DEVELOPING A MODEL TO PREDICT TIME DELAY IN ROAD CONSTRUCTION PROJECTS USING BAYESIAN NETWORKS

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ABSTRAK

Masa adalah salah satu daripada tiga petunjuk utama bagi mengukur kejayaan sesuatu projek pembinaan itu. Dalam mengejar status sebagai salah sebuah negara maju, keperluan infrastruktur yang cekap dengan masa penyiapan yang tepat adalah penting. Walaubagaimanapun, kebanyakan projek pembinaan di Malaysia mengalami kemerosotan prestasi yang ketara sekaligus menjadi permasalahan utama yang dihadapi. Kajian ini dijalankan bagi mengenalpasti punca-punca berlakunya kelewatan dalam projek pembinaan dan mengenal pasti petunjuk risiko utama yang mempunyai kesan yang signifikan ke atas tempoh projek. Rangkaian Bayesian (BN) digunakan untuk meramal kelewatan masa yang berlaku bagi sesuatu projek. Skop kajian ini bertumpu kepada projek pembinaan jalan persekutuan di Malaysia. Kajian literatur telah dijalankan meliputi projek-projek pembinaan jalan raya di negara-negara membangun, di mana sebanyak enam puluh tujuh (67) punca-punca kelewatan dikenalpasti dan dibahagikan kepada 12 kumpulan. Temubual berstruktur dijalankan bersama-sama dengan tiga panel pakar yang dicalonkan oleh Jabatan Kerja Raya (JKR) bagi menilai punca kelewatan. Hasil temubual tersebut, sejumlah lima puluh enam (56) punca telah ditentukan sebagai relevan bagi projek pembinaan jalan raya persekutuan Malaysia. Pengumpulan data dilakukan dengan menggunakan borang kaji selidik di mana responden dipilih secara rawak. Populasi yang disasarkan terdiri daripada jurutera yang terlibat dalam pembinaan jalan yang mewakili empat entiti iaitu pemilik, kontraktor, sub-kontraktor dan perunding. Sebanyak 500 borang kaji selidik telah diedarkan dan 219 respon diterima semula. Data tersebut dianalisis menggunakan indeks kepentingan relative (RII) bagi tujuan kekerapan dan kesan risiko. Penilaian risiko (RR) kemudiannya diterbitkan hasil darab kedua-dua elemen yang menghasilkan punca kelewatan daripada yang penting kepada yang kurang penting. BNs kemudiannya digunakan untuk membangunkan model ramalan kelewatan masa berdasarkan punca-punca yang diperolehi terlebih dahulu. Struktur dan parameter bagi model BN ditakrifkan berdasarkan pengetahuan pakar jalan raya yang telah ditemubual untuk mengesahkan output BN diperolehi. Punca yang paling ketara menyebabkan kelewatan dalam projek pembinaan jalan raya persekutuan di Malaysia adalah: masalah kewangan yang dihadapi oleh pemilik / pelanggan, keadaan cuaca yang buruk, kelewatan pembayaran oleh pemilik bagi kerja yang telah siap, perubahan turun naik harga bahan mentah, aliran tunai kontraktor tidak mencukupi, kegagalan peralatan (kerosakan), pengalaman kontraktor yang tidak mencukupi, penjadualan dan perancangan projek yang tidak berkesan oleh kontraktor, pergerakan peralatan perlahan dan lemah dalam membuat keputusan. Nilai RR bagi sepuluh punca kelewatan tertinggi adalah 13.818 yang berkaitan dengan masalah kewangan dihadapi oleh pemilik/klien, manakala 9.993 berkaitan lemah dalam membuat keputusan. Kebolehpercayaan model ini adalah melalui pandangan pakar yang mengesahkan bahawa struktur model BN ini mencukupi bagi mewakili masa berlakunya masalah dalam projek jalan raya dan boleh digunakan untuk projek pembinaan lain dengan pengubahsuaian kecil. Namun demikian, pengenalpastian kebarangkalian sebelum dan bersyarat bagi model digalakkan bagi mendapatkan hasil yang lebih dipercayai.

