplified by using event tree diagram. The most important consideration is the RM that will be included in the model, must easily be assessed by the user and does not have any bias to other risk factors.

4.3 Determination of Risk Factor for the Model

The cost contingency model developed in the previous section represents a general concept for all construction types. However, the number and type of risk factors could be different for a specific construction types. Therefore, in this research, the implementation of the proposed concept will be mainly focused on building and infrastructure that are the most common types of project undertaken by the contractors. The types of risk factors used in this model are the common risk factors

that are usually considered significant for common construction projects and for most contractors.

In order to determine the risk factors for the model, several steps have been determined, which are adapted from Wiguna [33]. The steps involves: (i) identification of all potential risk factors, (ii) risk factor classification, and (iii) risk screening and project risk hierarchy development. The details of these steps are presented in the following sections.

4.3.1 Identification of All Potential Risk Factors

This step is aimed at identifying every potential risk factor that could happen during the construction process. It is a process to find what will happen and how it happens. The risk factor identification is the key of a successful risk analysis method. Without a proper identification, significant risk factors will not become obvious and will be missed.

The identification of potential risk factors was carried out by conducting a literature review. The work of previous researchers who have presented the type of risk factors present in construction projects were reviewed, [34], [1], [11], [35], [7], [36]. The detail process of identifying the risk factor is given in Appendix A.

4.3.2 Risk Factor Classification

The risk factors obtained from the identification stage were re-evaluated and reclassified to reduce the number of risk factors. This was done due to two reasons. First, not all of the identified risk factors have significant influence to the project. According to Pareto's Law or what is known as the 80/20 rule, the significant are few and the insignificant are many [38]. In most cases, only a few of the identified risk factor are significant to a project. However, this few risk factors can have great impact

on the project. Second, too many factors listed in the model might cause confusion for the user.

All these identified risk factors were then reviewed by classifying the risk factors into major risk (MR) categories depending on the nature of the risk factor. Similar risk factors were combined or developed into a new risk factor type. Finally, 25 risk factors were identified and listed in Appendix B.

4.3.3 Risk Factor Screening and Development Project Risk Hierarchy

For the risk screening step, the 25 combined risk factors are further reviewed and reduced to make it easier during the interview session. The risk factor screening was conducted based on two considerations. First, several extraordinary risk factors such as natural disasters, failure of owner (bankruptcy), monetary crisis, high interest rate and public disorder which can be categorized as force majeure, were not included in the model since they are usually not considered by the contractor in the calculation of cost contingency [38]. Second, risk factors that can be transferred or shared to other parties were also excluded from the model. These risk factors are defective design, incomplete design, condition of contract, changes in work scope, and availability of funding cost.

Finally, 14 risk factors were selected for the model. These risk factors that have been selected from the potential risk factors were classified and constructed into a project risk hierarchy [11], [36]. The 14 risk factors obtained from the previous section were classified as either internal or external risk and were used to develop the project risk hierarchy as shown in Figure 4.4.

In general, the project risk hierarchy consists of two major risks, internal and external. The external major risk term is used to categorize the risk factors that are not within the contractor's control. Usually this kind of risks is associated with the force of nature, regulations, economic conditions or involving a third party.

The risk factors identified as external risks in this model are; site condition, weather condition, changes in government policy, social impact, changes in economic condition, delayed on payment, and third party delays. Site condition relates to the field topography, which is sometimes difficult to be quantified accurately. Weather Condition relates to daily weather in particular rainy days, which usually cannot be predicted accurately but has impact on the construction progress. Changes in government policy relates to new regulation pertaining to permit, tax, and other policies that influence the construction industry. Social impact is concerning the impact of the construction project to the surrounding environment such as pollution, damage to other facilities and so on. Changes in economic condition, addresses the financial impact to a project such as increase in prices of building materials. Delayed payment concerns the delay in payment from the owner. The construction could also be affected by any delays by the sub contractors or suppliers, which is classified as third party delays.

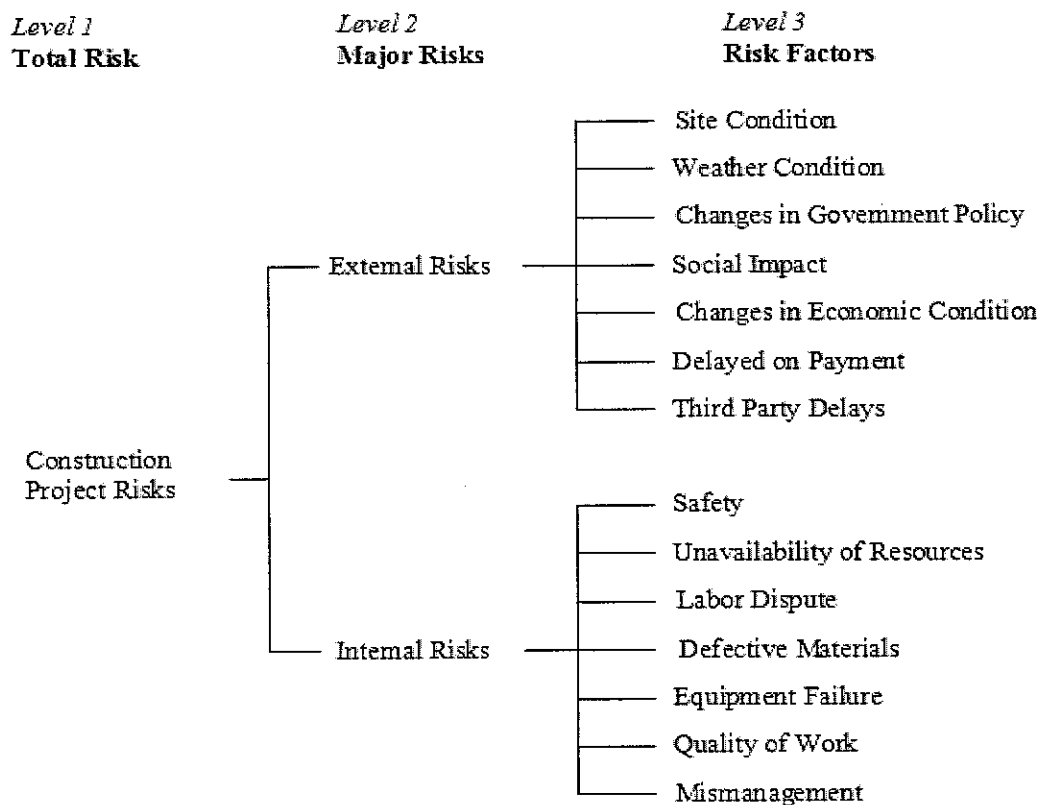


Figure 4.4 Project Risk Hierarchy

Other risk factors in the risk hierarchy such as safety, unavailability of resources, labour dispute, defective material, equipment failure, quality of work, and mismanagement are classified as internal risks. Safety is a risk related to accidents that might happen during the construction process. Unavailability of resources relates to the difficulty in getting labour, equipment or material. Labour dispute could arise due to dissatisfaction among the workers and could be in the form of a strike. Defective material is related to the defect of the construction material either because of flood or off-spec material that is not returnable. Equipment failure or problem such as inoperability of the tower crane, electricity failure etc, also present a risk. Quality of work, a complaint from the owner regarding the work quality could arise due to owner's dissatisfaction. Mismanagement of the project could be due to inaccurate calculation or prediction from the contractor.

For the confirmation, the opinions of two construction experts who were contractor project managers were sought to determine whether the risk factors used in this model were suitable for building and infrastructure work. Both the experts agreed that the risk factors included in this model are appropriate for this type of construction project.

4.4 Fuzzy Expert System Development

As described earlier, the relationship between three risk variables; RL, RS and RM will be represented using IF-THEN rule, which involves the use of linguistic terms. The use of fuzzy logic is proposed to relate the three risk variables since the use of linguistic terms is usually vague and imprecise. Besides, fuzzy logic can also be applied to accommodate the use of subjective judgment based on linguistic terms such as "low", "medium" and "high" in the risk analysis.

The development of fuzzy expert system can be described into several parts, namely specification of model input and output, assumptions used in fuzzy expert system design, data to develop the model, development of preliminary fuzzy expert system,

composition of preliminary fuzzy expert system scenario, model building in MATLAB software, model testing and tuning.

4.4.1 Specification of Input and Output

The input and output for the fuzzy expert system can be identified from the expected outcome and type of factors that influence the outcome. The project cost contingency model using event tree diagram, which is shown in Figure 4.3 was used as a guidance to determine the input and output of the fuzzy expert system. The project risk hierarchy which is shown in the Figure 4.4 was then incorporated to the model in the Figure 4.3 to get the proposed cost contingency model as can be seen in Figure 4.5.

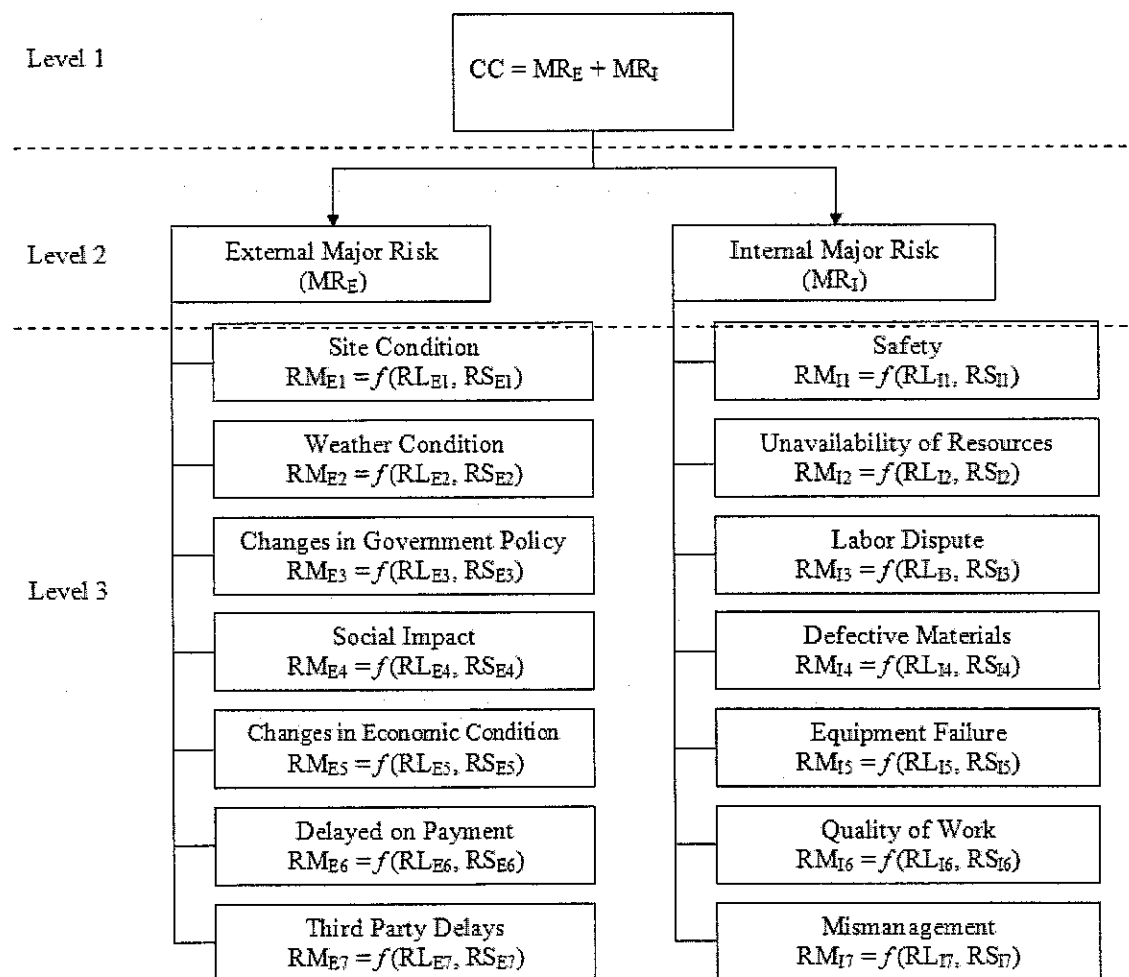


Figure 4.5 Fuzzy Expert System for Cost Contingency Model

The fuzzy expert system is applied in the third level of the project risk hierarchy to estimate the RM value for individual risk factor. RM is set as the output, while RL and RS are the input to the system. The major risks (MR) variable is calculated as a summation of the all risk factors within its class. This process is conducted in Level 2. All the major risk obtained in Level 2 is summed up to retrieve CC value in Level 1. It is not necessary to model the MR and CC as a fuzzy expert system since the individual RM value obtained is in the single point estimate or crisp number, not in the fuzzy set. The defuzzification process will be performed in every fuzzy expert system to obtain this crisp number.

4.4.2 Assumptions Used in Fuzzy Expert System Design

In this research, the fuzzy expert system was developed based on several assumptions as follows:

1. The number of fuzzy expert systems properties that needs to be developed in this model is equal to the number of significant risk factors that have been identified earlier, which are 14 in this case. However, in this model, all risk factor types are designed as a generic or uniform fuzzy expert system property. A previous research opted to design one uniform fuzzy model for all risk factors in order to simplify the model [8]. Designing different fuzzy expert systems for every risk factor will cause difficulties in the tuning process since there will be so many possibilities that must be specified.
2. The preliminary fuzzy expert system was designed based on scenarios. The scenarios were constructed based on possible fuzzy expert system properties. To reduce the number of scenarios, several background theories can also be used. At the end, the best scenario was chosen after testing and tuning the model.
3. A number of computer programs can be used to develop fuzzy expert systems such as C/C++, Visual Basic, Fuzzy CLIPS and Matrix Laboratory (MATLAB). In this model, MATLAB is used to develop the fuzzy expert system using its Fuzzy Logic Toolbox which is easy to be used.

4.4.3 Data Used to Develop the Model

The data used can be classified into two types: data to develop preliminary fuzzy expert system and the actual project cost contingency data to test and validate the model. The data or information required to develop the preliminary model were obtained from literature. These data or information will be further explained in Section 4.5.4, The Fuzzy Expert System Development.

Actual project cost contingency data were obtained from the survey interviews, which were used to test and to validate the model. The interview form is appended in Appendix C. In total, there were 11 case projects obtained from a series of interviews involving 8 construction experts. From these 11 case projects, 8 case projects were used for the testing and tuning and 3 case projects were used for the validation. The validation process will be explained in Chapter 5.

The experts were project managers with very experience in the construction business, who were selected from the list of G7 (large) contractors in the Construction Industry Development Board (CIDB) website [42].

Six contractors were located in Perak, while the other two located in Selangor and Penang. The location of the contractors is considered as not influencing on the data because every contractor in the G7 class is qualified to carry out a project in any part of Malaysia and including overseas.

In terms of educational background, most of the project managers hold a Bachelor's degree and only one project manager who hold Bachelor and also Master's degree. The expert's experiences are mostly between 10 to 25 years in the construction industry. For the numbers of projects that have been managed, most of the experts have experiences in managing more than six building projects while half of them have experience managing more than six infrastructures projects. The backgrounds of the experts are summarized as in Table 4.1.

Table 4.1 Construction Experts Background

No	Item	No. of Experts		
1	Location of Company	Perak	6	
		Selangor	1	
		Penang	1	
2	Educational Background	BSc.	7	
		Master	1	
3	Total Experience in Construction Industry	5-10 Years	1	
		10-15 Years	2	
		16-20 Years	3	
		21-25 Years	2	
		0-5 Projects	2	
4	Construction Project Involved	Buildings	6-10 Projects	3
			11-20 Projects	2
			> 20 Projects	1
		Infrastructures	0-5 Projects	4
			6-10 Projects	2
			11-15 Projects	2

The data provided by the experts were both input and output data. The input data are the type of risk factors that were considered significant to the project and the value of its RL and RS variables. The output is the total cost contingency value for the project. The projects that were chosen for developing the model (including validation) were projects that have cost contingency between 3 to 8 % of the total cost. Seven out of the eleven selected projects were government projects while four other were private projects. More detailed information to those eleven projects is provided in Appendix D.

4.4.4 Development of Preliminary Fuzzy Expert System Properties

This section discusses the process of designing the preliminary fuzzy expert system properties at the conceptual stage. The development of the fuzzy expert system properties utilizing MATLAB Fuzzy Logic Toolbox will be explained in detail in Section 4.5.6.

4.4.4.1 Fuzzy Membership Function

According to Kasabov [9], there are three methods that can be used to develop the membership function, which are expert's interview, designer's own mind, and machine-learning of the input and output data. From these methods, the second method was chosen to be applied in this research. The first method is difficult to be applied since the expert is not very familiar in articulating their linguistic terms [9]. Even though they usually use this term to represent the risk parameter value, but it is not articulated in a systematic way. The third method is also difficult to be applied since it usually requires large amount of data. Therefore, the second method which is based on designer's own mind was chosen.

The membership function of every risk parameters (RL, RS and RM) consist of properties that must be specified such as the universe of discourse, the number of linguistic terms, the membership function shape, the numerical range of linguistic terms and also the overlap between each term. For each property, there are several possible numerical ranges or descriptions that can be used. However, not all possibilities need to be considered. Only those that seem appropriate to the model were developed. In order to identify the appropriate possibilities, information and theory related to the model behavior and fuzzy expert system were used.

Risk Likelihood (RL)

As defined earlier, in this work, risk likelihood (RL) represents the subjective probability of a risk factor occurrence. There are five properties must be specified for the RL membership functions which are the universe of discourse, linguistic terms, membership function range, membership function shape, and overlap value between each membership function.

The "universe of discourse" for the RL membership function is in the scale of 0 to 100. It was intended to give a larger scale for the users in order to get an accurate RL value. The universe of discourse is mainly used to represent the degree of belief of

the user on the RL variable. The number used in the universe of discourse in the membership function is more intended to represent the subjective probability rather than objective probability, which is usually represented using a number between 0 to 1 [1], [9].

Regarding the number of linguistic terms for the model, there is no strict guidance that can be used to determine the suitable number of terms. However, the number of linguistic terms used in the model must represent the actual field condition [9]. In order to meet this requirement, five linguistic variables are recommended to represent the RL level, even though, in actual practice, there may be only three terms used to specify the level of risk, such as “low”, “medium” and “high”. This is because sometimes the use of those three terms may not be sufficient to represent the level of risk occurrence. Therefore, the use of additional terms such as “very low” or “very high” is unavoidable. In this design model, five linguistic terms were used for representing the RL value, namely very low (VL), low (L), medium (M), high (H) and very high (VH).

The membership function range of each linguistic term was determined by dividing the universe of discourse area into five parts according to the number of linguistic terms used. In each case, the area is made equal. The third property of the membership function, i.e. the membership function shape does not have much influence on the performance of the fuzzy expert system. Fuzzy expert system can still behave well even though its membership function is not defined precisely [28].

The membership function shapes can be a single value or singleton, triangular, trapezoidal, sigmoid, Z function or bell function [9]. However, in fuzzy expert system developments, triangular and trapezoidal membership functions are usually used [27], [29]. Therefore, the triangular membership function shape was used for all RL values because it is the simplest type of membership function to be used. This type of membership function is very simple to be developed since only three parameters need to be specified, i.e. left and right leg and also the peak of membership value.

As for the overlapping values of fuzzy membership function between two adjacent linguistic terms this was set in the range of 25-50% [28]. The design of fuzzy membership function for RL variable can be seen in Figure 4.6 .

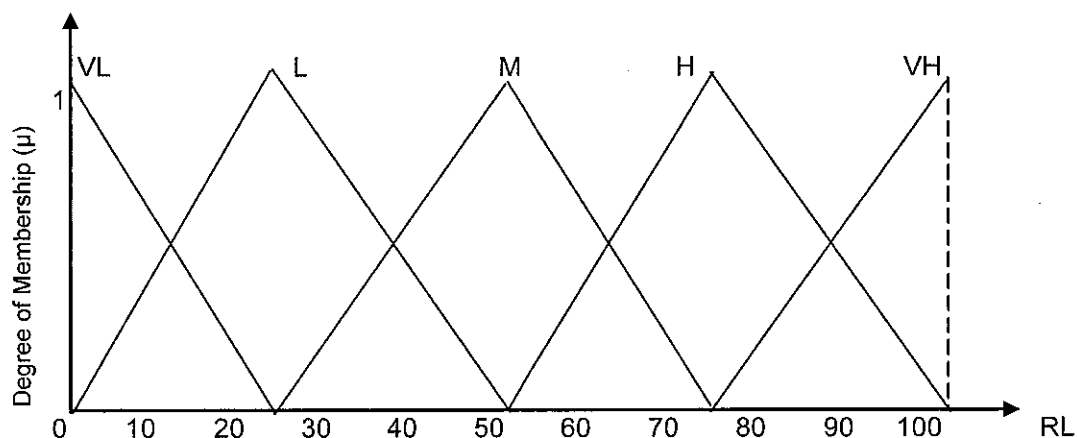


Figure 4.6 Preliminary Membership Function of RL Variable

The property of the RL membership function is described in Table 4.2. The first column represents the linguistic value used in the RL membership function. The second column represents the type of membership function used while the third column in the table represents the three parameters of the triangular membership function. Those three numbers represent the property of triangular membership function. The first and third numbers represent left and right leg of the triangular membership function and the middle represents the peak of the membership function.

Table 4.2 Preliminary Membership Function Properties for RL Variable

No	RL Value	Shape of Membership Function	Membership Function Parameters (Likelihood 0 -100)
1	Very Low (VL)	Triangular	(0, 0, 25)
2	Low (L)	Triangular	(0,25,50)
3	Medium (M)	Triangular	(25,50,75)
4	High (H)	Triangular	(50,75,100)
5	Very High (VH)	Triangular	(75,100,100)

Risk Severity (RS) and Risk Magnitude (RM)

The same design of membership function for the RS and RM was used since both RM and RS represent the level of impact of risk factor. These two variables are usually represented in terms of monetary value. Therefore, in this design, all the membership function properties such as unit, shape and overlap for these two variables were designed the same.

With regard to the unit used, the RS and RM were represented as a percentage of the total project cost or project contract value [7]. By setting the membership function unit as uniform, the system can be used for other project types too. This means that although the RS value can vary depending on the project, this model can still be used by converting the RS value into a percentage of the total project cost. Moreover, by representing the RS value in percentage terms of total project cost, it will be easier for the user to remember its value from their previous project.

The universe of discourse used for RS and RM variables were determined based on scenarios since their maximum values cannot be known precisely. However, according to the interview results, the maximum RS for a project is 2% from the total project cost. Therefore, in this case, the scenario for the maximum universe of discourse for the RS and RM were designed up to 4% of the total project cost since this value is considered as high for every risk factor.

Five alternatives were designed for the RS and RM membership functions. The first alternative was designed using a universe of discourse between 0 - 2% of the total project cost. The second, third, fourth and fifth were designed using a scale between 0 - 2.5%, 0 - 3%, 0 - 3.5%, and 0 - 4%, respectively.

An example of the RS or RM membership function for the first alternative can be seen in Figure 4.7. The maximum universe of discourse is 2% as shown by the dashed line. This universe of discourse is divided into five areas according to the number of

linguistic terms used, VL, L, M, H, and VH. The interval value of each linguistic term as well as the RL membership function was determined subjectively.

Fuzzy triangular membership functions were also used for all RS and RM variables. The fuzzy membership function property for RS and RM variables for the first alternative is tabulated in Table 4.3. The overall fuzzy membership function properties can be seen in Table 4.4. The procedures used to develop all those alternatives are the same as for the first alternative as described before.

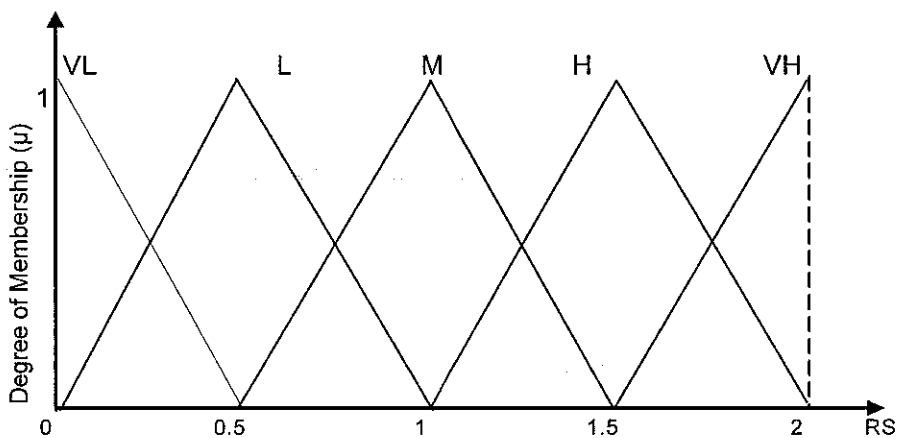


Figure 4.7 First Alternative of Preliminary Membership Function for RS or RM Variables

Table 4.3 Preliminary Membership Function Properties for RS and RM Variables of First Alternative

No	RS Value	Type of MF	MF Parameters (% Total Project Cost)
1	Very Low (VL)	Triangular	(0, 0, 0.5)
2	Low (L)	Triangular	(0, 0.5, 1)
3	Medium (M)	Triangular	(0.5, 1, 1.5)
4	High (H)	Triangular	(1, 1.5, 2)
5	Very High (VH)	Triangular	(1.5, 2, 2)

Table 4.4 Overall Membership Function Properties for Five Alternatives of RS or RM Variables

Alternative	Range of Discourse	Linguistic Terms Parameters	MF Parameters
1	0-2	Very Low	(0, 0, 0.5)
		Low	(0, 0.5, 1)
		Medium	(0.5, 1, 1.5)
		High	(1, 1.5, 2)
		Very High	(1.5, 2, 2)
2	0-2.5	Very Low	(0, 0, 0.625)
		Low	(0, 0.625, 1.25)
		Medium	(0.625, 1.25, 1.875)
		High	(1.25, 1.875, 2.25)
		Very High	(1.875, 2.5, 2.5)
3	0-3	Very Low	(0, 0, 0.75)
		Low	(0, 0.75, 1.5)
		Medium	(0.75, 1.5, 2.25)
		High	(1.5, 2.25, 3)
		Very High	(2.25, 3, 3)
4	0-3.5	Very Low	(0, 0, 0.875)
		Low	(0, 0.875, 1.75)
		Medium	(0.875, 1.75, 2.63)
		High	(1.75, 2.63, 3.5)
		Very High	(2.63, 3.5, 3.5)
5	0-4	Very Low	(0, 0, 1)
		Low	(0, 1, 2)
		Medium	(1, 2, 3)
		High	(2, 3, 4)
		Very High	(3, 4, 4)

4.4.4.2 Fuzzy Rule Base

Fuzzy rule base is the main component of the fuzzy expert system or fuzzy inference mechanism. It is used as the basis to perform approximate reasoning. Fuzzy rule base is represented using IF (antecedent) – THEN (consequent). The RL and RS variables are designed as the antecedent parts, while the RM variable as the consequence part. Since there are two antecedent parts, there must be a connection operator to connect them. Two choices can be used to connect the antecedent part, either using an “OR”

or an “AND” fuzzy operator. “OR” operator is used to evaluate the disjunction of the rule while “AND” is used for conjunction evaluation [27].

In this model, since these two conditions must be satisfied to obtain the RM value, the “AND” operator is used to connect the antecedent part of RL and RS variables. The general form of the fuzzy rule base used can be stated as in Equation 4.3.

$$R^k: \text{IF } RL_i^k \text{ is } A_i^k \text{ AND } RS_i^k \text{ is } B_i^k \text{ THEN } RM_i^k \text{ is } C_i^k \quad (4.3)$$

where:

R = rule base

K = number of rule base (1, 2, 3,...m)

RL, RS and RM = risk variables

A, B and C = risk values / linguistic terms

i = risk factors (1, 2, 3,.....n)

The number of fuzzy rule bases that should be developed is equal to the number of risk factors (i) and the number of linguistic terms used. However, since in this preliminary model all risk factors will be designed as generic fuzzy expert system, so the number of fuzzy rule only depend on the number of linguistic terms used. In this case, since there are five linguistic terms used, therefore, the rules that have to be developed is equal to $5^2 = 25$ fuzzy rule bases.

Previous fuzzy rules, which have been found in the literature, as presented by Tah and Carr [25] and An et al. [39], were used as guidance. Based on this, two alternatives of fuzzy rule bases have been developed. These two fuzzy rules were referred to as rule alternatives, A and B. These two fuzzy rules are represented as a risk matrix as shown in Table 4.5 and Table 4.6. In these tables, the RL, RS and RM values are assigned based on five linguistic terms as has been specified in the membership function model, namely “very low” or “VL”, “low” or L, ‘medium” or “M”, high or “H” and

“very high” or “VH”. The RM value is assigned in the matrix based on the combination of the RL categories in the second left column and the RS value in the second row in the tables.

Table 4.5 Preliminary Fuzzy Rule Base Alternative A

Risk Magnitude (RM)		Risk Severity (RS)				
		VL	L	M	H	VH
Risk Likelihood (RL)	VL	<u>VL</u>	VL	L	L	M
	L	VL	<u>L</u>	L	M	M
	M	VL	L	<u>M</u>	M	H
	H	VL	L	M	<u>H</u>	H
	VH	VL	L	M	H	<u>VH</u>

Table 4.6 Preliminary Fuzzy Rule Base Alternative B

Risk Magnitude (RM)		Risk Severity (RS)				
		VL	L	M	H	VH
Risk Likelihood (RL)	VL	<u>VL</u>	$L^{0.5}$	L	$M^{0.5}$	M
	L	VL	<u>L</u>	$M^{0.5}$	M	$H^{0.5}$
	M	VL	L	<u>M</u>	$H^{0.5}$	H
	H	VL	L	M	<u>H</u>	$VH^{0.5}$
	VH	VL	L	M	H	<u>VH</u>

These two fuzzy rule bases were developed by assigning the RM values for every combination of RL and RS values using the following steps. First, for the RM values in the main diagonal line/area (bold underlined letters), their values are set to be the same as the RL and RS values since both variables also have the same values. Second, the RM values for the other diagonal area were assigned based on two categories: diagonal lines below and above the main diagonal line. First, for the RM values in the area below the main diagonal line, the RM values were set same as the upper RM

values (in that diagonal area). This was based on the assumption that the maximum RM values for this area will be the same as the RS values in the same column even though for different RL values. The same RM values were set for both fuzzy rule alternatives, A and B.

Second, for the area above the main diagonal line, the RM value was assigned by using the middle value of the term between the RL and RS values. For example, for the RL value equals to “very low” and RS equals to “medium”, the RM value assigned was “low”, which is the middle value between “very low” and “medium”. However, for several cases, since the middle value cannot be estimated precisely, the RM values were assigned based on possible values. For example, for the RL value equals to “very low” and RS equals to “low”, the possible RM values are “very low” and “low”. These two possibilities of RM values were accommodated by composing two alternatives, A and B.

In rule alternative A, as tabulated in Table 4.5, the fuzzy rule was specified based on the “optimistic” or “progressive” estimation of the RM value. For example, when the RL value equals to “very low” and the RS value equals to “low” (row 1 column 2), the RM value assigned was “very low”. On the other hand, in Alternative B, as tabulated in Table 4.6, the RM value assigned was “low”. The estimation in alternative B can be considered as “conservative” compared to that in alternative A. In this alternative, more weightage was given to RS rather than RL as suggested by Ayyub [19] and Loosemore et al. [21]. This was in consideration that RS has a greater influence on RM rather than RL. This can be illustrated in the case when a risk factor that has a “very high” RL value but a “very low” RS value can still resulted in a “very low” RM value.

On the contrary, a risk factor that has “very low” RL value, but “very high” RS value could have a “very high” RM value. However, the numerical weightage between 0 to 1 can be given to the fuzzy rule in order to differentiate the RM values between the RL in this category from other higher level of RL values. In this table, the weightage

given is 0.5. The same method was also applied when assigning the RM values whenever their terms cannot be estimated precisely. In this research, both fuzzy rules were then used as the fuzzy rule alternatives, which were later composed as fuzzy expert system scenarios.

The fuzzy rule base can then be read using IF (antecedent) THEN (consequent). For example, the rule which is taken from Table 4.5 can be read as follows:

- IF RL is VL AND RS is VL THEN RM is VL
- IF RL is VL AND RS is L THEN RM is VL
- IF RL is VL AND RS is M THEN RM is L

4.4.4.3 Fuzzy Inference Mechanism

Fuzzy inference is a process of mapping a given input to an output by using the theory of fuzzy set. This process can be divided into five stages, i.e. fuzzification, fuzzy rule evaluation, implication, aggregation and defuzzification.

Fuzzification

Fuzzification is a process to convert a crisp input (non fuzzy) into a fuzzy expert system. The process is conducted by mapping the input of RL and RS variables into the fuzzy membership function. In this model, the RL and RS inputs are designed as crisp input. The fuzzy input which is usually represented using linguistic terms such as “very low”, “low”, “medium” and “high” can be transferred into crisp number with the guidance of linguistic terms membership function. For example, if the input of RL variable is considered as belonging to “medium” term, the numerical number within the range of the “medium” membership function can be chosen to accommodate the subjective judgment from the user. As for the input using fuzzy number such as “between 10 to 20”, the middle value can be chosen. In cases where the input is in the form of fuzzy data such as “about 20”, the input number that equals to 20 will be taken as the value.

Since the number of antecedent parts (RL and RS) is more than one, which is called “multiple antecedents”, the fuzzy rule base should be connected using a fuzzy operator to obtain only one strength of fire (α) that will be mapped into the consequence part (RM variable).

In this model, since both of these two variables are believed to have influence on the output (RM value), therefore, “AND” operator was applied as fuzzy operator. Two types of functions can be assigned from the use of “AND” fuzzy operator, namely truncation and product. The truncation is the most widely used, and therefore, it was also applied for this model. By using truncation type, the fuzzy rule evaluation was conducted by using minimum function as stated in Equation 4.4.

$$\alpha_k = \mu_{RL_i^k}(x_i) \wedge \mu_{RS_i^k}(y_i) \quad (4.4)$$

Where:

α = firing strength

μ_{RL} , μ_{RS} = membership function of risk factors of RL and RS variables, respectively

\wedge = minimum function

k = number of rule base (1, 2, 3...m)

x , y = crisp input of RL and RS, respectively

Implication

Implication is the process of mapping the antecedent part (RL and RS variables) into the consequence (RM variable). This step is performed by mapping the level of strength of fire (α) to the fuzzy membership of RM variable.