ABSTRACT

Time is one of the three leading indicators by which project success measured. As Malaysia is looking forward to becoming an advanced nation, efficient infrastructure is needed. Therefore, completing these projects on time is very important to achieve this goal. However, a considerable number of construction projects in Malaysia have experienced poor time performance. Time delay is considered to be one of the major problems faced by Malaysian construction projects. Thus, this research is carried out to investigate the causes of delay in construction projects and further identify key risk indicators that have a significant effect on project duration. Bayesian networks (BNs) utilized for time-delay prediction by which project status in terms of time can be examined. Scope of this study focus to federal road projects in Malaysia. A literature review was undertaken covering construction projects in Malaysia and road projects in developing countries which resulted in 67 causes of delay divided into 12 groups. Semi-structured interview with three expert panels nominated by Public Work Department (JKR) conducted to evaluate the delay causes. A total of 56 causes were determined as relevant to Malaysian road projects. Data collection was then carried out using a questionnaire survey in which respondents were randomly selected. The targeted population was drawn from construction practitioners involved in road construction representing four entities, namely: owner, contractor, sub-contractor and consultant. A total of 500 copies were distributed and 219 valid responses were received. The data were then analysed using relative importance index (RII) for risk frequency and impact. Risk rating (RR) was further established based on the multiplication of both attributes leading to rank the delay factors from the most to least important. Bayesian networks (BNs) were employed to develop a prediction model of time delay based on significant factors causing the delay. The structure and parameters for the BNs model were defined based on knowledge of road experts who have been also approached to verify and validate the BNs outputs. The results indicated that the most significant factors causing delay in federal road construction projects in Malaysia are: financial difficulties faced by owner/ client, bad weather conditions, delay in payment for completed work by owner, material price fluctuation/ increase, cash flow of contractor is insufficient, equipment failure (breakdown), inadequate contractor's experience, ineffective scheduling and planning of project by contractor, slow equipment movement and slow decision making. The RR value for top ten delay causes ranges between 13.818 related to financial difficulties faced by owner/ client and 9.993 related to slow decision making. In addition, the validation of this model through expert's opinion confirms that the BNs model is adequate to represent the timeframe of the road projects and can be used for other construction projects with minor modifications. However, it is recommended to apply more reliable methods to identify prior and conditional probabilities for the model to obtain more reliable outcomes.

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LIST OF SYMBOLS

$P(A \mid B)$	Conditional probability function
$P(A)$	Probability function
$P(A \cap B)$	Probability of events intersection
n	Minimum sample size
P	Population proportion
e	Sampling error of the point estimate
Z	Statistical value for the confidence interval used
X	Discrete random variable
x	The values of the variable
S	The states of the variable

LIST OF ABBREVIATIONS

ANNs	Artificial Neural Networks
BNs	Bayesian networks
CIDB	Construction Industry Development Board
CPTs	Conditional probability tables
DAG	Directed Acyclic Graph
GDP	Gross Domestic Product
HM	Her Majesty's Treasury
IRM	Institute of Risk Management
ISO	International Organization of Standardization
JKR	Public Work Department
OGC	Office of Government Commerce
PMI	Project Management Institute
PMF	Probability mass function
RM	Risk management
SD	Standard Deviation
SPSS	Statistical Package for Social Sciences

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Construction industry is a key element in supporting the economy in any country where huge amount of income is being allocated for the construction development process. This industry helps to improve a country's gross domestic product (GDP) and quality of life by providing necessary infrastructure such as roads, hospitals, schools and others (Shehu, Endut & Akintoye, 2014). In Malaysia, this industry is expected to contribute to 5.5% to the Malaysian GDP by 2020 (CIDB, 2016b). As Malaysia is looking forward to becoming an advanced nation, efficient infrastructure is needed. This fact clarifies the huge investment received by infrastructure sector and most of it went for construction of roads (Tahir, Haron, Alias & Diugwu, 2019).