The firing strength (α) values obtained from the fuzzy rule evaluation is then mapped into the consequence part of the fuzzy membership (RM variable) through the implication process. The height of intersection between α and the RM fuzzy

membership function is the control output (CO) and can be expressed mathematically as in Equation 4.5.

$$CO_i = \alpha_k \wedge \mu_{RM_i^k}(z_i) \quad (4.5)$$

Where:

CO = control output

i = risk factors (1, 2, 3,n)

α = firing strength

μ_{RM} = membership function of risk factors of RM variable

z = fuzzy output of RM

k = number of rule base (1, 2, 3....m)

Aggregation

The implication process is conducted when the appropriate fuzzy rules are fired. The fuzzy rule can be fired by entering the input to the fuzzy expert system. From the input given, more than one fuzzy rule can be fired at the same time. Therefore, this implication process will result in several CO values that must be combined. The combination of the several CO values is called the aggregation process. The aggregation process can be conducted using Equation 4.6.

$$\mu_{agg}(z_i) = \{(\alpha_k \wedge \mu_{RM_i^k}(z_i)) \vee (\alpha_{k+1} \wedge \mu_{RM_i^{k+1}}(z_i)) \vee (\alpha_{k+2} \wedge \mu_{RM_i^{k+2}}(z_i)) \vee \dots \vee (\alpha_m \wedge \mu_{RM_i^m}(z_i))\} \quad (4.6)$$

Where:

α = firing strength

μ_{RM} = membership function of RM variable

z = fuzzy output of RM

i = risk factor (1, 2, 3....n)

k = number of rule base (1, 2, 3....m)

Defuzzification

Defuzzification is the process of converting the aggregation result, which is in fuzzy set into a crisp value. There are five types of defuzzification can be used in the fuzzy expert system, namely Centroid, Bisector, LOM, MOM, SOM [29]. However, the centroid (or center of area/COA) is the most widely used for fuzzy expert system development [27]. This method was used in this model as stated in Equation 4.7.

$$z_{COA}^* = \frac{\sum_{x=a}^b \mu_A(x)x}{\sum_{x=a}^b \mu_A(x)} \quad (4.7)$$

where:

z_{COA}^* = fuzzy output of center of area

μ_A = membership value of the output from fuzzy set A

x = subset of the fuzzy set A

4.4.5 Composition of Scenarios for Preliminary Fuzzy Expert System

Based on the alternatives developed in section 4.5.4, ten model scenarios for the preliminary fuzzy expert system design was composed. Scenario is a possible combination of alternatives of the RL membership function, RS and RM membership function, and the fuzzy rule base developed in the model. Table 4.7 shows the scenario composition of the preliminary fuzzy expert system model. For example, Scenario 1A is composed of RL membership function (uniform type for all RL), alternative 1 of RS and RM membership function, and alternative A of the fuzzy rule base.

In general, the scenarios can be classified into A and B. Every scenario consists of 5 types of the RS and RM membership function, while membership function of RL variable was fixed. For the fuzzy inference mechanism, only the Mamdani inference type was used since it is most widely accepted to capture expert's knowledge [27]. The Mamdani type consists of MIN implication and MAX aggregation.

Table 4.7 Composition of Scenarios Used in Fuzzy Expert System

No	Scenario	Fuzzy Expert System Properties						
		RL Membership Function	RS & RM Membership Function	Rule Base	Fuzzy Operator	Implication	Aggregation	Defuzzification
1	1A	Uniform Type	Alternative 1	Alternative A	AND	MIN	MAX	COA
2	2A	Uniform Type	Alternative 2	Alternative A	AND	MIN	MAX	COA
3	3A	Uniform Type	Alternative 3	Alternative A	AND	MIN	MAX	COA
4	4A	Uniform Type	Alternative 4	Alternative A	AND	MIN	MAX	COA
5	5A	Uniform Type	Alternative 5	Alternative A	AND	MIN	MAX	COA
6	1B	Uniform Type	Alternative 1	Alternative B	AND	MIN	MAX	COA
7	2B	Uniform Type	Alternative 2	Alternative B	AND	MIN	MAX	COA
8	3B	Uniform Type	Alternative 3	Alternative B	AND	MIN	MAX	COA
9	4B	Uniform Type	Alternative 4	Alternative B	AND	MIN	MAX	COA
10	5B	Uniform Type	Alternative 5	Alternative B	AND	MIN	MAX	COA

4.4.6 Model Building using MATLAB Fuzzy Logic Toolbox

Having set all parameters of the preliminary fuzzy system, the next step is to develop the system using MATLAB Fuzzy logic toolbox. Scenario 1A will be used as an example to demonstrate the fuzzy expert system development in MATLAB Fuzzy Logic Toolbox.

The process of developing fuzzy expert system using the MATLAB Fuzzy Logic Toolbox can be divided into three stages, namely specifying the membership function, building fuzzy rule base, and determining the fuzzy inference mechanism. The fuzzy membership function was specified for RL, RS and RM variables in similar way as in the previous model development. For RL variable, the membership function can be specified by entering the property of the membership function for the RL variable as can be seen in Figure 4.8.

In that figure, the range of universe of discourse between 0 to 100 was specified for the RL variable. Linguistic terms such as very low (VL), low (L), medium (M), high

(H) and very high (VH) can be entered into the toolbox by specifying the parameter. Since a triangular shape fuzzy membership function was used in this model, so three parameters of the triangular membership function should be determined, namely the left and right legs values and also the peak value. All the three membership function parameters for each linguistic term can be input in the “params” space.

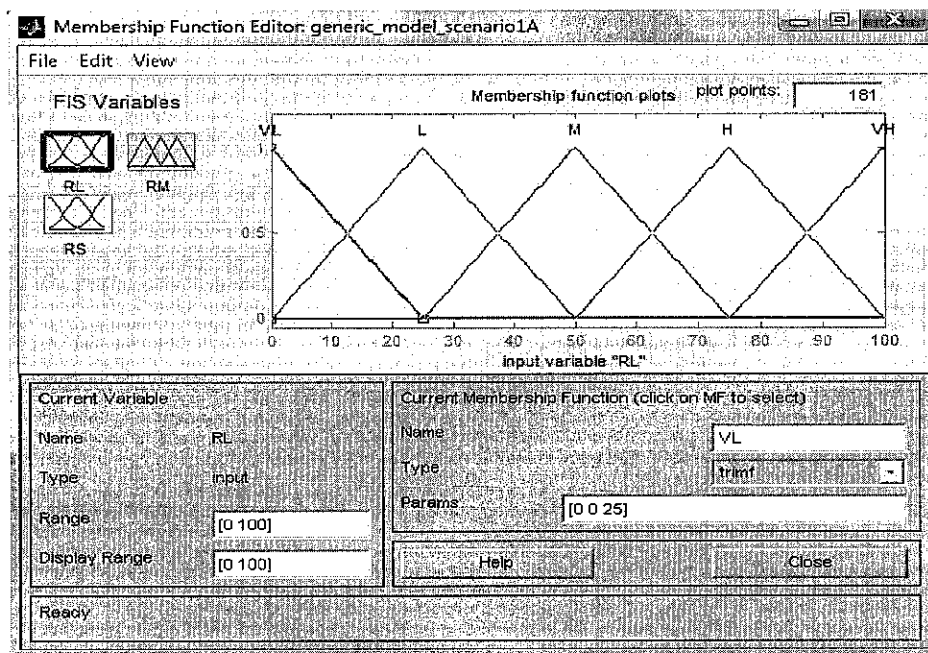


Figure 4.8 Development of RL Membership Function
in MATLAB Fuzzy Logic Toolbox

As for the RS and RM variables, the types of membership function developed can be seen in Figure 4.9 and Figure 4.10. The procedures to develop the membership function for these two variables were the same as for the RL variables. However, the ranges of universe of discourse used were 0 to 2 %.

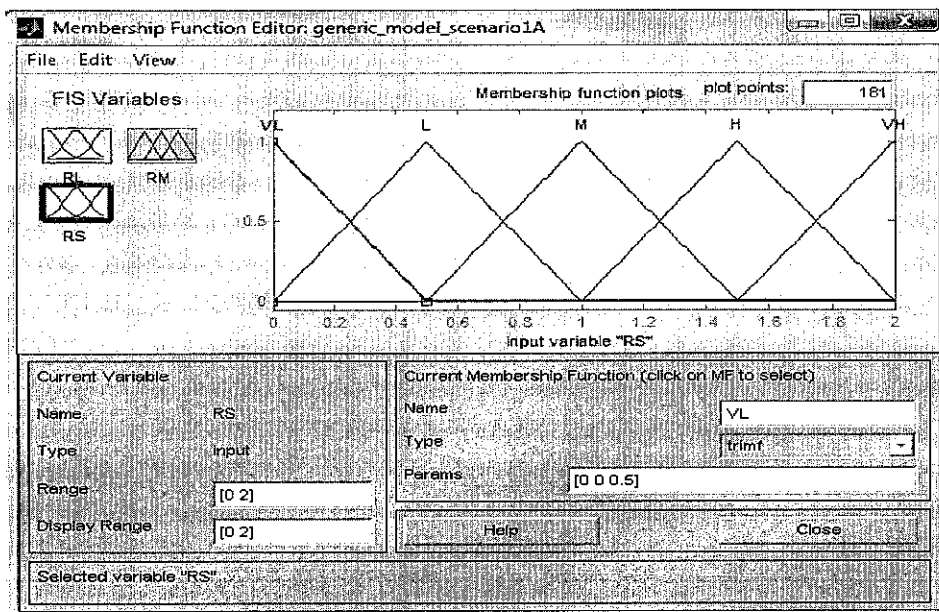


Figure 4.9 Development of RS Membership Function in MATLAB Fuzzy Logic Toolbox

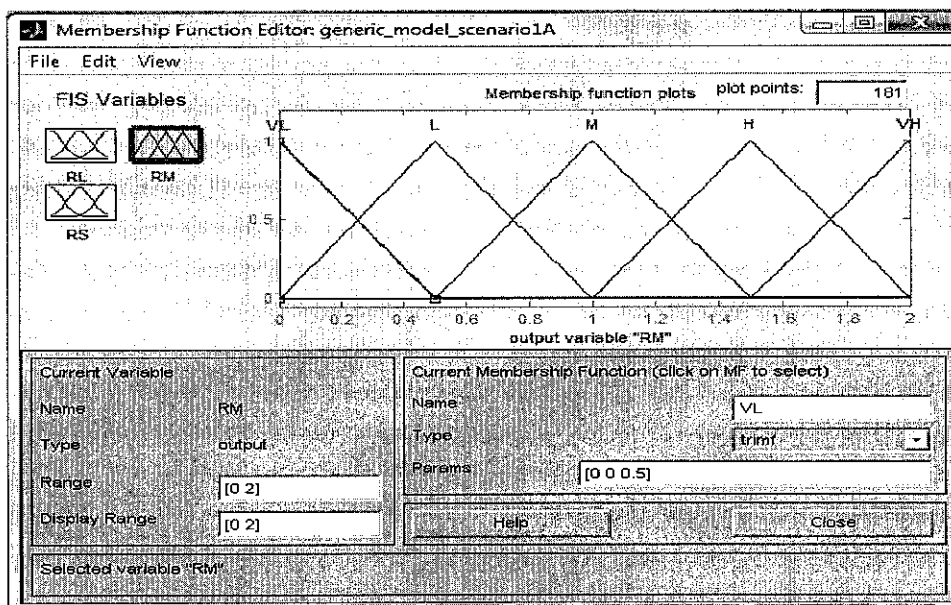


Figure 4.10 Development of RM Membership Function in MATLAB Fuzzy Logic Toolbox

The fuzzy rule base can be built in the rule dialog box as shown in Figure 4.11. To build the fuzzy rule base in MATLAB, the RL, RS, and RM linguistic values must be

specified and connected using a fuzzy operator, which has been pre-determined in the conceptual design. The total 25 rules must be entered into the toolbox.

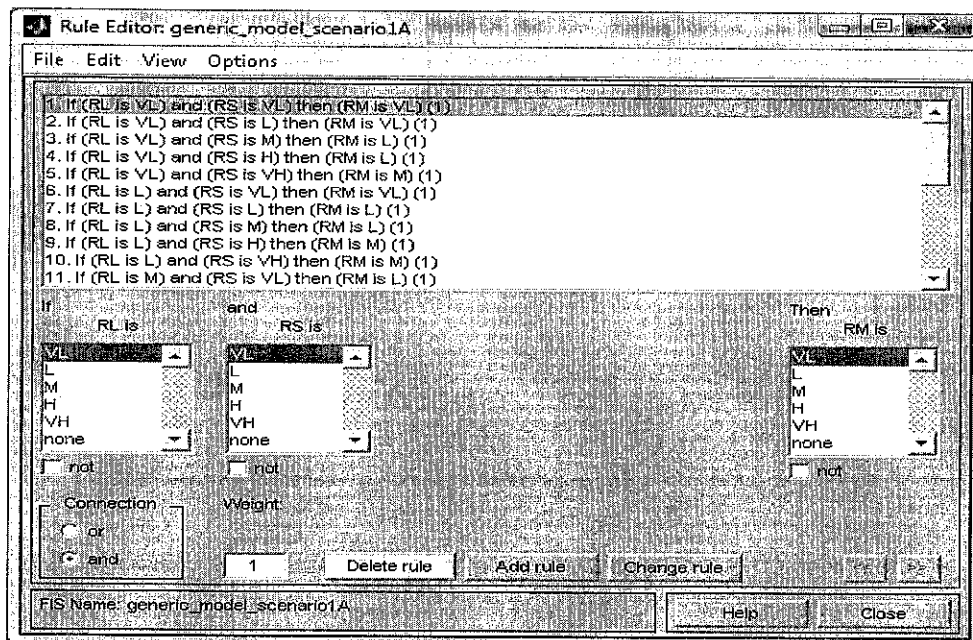


Figure 4.11 Development of Fuzzy Rule Base in MATLAB Fuzzy Logic Toolbox

The fuzzy inference mechanism specified in the conceptual design can be set in the dialog box as shown in Figure 4.12. The inference mechanism that involves the use of fuzzy operator, implication, aggregation and defuzzification type must be specified. Based on the preliminary model design, the “AND” fuzzy operator and the Mamdani fuzzy inference mechanism were selected for the model. For “AND” fuzzy operator, MIN function is entered in the toolbox. For the implication and aggregation, MIN and MAX operation is specified since the Mamdani fuzzy inference mechanism has been incorporated in this model.

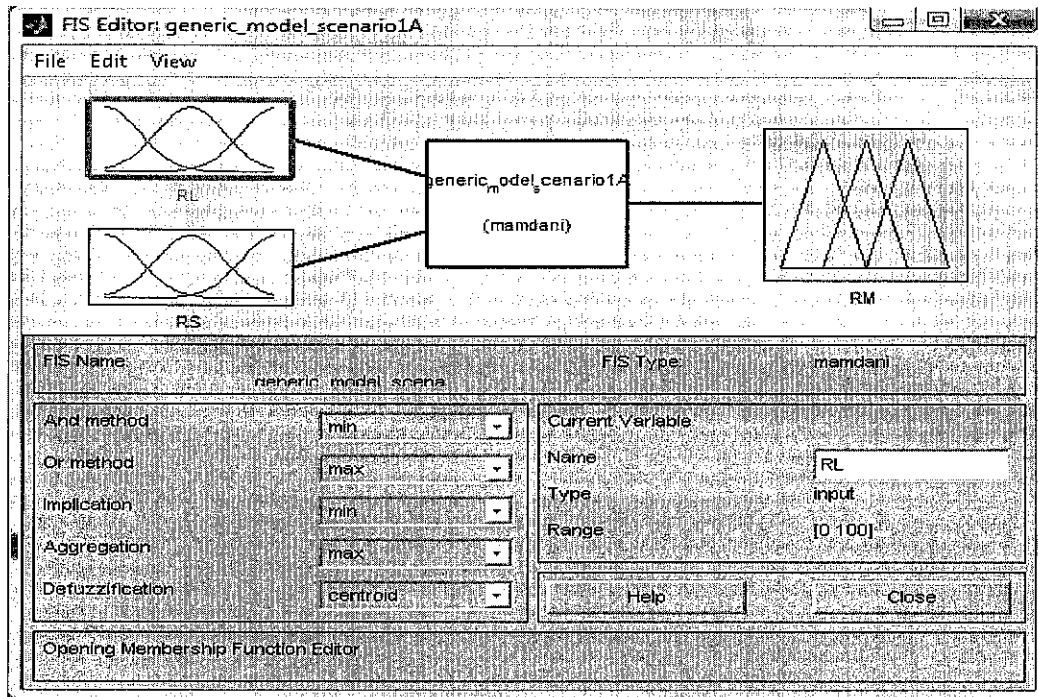


Figure 4.12 Fuzzy Inference Mechanism Setting in MATLAB Fuzzy Logic Toolbox

4.4.7 Model Testing

As described in the research methodology, the purpose of the model testing is to choose the best model from the possible scenarios of the preliminary fuzzy expert system have been developed. The model testing was performed using eight case projects that were obtained from interview.

4.4.7.1 Testing Procedure

The testing was performed by entering the RL and RS values for all significant risk factors in the project into the fuzzy expert system. RM value for every risk factor was calculated by using fuzzy expert system. The cost contingency is obtained by summing all the RM values for all risk factors.

The cost contingency values predicted by the system were then compared to the actual cost contingency concluded or revealed at the end of the project (Actual CC). An error analysis was used to compare between the prediction and the actual cost

contingency to the project. The comparison was conducted by calculating the error value, which has been formulated in Equation 3.1. Mean Absolute Error (MAE), which has been formulated in Equation 3.2, was also used, in order to choose the best scenario. Both equations have been stated in Section 3.6 Chapter 3.

4.4.7.2 Testing Example

All testing was performed by Fuzzy Logic toolbox simulation. However, to demonstrate the mechanism on how fuzzy expert system is used in this system, an example of the analysis, which is part of the testing, will be given in this section.

Project 1 was used as the example to demonstrate the manual calculation of the fuzzy expert system. This project was an infrastructure work owned by the government. The planned cost contingency in the bidding stage was around 5% from the total project cost while the actual cost contingency was around 4.7%. Details of the project are given in the Table 4.8.

The project data obtained from the contractor were a set of input and output values. The input values are RL and RS for each risk factor that was considered significant to the project. The output value is the actual total cost contingency for the project. The risk factors that were considered significant and the RL and RS values estimated by the contractor are shown in Table 4.9.

The RL and RS values in the table were then entered into the fuzzy expert system. In the example given here, only the calculation of the second risk factor “Site Condition” will be shown. The calculation of the other risk factor was conducted using the same procedure.

Table 4.8 Project 1 Information

Project type	Infrastructure work
Owner	Government
Location	Putrajaya
Year	2004 - 2005
Contract type	Bill of Quantity
Total duration	12 months
Nominal contract price	RM 20 million
Base cost estimate	RM 18 million
Planned cost contingency (% of total project cost)	5 %
Actual cost contingency (% of total project cost)	4.7 %

Table 4.9 Input Values for Project 1 Risk Parameters

No (1)	Risk Factors (2)	RL (0 – 100 scale) (3)	RS (% total project cost) (4)
<i>A. External Risks</i>			
1.	Different Site condition	60	1
2.	Weather condition	20	0.25
3.	Social impact	20	0.25
4.	Changes in economic condition	50	1
5.	Third party delays	10	0.25
<i>B. Internal Risks</i>			
1.	Defective material	40	0.25
2.	Quality of work	30	0.3

The manual calculation can be described based on four steps, i.e. fuzzification, implication, aggregation and defuzzification.

Fuzzification

The fuzzification process can be described in Figure 4.13 and Figure 4.14. For RL variable, the input value to the system was 60. Fuzzification process was then performed by drawing a vertical line at the value $RL = 60$. The vertical line intersects “M” and “H” membership functions. The horizontal line was then drawn from each intersection point to obtain the degree of belief from the fuzzification process. The belief of degree obtained was 0.6 for the “M” membership function and 0.4 for the “H” membership function.

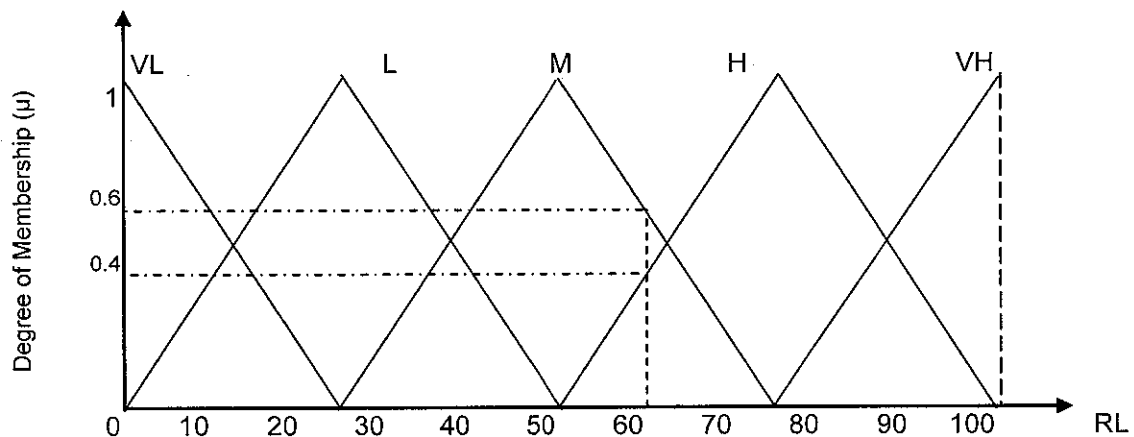


Figure 4.13 Fuzzification Process for RL Input

The same process was performed for RS variable. The RS input given to the system was 1%. The vertical line drawn from 1% intersects the “M” membership function with a degree of belief equal to 1. The fuzzification results stated as RL^* and RS^* can be written as:

$$RL^* = \{(M, 0.6), (H, 0.4)\}$$

$$RS^* = \{(M, 1)\}$$

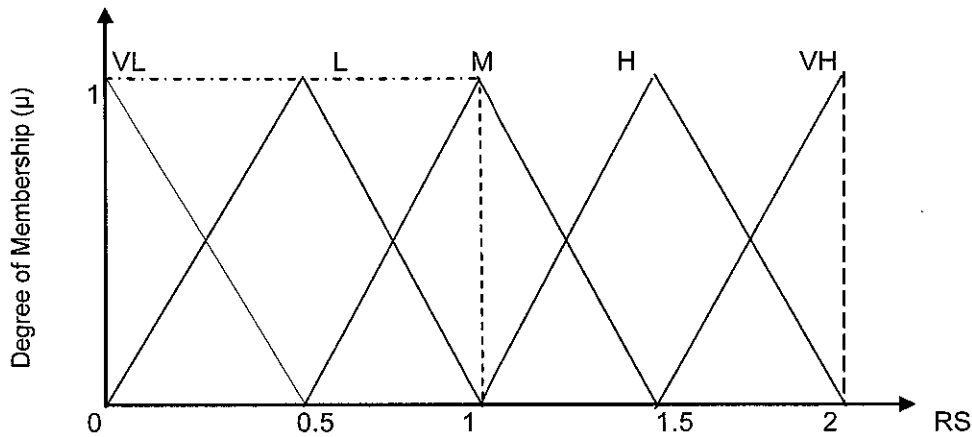


Figure 4.14 Fuzzification Process for RS Input

Implication

The implication process was performed by combining the RL^* and RS^* values using “AND” fuzzy operator. In this case, AND operator has been specified in this model to connect RL and RS variables since both conditions are required to determine the RM membership value. Minimum fuzzy operation was used as the “AND” operator to connect the antecedent parts.

According to the fuzzification process described above, two rules were fired from this process. RL input firing the VL and L membership function while RS input firing the L membership function. According to the rule base in Scenario A, the rules that were fired are:

1. IF RL is M and RS is M Then RM is M
2. IF RL is H and RS is M Then RM is M

This rule can be composed using the matrix shown in Table 4.10. Since an “AND” operator was used, the minimum membership value was used as the membership degree. In the first case, the combination between $RL = M$ (0.6) with $RS = M$ (1) resulted in M (0.6). M here means the RM value (consequence part) of the combination between RL and RS, while 0.6 is the membership degree, which is the

minimum value since AND operator was used. For the second combination, for RL = H (0.4) and RS = M (1), the result for the RM is M (0.4).

Table 4.10 Implication Process Result

RM		RS	
		M (1)	
RL	M (0.6)	M (0.6)	
	H (0.4)	M (0.4)	

The implication result from Table 4.10 can be graphically depicted in Figure 4.15 and Figure 4.16. According to that figure, the RM membership function fired by the rule for the RL = 60 and RS = 1% is the M with the membership degree equal to 0.6 and 0.4. In the figure 4.15 and 4.16, the membership function in the shaded area represents the height of the fire strength (α).

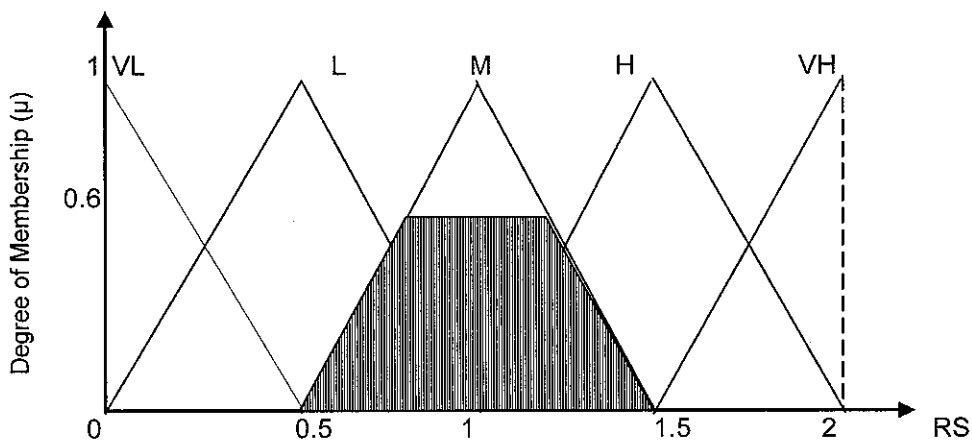
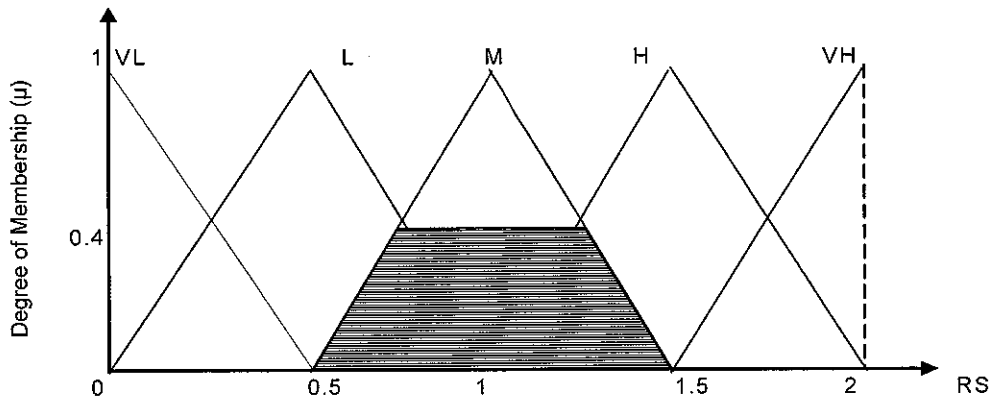


Figure 4.15 Implication Result for RM = M (0.6)

Figure 4.16 Implication Result for $RM = H (0.4)$

Aggregation

Aggregation is a process to combine the result of the implication, which produces the “Medium” (M) value. The aggregation result can be seen in Figure 4.17. The result of the aggregation is the same area as the implication result since the implication result is also generated from the same rule bases that are fired. Both implication processes produce the “M”.

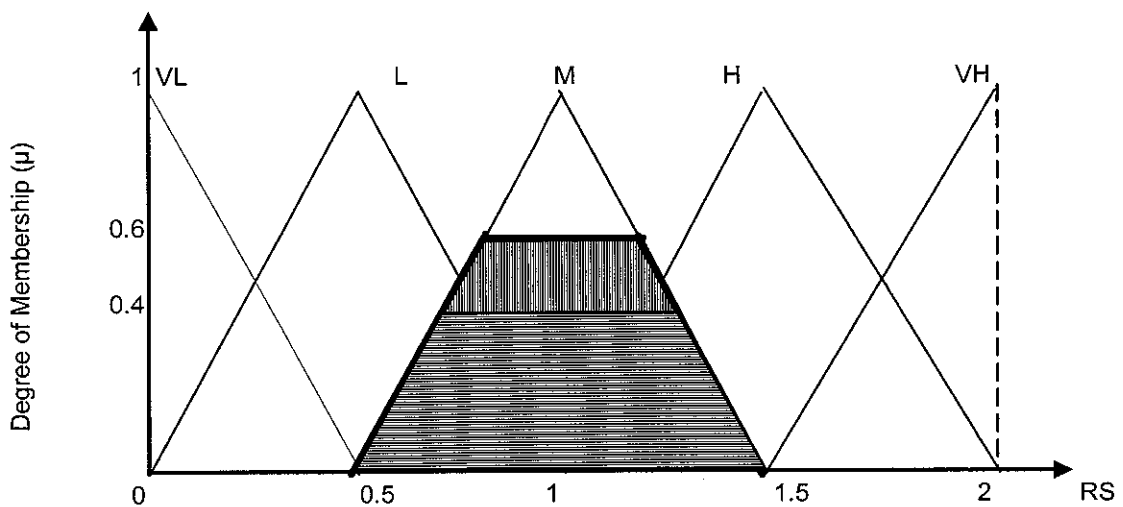


Figure 4.17 Aggregation of the Implication Result

Defuzzification

The aggregation result is a fuzzy set. For the individual cost contingency prediction objective, this aggregation process must be defuzzified. For this model, the center of gravity (COG) or center of area (COA) was chosen as the defuzzification method as illustrated graphically in Figure 4.18 .

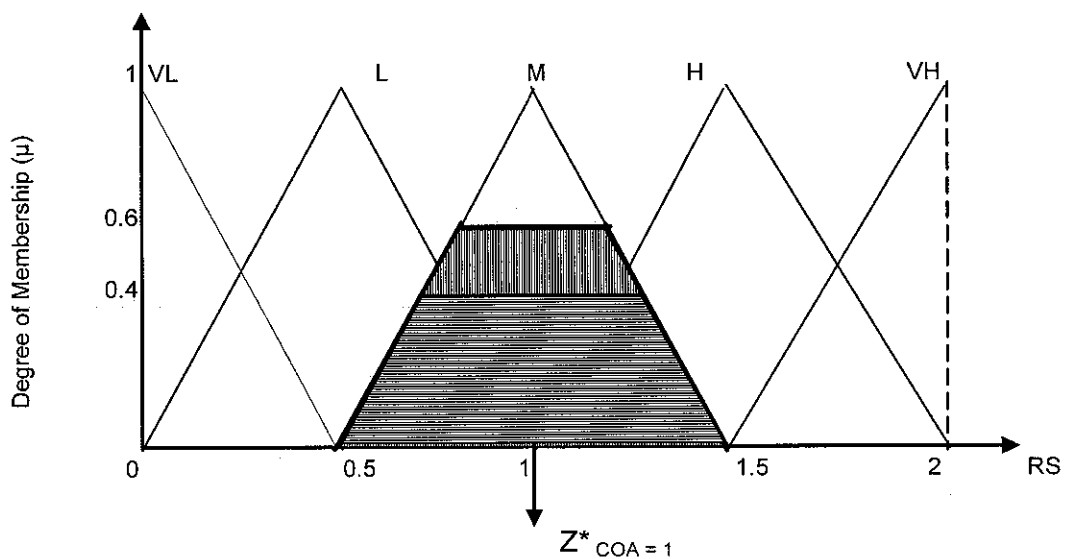


Figure 4.18 Defuzzification Result

The defuzzification result is the center of the shaded area and can be calculated using Equation 4.7 as follows:

$$Z^*_{COA} = \frac{(0.5 \times 0) + (0.8 \times 0.6) + (1.2 \times 0.6) + (1.5 \times 0)}{0 + 0.6 + 0.6 + 0}$$

$$= 1\%$$

The RM value for other risk factor types can also be calculated using the same procedure. The overall RM results of all risk factors then were summed up to obtain the cost contingency value for Project 1. According to the analysis result, the cost contingency value predicted by Scenario 1 A for the Project 1 is 4.19% of the total project cost. The actual cost contingency for this project was 4.7% of the total project

cost. From the output analysis, the error between the predicted and actual cost contingency value was calculated, which is 10.85%. The same procedures were used to calculate the cost contingency for other case projects.

4.4.7.3 Testing Results

By using the same calculation procedure above, results of testing for the eight projects for all scenarios have been obtained. In order to choose the best model, all prediction results were then compared to the actual cost contingency allocation of each project.

The testing results can be presented into Group A Scenario and Group B Scenario. The scenarios that were categorized in Group A Scenario A and Group B Scenario uses fuzzy rule alternative A and B respectively. The difference is the universe of discourse for RS variable that was used in this scenario. The universes of discourse used are ranged from 2 to 4% of the total project cost. The overall predicted results by all scenarios in Group A for Project 1 to Project 8 are given in Table 4.11.

As can be seen in Table 4.11, Scenario 1A produces minimum Mean Absolute Error (MAE) in Group A Scenario, which is 9.86%. The minimum error is observed for Project 6 that is 2.98%, while the maximum error, 16.67% is observed for Project 7. This means that the maximum universe of discourse equal to 2% of total cost for RS value is the most appropriate membership function that can be used for the model.

Table 4.11 Comparison Result from Five Scenarios in Group A Scenario

Scenario	% Error between Prediction and Actual Cost Contingency								MAE (%)
	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Project 8	
1A	-10.85	6.27	10.20	9.00	-14.93	2.98	16.67	8.01	9.86
2A	-3.40	22.16	20.00	25.67	-11.73	11.40	36.00	16.26	18.33
3A	6.17	37.45	31.80	39.67	0.93	19.47	53.00	26.70	26.90
4A	14.04	51.37	40.80	58.67	11.20	29.12	69.33	36.17	38.84
5A	18.72	63.73	43.20	77.33	12.80	38.25	86.33	47.09	48.43

The predicted results for Group B Scenario are given in Table 4.12. According to the table, it can be seen that the Scenario 1B produces minimum MAE compared to other scenarios. However, when this compared to Scenario 1A in Group A, the MAE resulted by Scenario 1B is still higher. This means that Scenario 1A is still the best model that can be tuned further to improve the accuracy of the prediction.

Table 4.12 Comparison Result from Five Scenarios in Group B Scenario

Scenario	% Error between Prediction and Actual Cost Contingency								MAE (%)
	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Project 8	
1B	-10.85	11.76	4.00	16.67	-11.33	4.56	20.00	8.01	10.90
2B	-3.40	26.08	22.20	36.33	1.20	11.58	36.00	16.26	19.13
3B	6.17	40.59	31.80	54.33	3.47	19.47	53.00	26.70	29.44
4B	14.04	53.33	40.80	70.00	11.20	29.12	69.33	36.17	40.50
5B	18.72	63.73	43.30	83.67	20.00	38.25	86.33	47.09	50.14

4.4.8 Tuning the Model

Tuning is performed to improve the model accuracy by conducting several iterations to obtain the optimum model. It is more an art rather than engineering technique [27]. Tuning process can be conducted by modifying the membership function and modifying the fuzzy rule base [27]. However, in this research, tuning was performed by modifying only the membership function [41]. In this tuning process, the fuzzy rule base is assumed unchanged since it has been developed based on the possible alternatives by considering the contingency system behaviour.

Tuning was only performed to Scenario 1A as the best scenario from the testing process. Tuning was conducted by shifting the left and right leg of the membership value. Every tuning step conducted by changing the fuzzy expert system properties, was tested using all data from the eight projects. All the outputs from the model were compared to the actual cost contingency.

The steps in tuning process were:

1. Shifting the left and right leg of each membership function for the RL variable. It was changed from the preliminary design as can be seen in Figure 4.19. The changing, then, was tested by inputting the case project data into the model and comparing the output of the model results with the actual cost contingency values.
2. Changing the RS membership function as can be seen in Figure 4.20. At this step, the membership function for RL variable was changed back into the original shape as before the first tuning.
3. Changing the RM membership function as can be seen in Figure 4.21. Meanwhile, the RL and RS membership function were changed back into their original shapes before the first and second tuning.
4. Changing the RL membership function as the first tuning, and changing the RS membership function as the second tuning. The RM membership function was changed back to its original shape.
5. Changing all three membership functions. In this step, the membership function for RL and RS variables at the fourth tuning was maintained, and the RM membership function was changed as the third tuning.

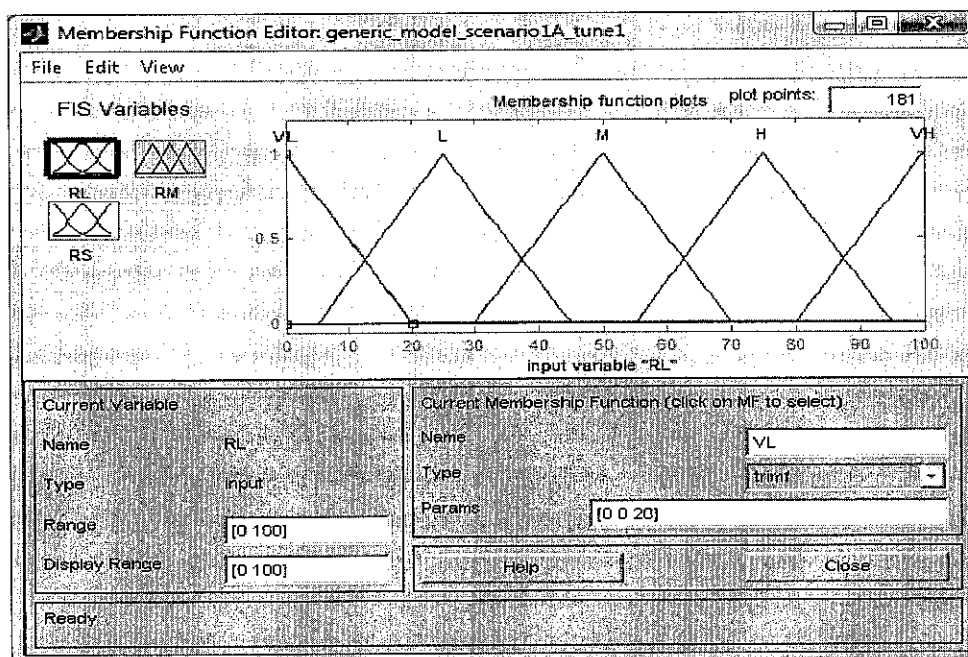


Figure 4.19 First Tuning for Scenario 1A (Shifting RL Membership Function)

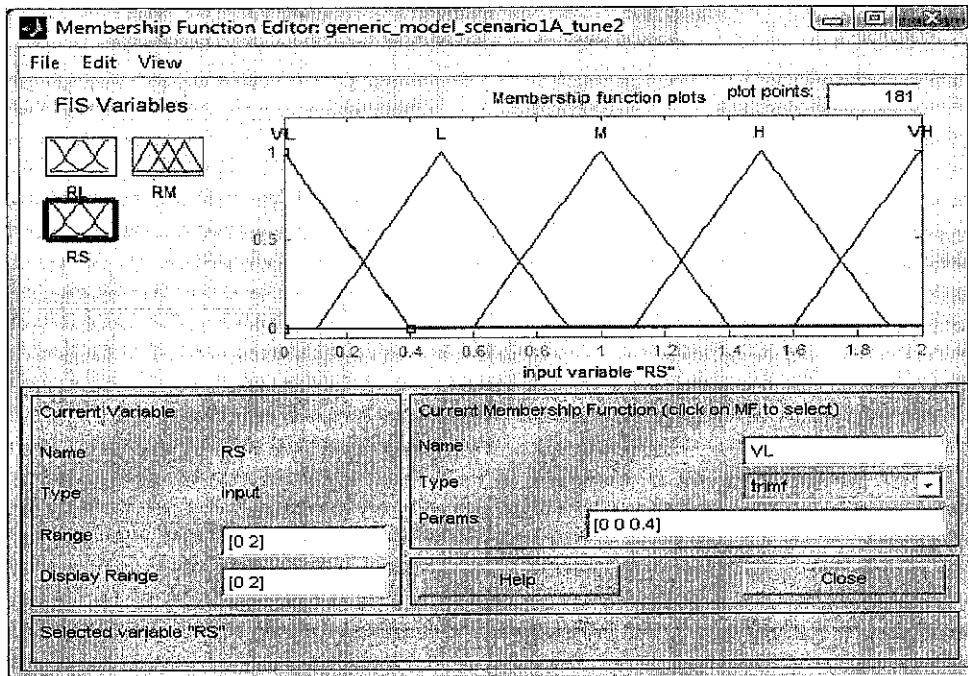


Figure 4.20 Second Tuning for Scenario 1A (Shifting RS Membership Function)

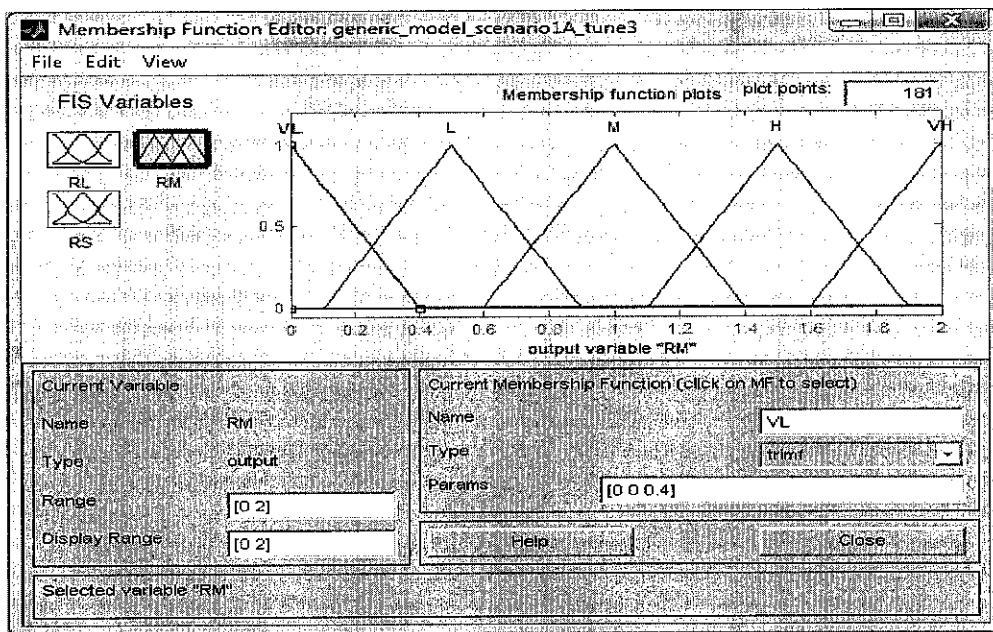


Figure 4.21 Third Tuning for Scenario 1A (Shifting RM Membership Function)

The tuning process was performed step by step to find the best combination of the membership function for all three membership functions, RL, RS and RM. Therefore, every combination was tried in the tuning process to find model that gives optimum

level of accuracy. The membership function for one variable was changed while that of the other two variables was maintained in the original form so as to check the impact of the change to the result. For example, during the first tuning, the RL variable was changed, but the RS and RM membership function were maintained in the original form.

The results of the tuning processes are tabulated in Table 4.13. According to the tuning results, the minimum MAE was obtained after the fourth tuning, which is 6.41%. Therefore, this tuning result was then applied to the model, and its accuracy will be improved further by applying other defuzzification methods. Earlier in Section 4.5.4.3, centroid or center of area (COA) has been set as the defuzzification method. However, in this step, other defuzzification methods such as bisector, largest of maximum (LOM), middle of maximum (MOM), and smallest of maximum (SOM) were applied to the model to improve its accuracy.

Table 4.13 Comparison of Tuning Results

Model	% Error between Prediction and Actual Cost Contingency								MAE
	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Project 8	
1A	-10.85	6.27	10.20	9.00	-14.93	2.98	16.67	8.01	9.86
1A_Tuning_1	-11.70	4.12	8.80	9.67	-15.60	3.16	8.67	8.01	8.72
1A_Tuning_2	-8.94	6.27	0.40	1.00	-21.73	-1.05	12.33	3.64	6.92
1A_Tuning_3	-14.89	1.96	7.80	4.67	-17.87	1.05	12.33	6.55	8.39
1A_Tuning_4	-9.79	4.12	-1.80	0.67	-22.40	-0.53	8.33	3.64	6.41
1A_Tuning_5	-13.83	0.20	-4.60	-4.00	-25.60	-2.11	5.00	2.18	7.19

The results after applying several defuzzification techniques are given in Table 4.14. According to the table, the COA method that has been used in model 1A_Tuning_4 still produced the minimum MAE comparing to other defuzzification techniques. Therefore, Scenario 1A_Tuning_4 with COA defuzzification is used as the best model in this research.

Table 4.14 Comparison from the Application of Several Defuzzification Methods
for Model 1A_Tuning_4

Defuzzification Type	% Error between Prediction and Actual Cost Contingency								MAE
	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Project 8	
COA	-9.79	4.12	-1.80	0.67	-22.40	-0.53	8.33	3.64	6.41
Bisector	-11.06	-3.53	2.80	-8.00	-23.73	-2.81	4.00	-1.46	7.17
LOM	-11.06	-5.88	6.40	-2.00	-9.60	18.60	27.33	11.17	11.51
SOM	-57.02	-48.24	-32.00	-66.00	-56.00	-37.19	-44.67	-32.52	46.71
MOM	-34.04	-27.06	-12.80	-34.00	-32.80	-9.30	-8.67	-10.68	21.17

CHAPTER 5

MODEL VALIDATION AND APPLICATION

5.1 Introduction

This chapter presents the validation of the model and its application in estimating cost contingency and tender price for a project during bidding stage. The purpose of the validation is to check whether the best model obtained from the testing and tuning process is capable of generating an adequate level of accuracy. The model application on the other hand, is intended to demonstrate the application of the model in estimating cost contingency in real-life project.

5.2 Model Validation

The validation test was performed using the same basic procedure as the model testing. However, the validation process was not followed by tuning process as in the testing. In addition, this step was conducted using data from three case projects which are different from those used in the testing and tuning process, namely Project 9, 10 and 11. Case data from the three projects were entered to the optimum model to obtain the cost contingency value. The results predicted by the model were then compared to the actual cost contingency of all three projects. The errors were calculated to analyze the difference between the predicted and actual cost contingency values.

The validation results are presented in Table 5.1. The results show that the minimum error was obtained for Project 11, which is 4.44 %, while the maximum error of 18 % was obtained for Project 10. According to Ashworth [43] and Idrus [44], an error of less than $\pm 20\%$ is considered acceptable for the purpose of costing in the construction business.

Table 5.1 Validation Result from the Optimum Model

Parameter		Project Number		
		Project 9	Project 10	Project 11
Cost	Actual	6.20	7.50	5.40
Contingency	Prediction	5.32	6.14	5.64
Error (%)		-14.19	-18.00	4.44

5.3 Determination of the Final Model of Project Cost Contingency

Several steps of the development of cost contingency model based on risk analysis and fuzzy expert system has been conducted in this research. The process was initiated by development a conceptual model of cost contingency, determination of the risk factors used in the model and development of the preliminary fuzzy expert. The process was further conducted by testing the model using actual case projects. Tuning processes and the application of the several methods of the defuzzification were also performed to improve the model accuracy. The best scenario is the model that produced the minimum MAE in the testing, tuning and applying the defuzzification method. Finally, the validation was also conducted to check the model consistency performance. Based on to the testing and validation, the final cost contingency model can then be specified.

The final model of the cost contingency estimation process consists of the risk analysis parameter within the project risk hierarchy as shown in Figure 5.1 and the best fuzzy expert system properties for the model, which is obtained from the Scenario A_Tuning_4 as given in Figure 5.2 to Figure 5.4.

The risk analysis parameter within the project risk hierarchy consists of 14 risk factors which can be classified into two main major risks which are external and internal risk and represented as a project risk hierarchy. Every major risk consists of seven risk factors. In this proposed model, cost contingency is calculated as the summation of the major risk or the total risk magnitude (RM) for all significant risk factors for the

projects. The RM is the function of two risk parameters, namely risk likelihood and risk severity (RS).

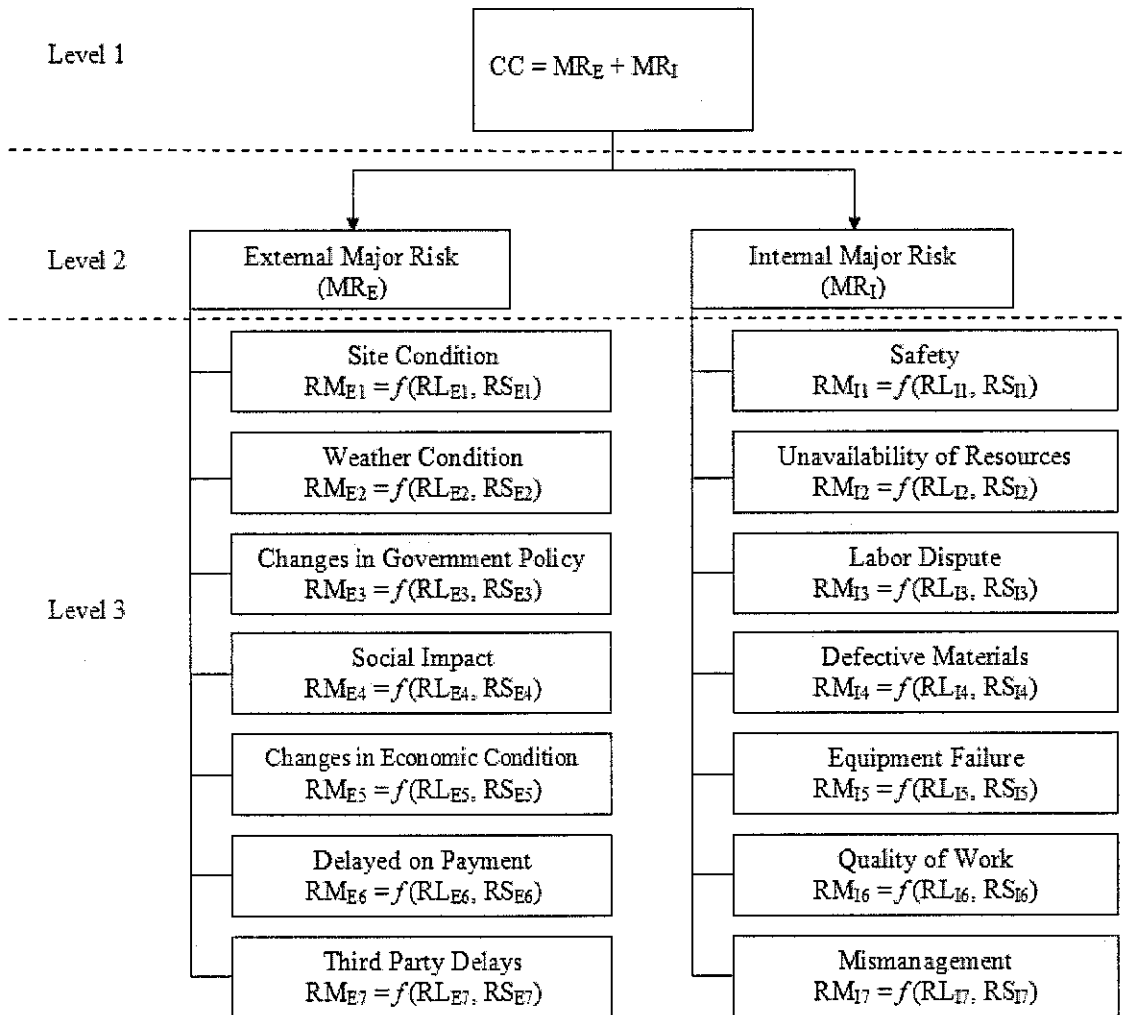


Figure 5.1 Final Cost Contingency Model: Risk Analysis Parameter and Risk Hierarchy

The final fuzzy expert system properties were also determined. It consists of final membership function, fuzzy rule base and fuzzy inference mechanism that involve the fuzzy operator, implication, aggregation and defuzzification procedures. The final membership function from the model can be seen in Figure 5.2 to Figure 5.4.

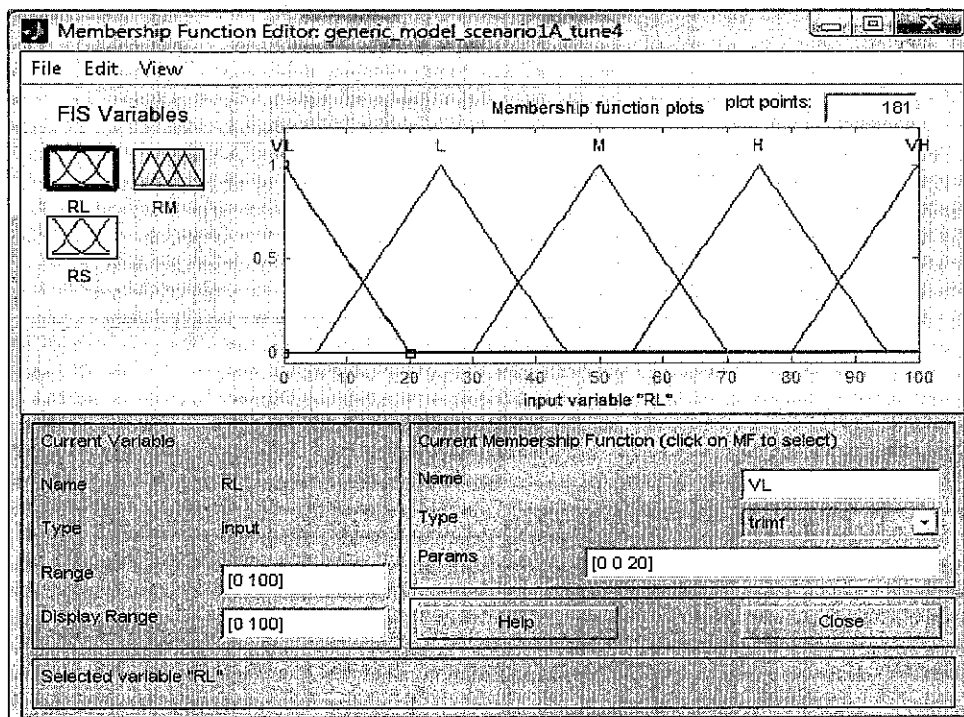


Figure 5.2 Final RL Membership Function

According to Figure 5.2, for the RL variable, the universe of discourse used is 100, with five linguistic terms. The overlap between adjacent fuzzy set is 37.5%. For the RS membership function as can be seen in Figure 5.3, the universe of discourse used is 2% in the unit of the total project cost. Five linguistic terms was also used in this membership function, and the overlap between each fuzzy set is the same as RL membership function, which is 37.5%. Finally, based on Figure 5.3, for the RM membership function, the universe of discourse is the same as the RS membership function, which is 2% of the total project cost. Five linguistic terms were also specified in this risk variable. However, the suitable overlap for this membership function is 50%.

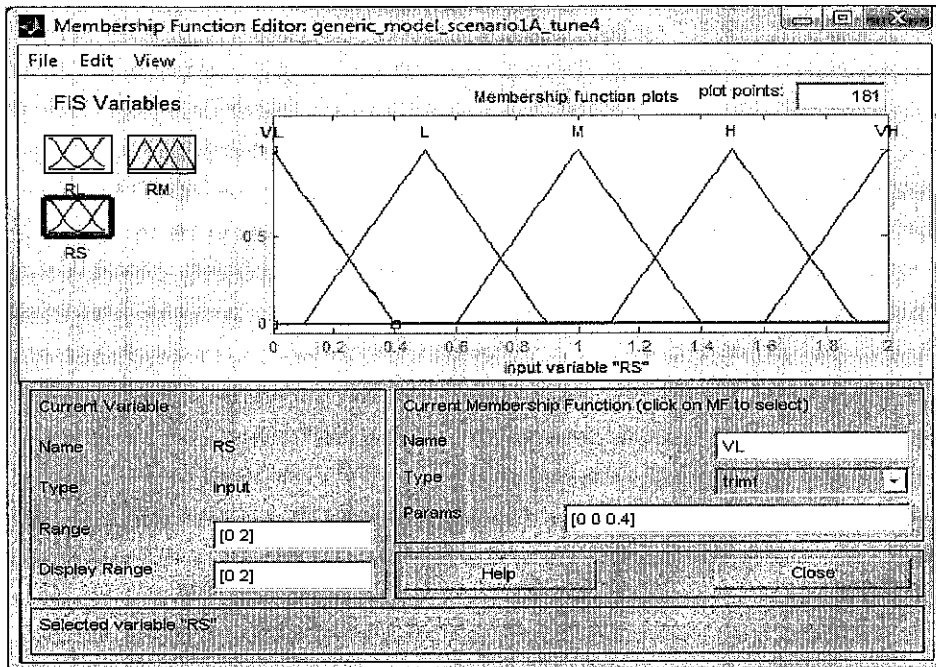


Figure 5.3 Final RS Membership Function

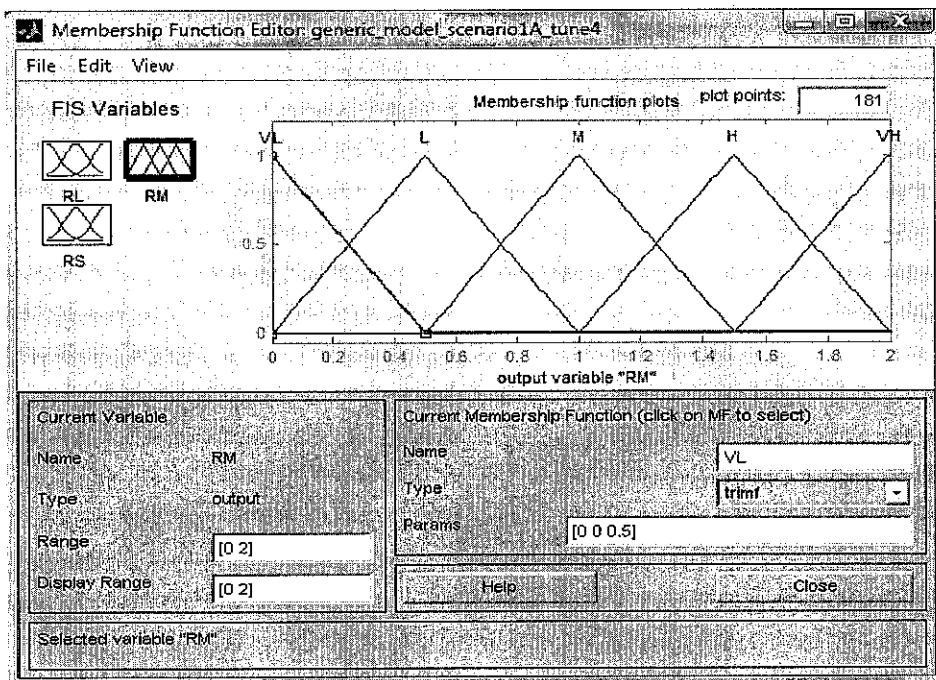


Figure 5.4 Final RM Membership Function

In terms of the fuzzy rule base, Alternative A can be concluded to be more suitable for this model than alternative B. Scenario 1A which was composed with the

Alternative A fuzzy rule base produced the minimum MAE compared to other scenario. The final fuzzy rule base is therefore Alternative A as shown in Table 5.2.

Table 5.2 The Final Fuzzy Rule Base for the Model

Risk Magnitude (RM)		Risk Severity (RS)				
		VL	L	M	H	VH
Risk Likelihood (RL)	VL	<u>VL</u>	VL	L	L	M
	L	VL	<u>L</u>	L	M	M
	M	VL	L	<u>M</u>	M	H
	H	VL	L	M	<u>H</u>	H
	VH	VL	L	M	H	<u>VH</u>

For the implication and aggregation process, the Mamdani Inference Mechanism which consists of MIN and MAX operation is appropriate for the model. Finally, the most appropriate for this model is the COA defuzzification method.

5.4 Development of Computer Tool for Project Cost Contingency Estimation

For the purpose of applying of the model that has been developed to estimate project cost contingency, a computer program was developed in MATLAB programming language. The computer tool was designed as a prediction tool that can be used to estimate project cost contingency during the tender bidding stage. The system was built using MATLAB graphical user interface development environment (GUIDE).

The GUIDE was modeled to guide the user to estimate the amount of tender price directly. The user will only need to specify the base cost estimate of the new project and the estimation of RL and RS variables for significant risk factor. In this case, the base cost estimate is the total construction cost that has not taken into account of risks in the calculation process. The system will automatically calculate the cost contingency and also a bidding price to be proposed.

The bidding price is determined based on the formula proposed by Paek et al. [10]. In this model, in order to determine the bidding price (BP), the base cost estimate (BC) must be summed with the cost contingency value (CC). BP is the amount of the project cost, which is free from risks. In this case, the estimator is required to estimate BC based on the most likely cost for each work item.

The relation between BP, BC and CC can be represented using Equation 5.1.

$$BP = BC + CC \quad (5.1)$$

where:

BP = bidding price

BC = base cost estimate (including profit)

CC = cost contingency = $RM_1 + RM_2 + RM_3 + \dots + RM_n$

$RM_i = RL_i \times RS_i$

The values of RL and RS can be estimated as percentage of the total project cost or BP. For example CC is equal to several percentage of BP, for example is $Z \times BP$. Therefore, BP can be calculated as Equation 5.2a.

$$BP = BC + (Z \times BP) \quad (5.2a)$$

or

$$BC = BP(1 - Z) \quad (5.2b)$$

Therefore,

$$BP = \frac{BC}{(1 - CC)} \quad (5.2c)$$

$$BP = \frac{BC}{1 - \sum (RL_i \times RS_i)} \quad (5.2d)$$

Based on the formula in Equation 5.2d, the BP value for the tender can be calculated based on the value of BC and the RL and RS input values from all significant risk factors. A computer tool for estimating tender price was then developed according to the formula. The MATLAB programming code for developing this computer tool can be shown in Appendix E. The application of the computer tool for risk analysis and risk management will be explained in the next section.

5.5 Application of the Computer Tool for Tendering Activity

To demonstrate the computer tool application, one of the case projects from the interview was chosen as an example. In this case, the process of estimating bidding price for the project based on the RL and RS input and base cost estimate is given. Project 10 is chosen as an example to estimate cost contingency and tender price. The project information is given in Table 5.3 while the estimated RL and RS values for relevant significant risk factors are given in Table 5.4.

Table 5.3 Project Information for Project 10

Project Type	Building (High-Rise)
Owner	Private
Location	Kuala Lumpur, Selangor
Year	1996 - 2000
Contract type	Turnkey
Total duration	48 months
Nominal contract price	RM 4.3 billion
Base cost estimate	RM 3.8 billion
Planned cost contingency (% of total project cost)	5 %
Actual cost contingency (% of total project cost)	7.5 %

Table 5.4 Estimated Risk Factor Parameters for Project 10

No (1)	Risk Factors (2)	RL (0 – 100 scale) (3)	RS (% total project cost) (4)
<i>A. External Risks</i>			
1.	Different site condition	5	1
2.	Changes in government policy	15	0.6
3.	Changes in economic condition	45	2
4.	Third party delays	25	1
<i>B. Internal Risks</i>			
1.	Safety	70	1
2.	Defective material	30	1.7
3.	Quality of work	80	1.2

Those project data were then entered into the computer tool. The step of entering the base cost estimate and, RL and RS values for significant risk factors is shown in Figure 5.5. The input for the RL variable can be chosen from the range 0 to 100. This scale is divided into five linguistic terms, namely Very Low (VL), Low (L), Medium (M), High (H) and Very High (VH) to guide the user in estimating the RL value. The same categorization is also used for the RS variable.

By using this tool, the users can input the RL and RS value based on their judgment and experience. For example, for the RL variable, if a “high” (H) level of RL variable is estimated, the user can choose a number between 62 – 88. However, if “very low” (VL) is estimated, the user can choose the range between 0 – 12.

tender_price_estimation1B_tuned

COST CONTINGENCY AND TENDER PRICE ANALYSIS

Base Cost Estimate : Currency Unit

External Risk

Risk Category	RL	RISK LIKELIHOOD (RL)	RS	RISK SEVERITY (RS)
Difference Site Condition (Subsurface, Topograf)	5	SCALE : 0 - 100	1	SCALE : 0 - 2% TOTAL COST
Weather Condition (Rain)	0	VL : 0 - 12	0	VL : 0 - 0.25
Changes in Government Policy	15	L : 12 - 38	0.5	L : 0.25 - 0.75
Social Impact	0	M : 38 - 62	0	M : 0.75 - 1.25
Changes in Economic Condition	45	H : 62 - 86	2	H : 1.25 - 1.75
Delay of Payment	0	VH : 86 - 100	0	VH : 1.75 - 2
Third Party Delays	25		1	

Internal Risk

Risk Category	RL	RISK LIKELIHOOD (RL)	RS	RISK SEVERITY (RS)
Safety (Accident)	70	SCALE : 0 - 100	1	SCALE : 0 - 2% TOTAL COST
Unavailability of Resources (Equipment, Labor & Material)	0	VL : 0 - 12	0	VL : 0 - 0.25
Labor Dispute	0	L : 12 - 38	0	L : 0.25 - 0.75
Defective Material	30	M : 38 - 62	1.7	M : 0.75 - 1.25
Equipment Failure	0	H : 62 - 86	0	H : 1.25 - 1.75
Quality of Work	80	VH : 86 - 100	1.2	VH : 1.75 - 2
Mismanagement (Cashflow, Overbudget)	0		0	

Figure 5.5 GUIDE Model Input for Estimating Tender Price Value

The analysis result from the model is presented in Figure 5.6. According to the analysis results, the total tender price that should be proposed by the contractor is RM 4.049 billion, and about 6.15 % of total project cost (from the tender price) should be allocated for cost contingency.

cost_contingency_result

ANALYSIS RESULT

Cost Contingency Prediction	<input type="text" value="6.1504"/>	% Total Project Cost
Total Project Risk Cost	<input type="text" value="249,029,580.1902"/>	Monetary Value
Tender Price Proposed	<input type="text" value="4,049,029,580.1902"/>	Monetary Value

Figure 5.6 GUIDE Model Output for Estimating Tender Price Value

However, the contractor may feel that the predicted cost contingency allocation is too high that their bidding price may not be competitive. If such is the case, the contractor can reduce the RL value for risk factors that has a high RL value, such as “Safety Risk Factor” in order to obtain a more reasonable prediction from the model.

For example, they can reduce the RL value to “very low” value, which is around 10. However, in order to reduce the RL parameter from “high” to “very low” they have to apply risk management aspect to the project. For example by enforcing additional safety procedures to reduce the number of accident during the construction process. In short, in order to reduce the RL value, the contractor must consider the relevant risk management step.

After including the appropriate risk management action plan to minimize the risk, the RL value can be reduced to “very low”. Instead of choosing word “very low” any suitable number between 0 to 12 can be chosen. For example, if 10 is chosen, a new cost contingency value will be calculated by the proposed computer tool. The new input for risk analysis can be seen in Figure 5.7 and the result of risk analysis using the new input can be seen in Figure 5.8. According to the new result, the amount of project cost contingency can be reduced to 5.65 % of total project cost.

5.6 Contractors’ Feedback

In order to get a feedback regarding to the computer tool interface performance has been developed, a subsequent interview surveys were conducted with two contractor’s project managers. The contractors were asked about the computer tool interface with regard to its user-friendly application.

The almost similar comments were obtained from both project managers. According to their opinion, the computer tool is user-friendly. It can help the contractors in estimating cost contingency value and tender price during the bidding stage. It can be used to estimate the competitive cost contingency value without ignoring the risk

factors that might be occur. Besides, it can accommodate the application of risk management system in the cost contingency estimation.

However, this computer still has two limitations with regard to its application in the construction industry. First, in order to use this tool, they need more time to understand the computer tools' system at the first time. The contractors are not accustomed to estimate cost contingency value by examining and assessing risk factor in a detail manner. In practice, they usually use a general approximation when estimating cost contingency value. Second, the computer tool is developed based on MATLAB programming language which is not familiar with construction business application. For the economic reason, the contractors might not buy and install the MATLAB software for using this computer tool to estimate cost contingency.

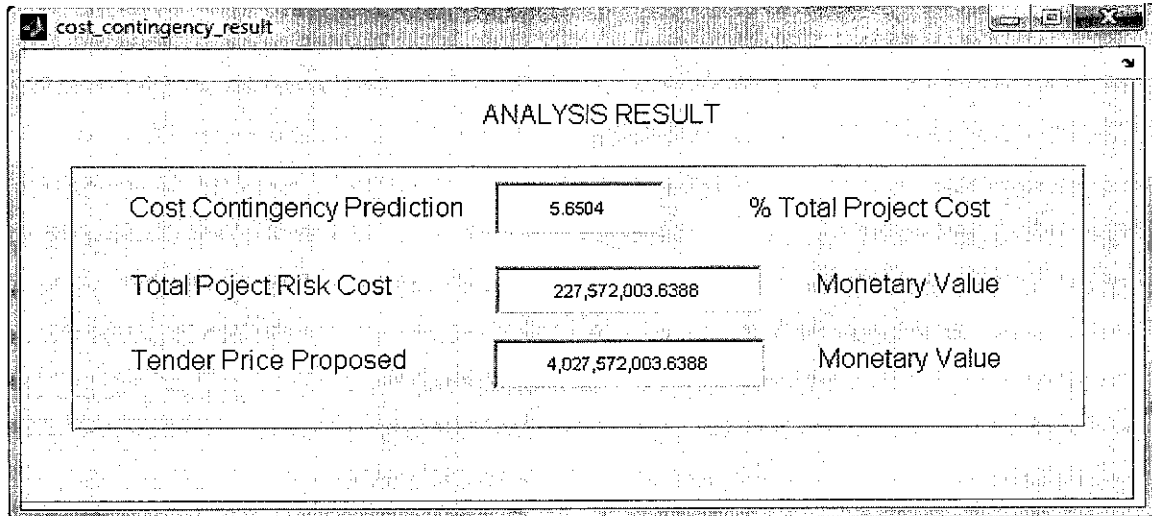
tender_price_estimation18_tune4

COST CONTINGENCY AND TENDER PRICE ANALYSIS

Base Cost Estimate : Currency Unit

External Risk		RL	RISK LIKELIHOOD (RL)	RS	RISK SEVERITY (RS)
Difference Site Condition (Subsurface, Topografi)	RL :	<input type="text" value="5"/>	SCALE : 0 - 100	RS :	<input type="text" value="1"/>
Weather Condition (Rain)	RL :	<input type="text" value="0"/>	VL : 0 - 12	RS :	<input type="text" value="0"/>
Changes in Government Policy	RL :	<input type="text" value="15"/>	L : 12 - 38	RS :	<input type="text" value="0.5"/>
Social Impact	RL :	<input type="text" value="0"/>	M : 38 - 62	RS :	<input type="text" value="0"/>
Changes in Economic Condition	RL :	<input type="text" value="45"/>	H : 62 - 88	RS :	<input type="text" value="2"/>
Delay of Payment	RL :	<input type="text" value="0"/>	VH : 88 - 100	RS :	<input type="text" value="0"/>
Third Party Delays	RL :	<input type="text" value="25"/>		RS :	<input type="text" value="1"/>
Internal Risk					
Safety (Accident)	RL :	<input type="text" value="10"/>	SCALE : 0 - 100	RS :	<input type="text" value="1"/>
Unavailability of Resources (Equipment, Labor & Material)	RL :	<input type="text" value="0"/>	VL : 0 - 12	RS :	<input type="text" value="0"/>
Labor Dispute	RL :	<input type="text" value="0"/>	L : 12 - 38	RS :	<input type="text" value="0"/>
Defective Material	RL :	<input type="text" value="30"/>	M : 38 - 62	RS :	<input type="text" value="1.7"/>
Equipment Failure	RL :	<input type="text" value="0"/>	H : 62 - 88	RS :	<input type="text" value="0"/>
Quality of Work	RL :	<input type="text" value="80"/>	VH : 88 - 100	RS :	<input type="text" value="1.2"/>
Mismanagement (Cashflow, Overbudget)	RL :	<input type="text" value="0"/>		RS :	<input type="text" value="0"/>

Figure 5.7 The Output Analysis for RL = 10 (Safety Risk Factor)



The screenshot shows a window titled "cost_contingency_result" with a tab titled "ANALYSIS RESULT". Inside the window, there is a table with three rows of data. The first row shows "Cost Contingency Prediction" as 5.6504, which is 5.65% of the total project cost. The second row shows "Total Project Risk Cost" as 227,572,003.6388, representing a monetary value. The third row shows "Tender Price Proposed" as 4,027,572,003.6388, also representing a monetary value.

ANALYSIS RESULT		
Cost Contingency Prediction	5.6504	% Total Project Cost
Total Project Risk Cost	227,572,003.6388	Monetary Value
Tender Price Proposed	4,027,572,003.6388	Monetary Value

Figure 5.8 GUIDE Model Output after Reducing the RL Value (Safety Risk Factor)

In the instance that the safety cost is fully covered by an insurance company, the contractor can even reduce the RL for safety to 0, as shown in Figure 5.9. In this case, it is assumed there is no safety risk present in the project. As the result, the RM value for the safety risk becomes 0 and the new cost contingency is reduced to 5.15% of total project cost. The new cost contingency predicted is given in Figure 5.10. The predicted bidding price is subsequently reduced to only RM 4.006 billion, which is more competitive since the contract value stated for this project was RM 4.3 billion.

tender_price_estimation1B_tune4

COST CONTINGENCY AND TENDER PRICE ANALYSIS

Base Cost Estimate : Currency Unit

External Risk

Risk Factor	RL	RISK LIKELIHOOD (RL)	RS	RISK SEVERITY (RS)
Difference Site Condition (Subsurface, Topograft)	<input type="text" value="5"/>	SCALE : 0 - 100	<input type="text" value="1"/>	SCALE : 0 - 2% TOTAL COST
Weather Condition (Rain)	<input type="text" value="0"/>	VL : 0 - 12	<input type="text" value="0"/>	VL : 0 - 0.25
Changes in Government Policy	<input type="text" value="15"/>	L : 12 - 38	<input type="text" value="0.6"/>	L : 0.25 - 0.75
Social Impact	<input type="text" value="0"/>	M : 38 - 62	<input type="text" value="0"/>	M : 0.75 - 1.25
Changes in Economic Condition	<input type="text" value="45"/>	H : 62 - 88	<input type="text" value="2"/>	H : 1.25 - 1.75
Delay of Payment	<input type="text" value="0"/>	VH : 88 - 100	<input type="text" value="0"/>	VH : 1.75 - 2
Third Party Delays	<input type="text" value="25"/>		<input type="text" value="1"/>	

Internal Risk

Risk Factor	RL	RISK LIKELIHOOD (RL)	RS	RISK SEVERITY (RS)
Safety (Accident)	<input type="text" value="0"/>	SCALE : 0 - 100	<input type="text" value="1"/>	SCALE : 0 - 2% TOTAL COST
Unavailability of Resources (Equipment, Labor & Material)	<input type="text" value="0"/>	VL : 0 - 12	<input type="text" value="0"/>	VL : 0 - 0.25
Labor Dispute	<input type="text" value="0"/>	L : 12 - 38	<input type="text" value="0"/>	L : 0.25 - 0.75
Defective Material	<input type="text" value="30"/>	M : 38 - 62	<input type="text" value="1.7"/>	M : 0.75 - 1.25
Equipment Failure	<input type="text" value="0"/>	H : 62 - 88	<input type="text" value="0"/>	H : 1.25 - 1.75
Quality of Work	<input type="text" value="80"/>	VH : 88 - 100	<input type="text" value="1.2"/>	VH : 1.75 - 2
Mismanagement (Cashflow, Overbudget)	<input type="text" value="0"/>		<input type="text" value="0"/>	

Figure 5.9 The GUIDE Model Input for RL = 0 (Safety Risk Factor)

cost_contingency_result

ANALYSIS RESULT

Cost Contingency Prediction	<input type="text" value="5.1504"/>	% Total Project Cost
Total Project Risk Cost	<input type="text" value="206,340,654.3539"/>	Monetary Value
Tender Price Proposed	<input type="text" value="4,006,340,654.3539"/>	Monetary Value

Figure 5.10 The Output Analysis for RL = 0 (Safety Risk Factor)

The contractor can also apply the same procedure to other risk factors in order to reduce the amount of project cost contingency. However, reducing RL values should be compensated by enforcing appropriate risk management procedure to minimize the RM as demonstrated in the “Safety risk factor” example before. By applying this method, a contractor can enhance their level of confidence in estimating project cost contingency and, also the tender price since the values are based on assessment of the risks.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Several investigations have been performed throughout the research, which include literature reviews, interview survey, data analyses and computer modeling to achieve the objectives of the research as stated at the beginning of the project:

1. To develop a model to estimate project cost contingency based on risk analysis and fuzzy expert system.
2. To demonstrate the applicability of the proposed model by developing a computer tool in estimating tender price during bidding stage.

Based on the works that have been conducted, the following conclusions can be drawn.

1. This research has developed a model for estimating cost contingency for Malaysian building and infrastructure work using risk analysis and fuzzy expert system. The model was developed based on information acquired from literature and field survey involving contractor's project managers. The information includes risk factors that were used in the model, fuzzy expert system properties and case project data that were used to test and validate the model. In this model, risk analysis is used as the method to identify and assess the level of risk for the significant risk factor in a project. The fuzzy expert system accommodates the use of subjective judgment in the estimation of cost contingency and also to relate the three risk parameters, which are risk likelihood (RL), risk severity (RS), and risk magnitude (RM). The validation exercise indicates that the model is acceptable since the error resulted by the model is $\pm 18\%$ compared to the actual project cost contingency values. According to Ashworth [43] and Idrus [44], an error of less than $\pm 20\%$ is considered acceptable for the purpose of costing in the construction business.

2. A computer tool has also been developed to demonstrate the application of the proposed model in estimating cost contingency and tender price during bidding exercise. By using this tool, contractors can accommodate risk management concept to the project right from the early stage of the project lifecycle. This tool can help the contractor to have a better estimation of project cost contingency and possibly avoid cost overrun during the construction process. The proposed method can also help the contractor to bid a competitive tender price without ignoring the risk factor that might occur during the construction process.

6.2 Limitations and Recommendations for Future Works

Several limitations and future development of the research have been identified and described as follows:

1. This model has been developed for normal construction such as building and infrastructure work. Therefore, the types of risk factors used and the range of universe of discourse selected for the fuzzy membership function used in this model maybe appropriate to these types of project only. Therefore, the model might not be suitable for other types of construction. However, the procedure proposed in this work can be slightly modified to develop model for such construction types.
2. Fuzzy expert system has been shown capable in accommodating subjective judgment based on linguistic term in this research. However, this method still has limitation, particularly in the model accuracy. The model may not produce the highest accuracy due to the limit amount of reliable project data for use in the testing and validation process. It was difficult to get an opportunity to interview construction expert during the research due to the confidential nature of the cost contingency data. Therefore, communication with the construction expert is very important to obtain information needed to build the model. Besides, close collaboration with construction field personnel during the research is very important in order to ensure the success of building a good expert system.

3. The model validation was performed based on two case projects from Perak and one case project from Selangor. Therefore, this model may be more suitable for the Perak case project, not to the whole Malaysia construction case. Hence, the future works can address this limitation by using the various case projects in the model testing, tuning and validation in order to achieve a more suitable cost contingency model for Malaysian construction case.
4. The computer tool that has been developed requires MATLAB program to be installed in the computer to enable the tool to be used. In future, it is recommended to develop the tool as stand alone program independent of MATLAB. As an alternative, fuzzy expert system can be developed using Visual Basic software.

6.3 Contributions to Knowledge

1. This research has contributed to the knowledge in the field of artificial intelligence in Construction Management by developing a model to estimate project cost contingency for tender bidding exercise based on risk analysis and fuzzy expert system. This method gives a more flexible and rational method compared with the conventional ones, in which is purely based on subjective judgment with no proper scientific basis. The fuzzy expert system method has been shown to be capable of adequately accommodating the contractor's subjective judgment by using linguistic terms such as low, medium or high to represent the risk likelihood and its severity. The fuzzy expert system method has also considered the concept of risk management in cost contingency estimation process. Fuzzy expert system properties such as membership function, fuzzy rule based and fuzzy inference mechanism have also been incorporated into this model.
2. Development of a flexible computer-based tool to demonstrate the application of the proposed model during the tendering stage of the project.

PUBLICATIONS

1. M. Arif Rohman and Arazi Idrus, "Fuzzy Methods in Quantitative Risk Analysis of Construction Project," National Postgraduate Symposium (NPC), Universiti Teknologi PETRONAS (UTP), Perak, Malaysia, March, 2008.
2. M. Arif Rohman, Arazi Idrus and Muhd. Fadhil Nuruddin, "Computer Tool for Estimating Project Contingency based on Risk Analysis and Fuzzy Expert System," International Conference on Project Management (ICoPM), University of Malaya (UM), Kuala Lumpur, Malaysia, 18-20 November 2008.
3. M. Arif Rohman, Arazi Idrus and Muhd. Fadhil Nuruddin, "Development of Construction Project Contingency Model Using Fuzzy Expert System," International Conference on Science and Technology (ICSTIE), Universiti Teknologi MARA (UiTM), Pulau Pinang, Malaysia, 12-13 December 2008.

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APPENDIX A. Identification All Potential Risk Factors

Risk Categories in a Construction Project by Kangari (1988)

1. Construction Related Risks
 - Labour.
 - Equipment.
 - Material.
 - Late completion.
 - Defective design.
 - Site access.
 - Quality variation.
 - Design changes

2. Contractual and Legal Risk
 - Payment failure.
 - Delayed disputes.
 - Coordination.
 - Change orders.
 - Insurance coverage

3. Physical Aspects Risk
 - Site condition.
 - Act of God.

4. Performance and Management Risk
 - Productivity.
 - Quality
 - Accidents.
 - Mistakes.
 - Management.

5. General Economic Factors Risk

- Inflation.
- Energy.
- Financial.

6. Political and Public Risk

- Environmental.
- Public disorder.
- Government Regulation.

Risk Categories in a Construction Project by Al-Bahar (1988)

1. Act of God Risk

- Flood.
- Earthquake.
- Landslide.
- Fire.
- Wind damage.
- Lighting.
- Weather.

2. Physical Risk

- Damage to structure.
- Damage to equipment.
- Labour injuries.
- Material and equipment fire and theft.

3. Financial and Economic Risk

- Inflation.
- Availability of funds from client.
- Exchange rate fluctuation.

-
- Financial default of subcontractor.
 - Non-convertibility.
4. Political and Environmental Risk
- Changes in laws and regulations.
 - War and civil disorder
 - Requirement to permits and their approval.
 - Pollution and safety rules.
 - Expropriation.
 - Embargoes.
5. Design Risk
- Incomplete design scope.
 - Defective design.
 - Errors and omissions.
 - Inadequate specifications.
 - Design changes.
6. Job Site-Related Risk
- Labour dispute and strike.
 - Labour productivity.
 - Different site conditions.
 - Defective work.
 - Equipment failure.

Risk Categories in a Construction Project by Tah et al. (1993)**I. Internal Risk****A. Local Risk**

1. Labour.
 - Availability.
 - Quality.
 - Productivity
2. Plant.
 - Availability.
 - Suitability.
 - Productivity
3. Materials.
 - Availability.
 - Suitability.
 - Supply
 - Wastage
4. Sub-Contractor.
 - Availability.
 - Quality.
 - Productivity.
 - Failure.
5. Site Risk.
 - Ground conditions.
 - Accessibility.
 - Type of work.
 - Complexity of work.

B. Global Risk

1. Performance Risk.
 - Management experiences.

- Availability of partners.
- Relationship with client.
- Workload commitment.
- 2. Contractual Risk.
 - Contract type.
 - Contractual liabilities.
 - Amendments to standard form.
- 3. Location Risk.
 - Head office.
 - Project.
- 4. Financial Risk.
 - Funding.
 - Cash flow.
 - Economic conditions.

II. External Risk

- A. Inflation Risk.
- B. Exchange rate fluctuation.
- C. Technology change.
- D. Major client induced changes.
- E. Politics.

Risk Categories in a Construction Project by Kangari (1995)

1. Permit and ordinances
2. Site access/right of way
3. Labour, equipment, and material availability
4. Labour and equipment productivity
5. Defective design
6. Changes in work
7. Differing site conditions (lump-sum contract)
8. Act of god

9. Defective material
10. Changes in government regulation
11. Labour disputes
12. Safety
13. Inflation
14. Contractor competence
15. Change order negotiation
16. Third party delays
17. Contract delay resolution
18. Delayed payment in contract
19. Quality of work
20. Indemnification and hold harmless
21. Financial failure – any party
22. Actual quantity of work
23. Defensive engineering

Risk Categories in a Construction Project by Smith et al. (1999)

1. Natural Risks
 - Act of God.
 - Loss due to fire and accident.
2. Design Risks
 - Scope changes.
 - New technology.
 - Specifications.
 - Loss or delay due to differing site or design change
3. Logistics Risks
 - Loss or delay due to damaged or late materials.
 - Loss or delay due to resource availability.
 - Site access.
 - Delays in addressing or solving problems.
 - Delay in presenting problems.

4. Financial Risks

- Adequacy of project financing.
- Adequate cash flow.
- Exchange rate and inflation.
- Underestimation of cost.
- Contractor default.
- Cost overrun due to schedule delays.

5. Legal and Regulatory Risks

- Problem with permits and licences.
- Third party liability.
- Direct liability.
- Contractual failure.
- Changes in regulations.

6. Political Risks

- Loss or delay due to war, revolution at site location.
- Changes in trade laws

7. Construction Risks

- Quality problems.
- Poor productivity.
- Poor site safety.
- Labour strikes.
- Construction changes.
- Inclement weather.
- Losses and delays due to improper means and methods of construction.

8. Environmental Risks

- Ecological damage, pollution, waste treatment.

Risk Categories in a Construction Project by Wiguna and Scott (2006)

1. External and site condition Risk
 - Unforeseen site ground condition.
 - Weather condition.
 - Difficult in obtaining permit and ordinances.
2. Economic and Financial Risks
 - High inflation/increased price.
 - Delayed payment on contract.
 - High interest rate.
 - Poor cost control.
3. Technical and Contractual Risks
 - Defective design.
 - Design change by owner.
 - Inadequately compensated variation order.
 - Delays in providing detail drawing.
4. Managerial Risks
 - Defective construction work.
 - Low labour and equipment productivity.
 - Inadequate project program.
 - Problems with availability of labour, material and equipment.

APPENDIX B. Classification of Risk Factors in Major Risk Categories

Major Risk Categories:

1. Site Condition and Technical Risk
2. Contractual and Legal Risk
3. Economic and Financial Risk
4. Managerial Risk
5. Political Risk

Site Condition and Technical Risk

- Natural disaster (earthquake, tsunami, landslide, fire, flood, wind damage, etc.)
- Site condition
- Weather condition
- Defective design
- Incomplete design

Contractual and Legal Risk

- Condition of contract (clarity, complexity, fairness, variations to standards)
- Delayed of payment
- Changes in work scope
- Failure of owner (bankruptcy)
- Third party delays

Economic and Financial Risk

- Monetary crisis
- High inflation/increased price
- High interest rate
- Market competition
- Availability of funding costs

Managerial Risk

- Safety
- Availability of labour, material and equipment
- Labour dispute
- Quality of work
- Defective material
- Equipment failure
- Mismanagement

Political and Environmental Risk

- Changes in government policy (law and regulation, permit, etc.)
- Public disorder (force majeure)
- Pollution / social impact (noise, waste, hazardous chemical).

APPENDIX C. Interview Form**INTERVIEW SURVEY ON
DETERMINING PROJECT COST CONTINGENCY ESTIMATION
BASED ON RISK ANALYSIS**

Determining appropriate project cost contingency is very important to the success of project management. Several methods to estimate cost contingency based on risk analysis concept have been proposed. However, most of those conventional methods rely on mathematical model that required statistical data which is sometimes not easy to be obtained in the construction industry.

This research is aimed at developing method in estimating project cost contingency that would accommodate the use of subjective judgment based on linguistic term in the analysis process.

In order to develop the system, this survey is intended to get the construction experts' estimation in cost contingency value based on your previous case project for building or infrastructure works. Please refer to the instructions in each section to answer the questions.

SECTION A. RESPONDENT INFORMATION

Please fill up the answers in the blank provided

1. Name of Company: _____
2. Name of Respondent: _____
3. Educational Background: _____
4. Experience in the construction industry: _____ years
5. Estimated the number of projects have been conducted:
 - a. Buildings _____ projects
 - b. Infrastructures _____ projects
 - c. Others (please specify) _____ projects

SECTION B. CASE PROJECT FOR COST CONTINGENCY ESTIMATION

In this section, we would like to get data on project cost contingency estimation based on previous case project. Please choose one of your previous completed projects that have a known cost contingency value.

I. PROJECT INFORMATION

Please fill up the following information for the project that you choose as the case project in the blank spaces provided.

1. Project name : _____
2. Owner : _____
3. Location : _____
 - a. Project start date : _____
 - b. Project finish date : _____
4. Contract type : _____
5. Construction type: _____ (building / bridge / infrastructure work)
6. Total project duration : _____ weeks / months
7. Nominal total contract price : RM _____
8. Base cost estimate allocated (does not include cost contingency): _____ (% of total project cost).
9. Planned of the total cost contingency allocated for this project is: _____ % of total project cost).
10. The actual cost contingency for this project : _____ (% of total project cost).

II. PROJECT COST CONTINGENCY ESTIMATION

1. Please determine the type of risks that is significant to **the chosen project** by putting a circle to the number corresponding to every significant risk factor in the column 1 **Table 1**. If there is any type significant risk other than the 14 risk types given in the table, you are welcomed to write down the type of risk in the row number 8 to 10, either for external or internal risk.
2. Please estimate the values of risk likelihood (RL) and risk severity (RS) only for those risk types that have been circled. The assessment is according to **your degree of belief** based on your experiences and judgment. Please fill the values in **column 3 and 4**. You can answer using input data using linguistic terms such as “**about...**” or “**between....to**” if you feel it is difficult to estimate the values precisely.

Table 1. Estimation of Risk Likelihood (RL) and Risk Severity (RS) Values based on Significant Construction Risk Types

No (1)	Risk Types in Construction Project (2)	Numerical Value		Risk Parameter Value Risk Severity (RS) (% of Total Project Cost) (4)
		Risk Likelihood (RL) (0 – 100 Scale) (3)		
1.	Unforeseen site condition (Site, topography)			
2.	Weather condition (rain)			
3.	Changes of government policy (tax, law)			
4.	Social impact (pollution)			
5.	Changes in economic condition (increased price)			
6.	Delay of payment			
7.	Third party delays			
8.	Other risk factor (please write) _____			
9.	Other risk factor (please write) _____			
10.	Other risk factor (please write) _____			
1.	Safety (accident on site)			
2.	Unavailability of resources (equipment, labor and material)			
3.	Labor dispute			
4.	Defective material			
5.	Equipment failure			
6.	Quality of work			
7.	Mismanagement (over budget, cash flow)			
8.	Other risk factor (please write) _____			
9.	Other risk factor (please write) _____			
10.	Other risk factor (please write) _____			

External Risk

Internal Risk

----- End of survey, thank you for your cooperation -----

APPENDIX D. Case Project Data and Risk Parameters Estimation

Project 1

Table D.1.A. Project Information for Project 1

Project type	Infrastructure work
Owner	Government
Location	Putrajaya
Year	2004 - 2005
Contract type	Bill of Quantity
Total duration	12 months
Nominal contract price	RM 20 million
Estimate base cost estimate	RM 18 million
Planned cost contingency (% of total project cost)	5 %
Actual cost contingency (% of total project cost)	4.7 %

Table D.1.B. Estimated Risk Parameters for the Project 1

No (1)	Risk Factors (2)	RL (0 – 100 scale) (3)	RS (% total project cost) (4)
<i>A. External Risks</i>			
1.	Different Site condition	60	1
2.	Weather condition	20	0.25
3.	Social impact	20	0.25
4.	Changes in economic condition	50	1
5.	Third party delays	10	0.25
<i>B. Internal Risks</i>			
1.	Defective material	40	0.25
2.	Quality of work	30	0.3

Project 2

Table D.2.A. Project Information for Project 2

Project type	Infrastructure work
Owner	Private
Location	Penang
Year	2007 - 2008
Contract type	Bill of Quantity
Total duration	12 months
Nominal contract price	RM 700 million
Base cost estimate	RM 595 million
Planned cost contingency (% of total project cost)	5 %
Actual cost contingency (% of total project cost)	5.1 %

Table D.2.B. Estimated Risk Parameters for the Project 2

No (1)	Risk Factors (2)	RL (0 – 100 scale) (3)	RS (% total project cost) (4)
<i>A. External Risks</i>			
1.	Different Site condition	10	0.2
2.	Changes in government policy	70	0.5
3.	Changes in economic condition	80	1
4.	Delay of payment	20	0.5
5.	Third party delays	10	0.3
<i>B. Internal Risks</i>			
1.	Safety	10	0.2
2.	Unavailability of resources	10	0.5
3.	Equipment failure	10	0.5
4.	Quality of work	10	0.3
5.	Mismanagement	50	1

Project 3

Table D.3.A Project Information for Project 3

Project type	Building
Owner	Government
Location	Seri Manjung, Perak
Year	2007-2008
Contract type	Lump-sum
Total duration	13 months
Nominal contract price	RM 2.13 million
Base cost estimate	RM 1.70 million
Planned cost contingency (% of total project cost)	3 %
Actual cost contingency (% of total project cost)	5 %

Table D.3.B Estimated Risk Factor Parameters for the Project 3

No (1)	Risk Factors (2)	RL (0 – 100 scale) (3)	RS (% total project cost) (4)
<i>A.</i>	<i>External Risks</i>		
1.	Weather condition	70	0.1
2.	Changes in government policy	10	0.1
3.	Delay of payment	50	1
4.	Third party delays	30	0.5
<i>B.</i>	<i>Internal Risks</i>		
1.	Safety	80	1
2.	Unavailability of resources	60	1
3.	Quality of work	20	0.1
4.	Mismanagement	30	1
5.	Supervisory by officer	60	0.2

Project 4

Table D.4.A. Project Information for Project 4

Project Type	Building
Owner	Government
Location	Ipoh, Perak
Year	2002 – 2004
Contract type	Lump-sum
Total duration	8 months
Nominal contract price	\$US 0.541 million
Base cost estimate	\$US 0.549 million
Planned cost contingency (% of total project cost)	5 %
Actual cost contingency (% of total project cost)	3 %

Table D.4.B. Estimated Risk Factor Parameters for the Project 4

No (1)	Risk Factors (2)	RL (0 – 100 scale) (3)	RS (% total project cost) (4)
<i>A.</i>	<i>External Risks</i>		
1.	Weather condition	30	0.2
2.	Changes in government policy	40	0.7
3.	Third party delays	20	0.2
<i>B.</i>	<i>Internal Risks</i>		
1.	Safety	10	0.1
2.	Defective material	10	1
3.	Quality of work	50	0.5
4.	Mismanagement	10	0.5

Project 5

Table D.5.A Project Information for Project 5

Project type	Building
Owner	Government
Location	Putrajaya
Year	2002 – 2004
Contract type	Lump Sump
Total duration	24 months
Nominal contract price	RM 34 million
Base cost estimate	RM 28.9 million
Planned cost contingency (% of total project cost)	5 %
Actual cost contingency (% of total project cost)	7.5 %

Table D.5.B. Estimated Risk Factor Parameters for the Project 5

No (1)	Risk Factors (2)	RL (0 – 100 scale) (3)	RS (% total project cost) (4)
<i>A. External Risks</i>			
1.	Different Site condition	50	0.1
2.	Weather condition	10	0.25
3.	Changes in government policy	10	0.1
4.	Social impact	40	0.6
5.	Changes in economic condition	10	2
6.	Delay of payment	20	0.3
7.	Third party delays	10	2
<i>B. Internal Risks</i>			
1.	Safety	50	0.1
2.	Defective material	40	0.3
3.	Equipment failure	10	0.25
4.	Quality of work	50	1

Project 6

Table D.6.A Project Information for Project 6

Project type	Building
Owner	Government
Location	Ipoh, Perak
Year	2007 – 2008
Contract type	Conventional
Total duration	15 months
Nominal contract price	RM 14.5 million
Base cost estimate	RM 13 million
Planned cost contingency (% of total project cost)	3.57 %
Actual cost contingency (% of total project cost)	5.7 %

Table D.6.B Estimated Risk Factor Parameters for the Project 6

No (1)	Risk Factors (2)	RL (0 – 100 scale) (3)	RS (% total project cost) (4)
<i>A.</i>	<i>External Risks</i>		
1.	Weather condition	75	0.7
2.	Changes in government policy	21	0.57
3.	Changes in economic condition	70	1.2
4.	Delay of payment	22	0.1
5.	Third party delays	85	0.5
<i>B.</i>	<i>Internal Risks</i>		
1.	Unavailability of resources	45	0.18
2.	Equipment failure	55	1
3.	Quality of work	65	0.8
4.	Mismanagement	15	0.4

Project 7

Table D.7.A. Project Information for Project 7

Project type	Building (Housing)
Owner	Government
Location	Taiping, Perak
Year	2000 – 2005
Contract type	Turnkey
Total duration	60 months
Nominal contract price	RM 15 million
Base cost estimate	RM 12 million
Planned cost contingency (% of total project cost)	5 %
Actual cost contingency (% of total project cost)	3 %

Table D.7.B Estimated Risk Factor Parameters for the Project 7

No (1)	Risk Factors (2)	RL (0 – 100 scale) (3)	RS (% total project cost) (4)
<i>A.</i>	<i>External Risks</i>		
1.	Different Site condition	30	0.8
2.	Weather condition	30	0.6
3.	Third Party delays	20	0.2
<i>B.</i>	<i>Internal Risks</i>		
1.	Unavailability of resources	20	0.4
2.	Equipment failure	20	0.3
3.	Quality of work	20	0.5
4.	Mismanagement	30	0.2

Project 8

Table D.8.A Project Information for Project 8

Project type	Infrastructure works
Owner	Government
Location	Seri Iskandar, Perak
Year	2002 – 2002
Contract type	Conventional
Total duration	24 months
Nominal contract price	RM 17 million
Base cost estimate	RM 15 million
Planned cost contingency (% of total project cost)	4 %
Actual cost contingency (% of total project cost)	4.12 %

Table D.8.B Estimated Risk Factor Parameters for the Project 8

No (1)	Risk Factors (2)	RL (0 – 100 scale) (3)	RS (% total project cost) (4)
<i>A. External Risks</i>			
1.	Different Site condition	70	0.15
2.	Weather condition	95	0.5
3.	Social impact	70	0.9
4.	Delay of payment	25	0.15
5.	Third party delays	55	0.5
<i>B. Internal Risks</i>			
1.	Equipment failure	78	1.2
2.	Quality of work	45	0.6

Project 9

Table D.9.A Project Information for Project 9

Project Type	Building (Housing)
Owner	Private
Location	Seri Manjung, Perak
Year	1997 - 1999
Contract type	Turnkey
Total duration	12 months
Nominal contract price	RM 33 million
Base cost estimate	RM 27 million
Planned cost contingency (% of total project cost)	6 %
Actual cost contingency (% of total project cost)	6.2 %

Table D.9.B Estimated Risk Factor Parameters for the Project 9

No (1)	Risk Factors (2)	RL (0 – 100 scale) (3)	RS (% total project cost) (4)
<i>A. External Risks</i>			
1.	Delay of payment	70	2
2.	Third party delays	50	0.7
<i>B. Internal Risks</i>			
1.	Defective material	60	1.3
2.	Quality of work	75	1.5
3.	Mismanagement	50	0.5

Project 10

Table D.10.A Project Information for Project 10

Project Type	Building (High-Rise)
Owner	Private
Location	Kuala Lumpur
Year	1996 - 2000
Contract type	Turnkey
Total duration	48 months
Nominal contract price	RM 4.3 billion
Base cost estimate	RM 3.8 billion
Planned cost contingency (% of total project cost)	5 %
Actual cost contingency (% of total project cost)	7.5 %

Table D.10.B Estimated Risk Factor Parameters for the Project 10

No (1)	Risk Factors (2)	RL (0 – 100 scale) (3)	RS (% total project cost) (4)
<i>A. External Risks</i>			
1.	Different Site condition	5	1
2.	Changes in government policy	15	0.6
3.	Changes in economic condition	45	2
4.	Third party delays	25	1
<i>B. Internal Risks</i>			
1.	Safety	70	1
2.	Defective material	30	1.7
3.	Quality of work	80	1.2

Project 11

Table D.11.A Project Information for Project 11

Project type	Infrastructure work
Owner	Government
Location	Lumut, Perak
Year	1996 - 1999
Contract type	Bill of Quantity
Total duration	36 months
Nominal contract price	RM 14 million
Base cost estimate	RM 11.2 million
Planned cost contingency (% of total project cost)	3 %
Actual cost contingency (% of total project cost)	5.6 %

Table D.11.B Estimated Risk Factor Parameters for the Project 11

No (1)	Risk Factors (2)	RL (0 – 100 scale) (3)	RS (% total project cost) (4)
<i>A. External Risks</i>			
1.	Different Site condition	50	1
2.	Delay of payment	50	0.8
4.	Third party delays	50	0.3
<i>B. Internal Risks</i>			
1.	Safety	20	0.2
2.	Unavailability of resources	30	0.5
3.	Labor dispute	20	0.5
4.	Defective material	10	0.5
5.	Equipment failure	30	0.5
6.	Quality of work	30	0.5
7.	Mismanagement	30	0.7

APPENDIX E. MATLAB Program for Developing Computer Tool

```
%input=guihandles(tender_price_estimation_final);
input=guidata(gcbo);

%Reading an input base cost estimate from
tender_price_estimation_final
basecost=str2double(get(input.Ebasecost,'string'));

%Reading of RL input
RL1=str2double(get(input.ERL1,'string'));
RL2=str2double(get(input.ERL2,'string'));
RL3=str2double(get(input.ERL3,'string'));
RL4=str2double(get(input.ERL4,'string'));
RL5=str2double(get(input.ERL5,'string'));
RL6=str2double(get(input.ERL6,'string'));
RL7=str2double(get(input.ERL7,'string'));
RL8=str2double(get(input.ERL8,'string'));
RL9=str2double(get(input.ERL9,'string'));
RL10=str2double(get(input.ERL10,'string'));
RL11=str2double(get(input.ERL11,'string'));
RL12=str2double(get(input.ERL12,'string'));
RL13=str2double(get(input.ERL13,'string'));
RL14=str2double(get(input.ERL14,'string'));

%Reading of RS input
RS1=str2double(get(input.ERS1,'string'));
RS2=str2double(get(input.ERS2,'string'));
RS3=str2double(get(input.ERS3,'string'));
RS4=str2double(get(input.ERS4,'string'));
RS5=str2double(get(input.ERS5,'string'));
RS6=str2double(get(input.ERS6,'string'));
RS7=str2double(get(input.ERS7,'string'));
RS8=str2double(get(input.ERS8,'string'));
RS9=str2double(get(input.ERS9,'string'));
RS10=str2double(get(input.ERS10,'string'));
RS11=str2double(get(input.ERS11,'string'));
RS12=str2double(get(input.ERS12,'string'));
RS13=str2double(get(input.ERS13,'string'));
RS14=str2double(get(input.ERS14,'string'));

%Reading of generic fuzzy inference system (FIS)
a=readfis('generic_model_scenario1A_tune4.fis');
b=readfis('generic_model_scenario1A_tune4.fis');
c=readfis('generic_model_scenario1A_tune4.fis');
d=readfis('generic_model_scenario1A_tune4.fis');
e=readfis('generic_model_scenario1A_tune4.fis');
f=readfis('generic_model_scenario1A_tune4.fis');
g=readfis('generic_model_scenario1A_tune4.fis');
h=readfis('generic_model_scenario1A_tune4.fis');
i=readfis('generic_model_scenario1A_tune4.fis');
j=readfis('generic_model_scenario1A_tune4.fis');
k=readfis('generic_model_scenario1A_tune4.fis');
```

```
l=readfis('generic_model_scenario1A_tune4.fis');
m=readfis('generic_model_scenario1A_tune4.fis');
n=readfis('generic_model_scenario1A_tune4.fis');

%Calculating of RM output from FIS
if ((RL1==0) || (RS1==0))
    RM1=0;
else
    RM1=evalfis([RL1 RS1],a);
end

if ((RL2==0) || (RS2==0))
    RM2=0;
else
    RM2=evalfis([RL2 RS2],b);
end

if ((RL3==0) || (RS3==0))
    RM3=0;
else
    RM3=evalfis([RL3 RS3],c);
end

if ((RL4==0) || (RS4==0))
    RM4=0;
else
    RM4=evalfis([RL4 RS4],d);
end

if ((RL5==0) || (RS5==0))
    RM5=0;
else
    RM5=evalfis([RL5 RS5],e);
end

if ((RL6==0) || (RS6==0))
    RM6=0;
else
    RM6=evalfis([RL6 RS6],f);
end

if ((RL7==0) || (RS7==0))
    RM7=0;
else
    RM7=evalfis([RL7 RS7],g);
end

if ((RL8==0) || (RS8==0))
    RM8=0;
else
    RM8=evalfis([RL8 RS8],h);
end

if ((RL9==0) || (RS9==0))
    RM9=0;
```

```
else
    RM9=evalfis([RL9 RS9],i);
end

if ((RL10==0) || (RS10==0))
    RM10=0;
else
    RM10=evalfis([RL10 RS10],j);
end

if ((RL11==0) || (RS11==0))
    RM11=0;
else
    RM11=evalfis([RL11 RS11],k);
end

if ((RL12==0) || (RS12==0))
    RM12=0;
else
    RM12=evalfis([RL12 RS12],l);
end

if ((RL13==0) || (RS13==0))
    RM13=0;
else
    RM13=evalfis([RL13 RS13],m);
end

if ((RL14==0) || (RS14==0))
    RM14=0;
else
    RM14=evalfis([RL14 RS14],n);
end

%Converting Risk Value from FIS system to percentage
Risk1=RM1/100;
Risk2=RM2/100;
Risk3=RM3/100;
Risk4=RM4/100;
Risk5=RM5/100;
Risk6=RM6/100;
Risk7=RM7/100;
Risk8=RM8/100;
Risk9=RM9/100;
Risk10=RM10/100;
Risk11=RM11/100;
Risk12=RM12/100;
Risk13=RM13/100;
Risk14=RM14/100;

%Calculating project cost contingency (cc)
cc=(Risk1+Risk2+Risk3+Risk4+Risk5+Risk6+Risk7+Risk8+Risk9+Risk10+Risk
11+Risk12+Risk13+Risk14);
tenderprice=(basecost/(1-cc));
```

```
%Setting the output format

% Calculating individual Risk Cost (RC) value
RC1=(Risk1*tenderprice);
RC2=(Risk2*tenderprice);
RC3=(Risk3*tenderprice);
RC4=(Risk4*tenderprice);
RC5=(Risk5*tenderprice);
RC6=(Risk6*tenderprice);
RC7=(Risk7*tenderprice);
RC8=(Risk8*tenderprice);
RC9=(Risk9*tenderprice);
RC10=(Risk10*tenderprice);
RC11=(Risk11*tenderprice);
RC12=(Risk12*tenderprice);
RC13=(Risk13*tenderprice);
RC14=(Risk14*tenderprice);

totalriskcost=cc*tenderprice;

costcontingencypercentage=cc*100;

%Opening risk analysis result window
openfig('cost_contingency_result.fig')

%Saving input window as global variable
handles=guihandles(cost_contingency_result);

format bank;

%Displaying analysis output
set(handles.Ecostcontingencyprediction,'string',num2str(costcontingen
cypercentage));
set(handles.Eriskcost,'string',num2str(totalriskcost));
set(handles.Etenderprice,'string',num2str(tenderprice));

%End of programming code
```