Malaysian Ministry of Works had established a federal statutory body which is Construction Industry Development Board (CIDB). The primary mission of this organization is to develop local construction industry to world-class industry and make it competitive locally and abroad (CIDB, 2016b).

However, many construction projects have failed to meet the required level of satisfaction. This satisfaction is basically measured by three key indicators, time, cost and quality (Abd El-Karim, El Nawawy & Abdel-Alim, 2015). Like any country, late completion of Malaysian construction remains a great concern (Hasmori et al., 2018). This delay is often accompanied by undesirable results for project parties forcing them to wait and pay more than expected. For instance, project owners may be adversely affected through loss of benefits that could have been gained from completed facilities. While contractors may have to utilize more labour and machineries, and pay penalties imposed due to the resulting delay not mentioning the decline of contractor's reputation (Mukuka, Aigbavboa & Thwala, 2015).

Delays occur due to many factors affecting project duration differently. However, the impact of risks in construction projects depends on project country, size and the nature of the project itself (Elawi, Algahtany & Kashiwagi, 2016). In principle, the impact of construction delay is commonly acknowledged as additional cost, loss of profits, waste of resources and disputes between project parties. Above all such negativities, time overrun has been realized as one of the main effects of delay proven through several studies (Arantes, Da Silva & Ferreira, 2016; Khair, Mohamed, Mohammad, Farouk & Ahmed, 2018; Amoatey, Ameyaw, Adaku & Famiyeh, 2015). Eventually, the project may be totally abandoned due to significant loss faced by project parties (Ayudhya & Kunishima, 2017).

One of the challenges of project success is risk and uncertainty involved in various construction stages. Thus, implementation of risk management (RM) in construction projects is recommended as a helpful tool for achieving the project within the planned goals. RM is applied thought all project phases allowing potential risks being identified and their effects being minimized (Szymański, 2017). Most importantly, giving the potential for key practitioners to meet their commitments and make the project more profitable (Serpella, Ferrada, Howard & Rubio, 2014).

There exist many approaches involved in expert systems, artificial intelligence and others that deal with uncertainty properly. However, probabilistic approach was claimed to be the most adequate description of uncertainty (Ye & Zheng, 2016). In contrast to this, it was argued that dealing with such approach requires obtaining all possibilities which makes the computation process tedious (Halabi, Kenett & Sacerdote, 2017). It is to overcome such problem, Bayesian networks (BNs) were introduced by Judea Pearl (Eshtehardian & Khodaverdi, 2016). BNs take advantage due to its capability of updating subjective beliefs when new evidence arrives. Thus, this work integrates RM and BNs to build a prediction model and handle uncertainty accompanied with risks in road construction projects.

1.2 Background of the Study

Economic development between the 1980s and 1990s has put Malaysia on the fast track to becoming one of the fast-southeast Asia's economies. During this period, the physical landscape transformed numerous construction projects emerged, especially for Kuala Lumpur making this city one of the most built-up capitals in the region (Khan & Khalique, 2014). Since that period, construction sector has witnessed a major prosperity despite the two crises that plagued the Asian economy and the global finance in the period 1997-1988 and 2007-2008, respectively (Khan, Liew & Ghazali, 2014).

Economically, all sectors proceeded to expand. Construction industry constitutes a critical element in terms of Malaysia's GDP and estimated to increase at 10% per year. Particularly, the growth of construction sector reached at 6.5% in the beginning of 2017 growing to 8.3% in the second quarter and ending up with 8% as an annual growth (CIDB, 2017). This is an indication that the construction activities and economic growth have strong correlation. This positive relationship was also recognized within the period between 1991-2010 (Khan et al., 2014).

The industry provides considerable contribution to employment sources offering many opportunities for people with different level skills. In this context, manufacturing occupies the first place followed by wholesale and retail trade, and agriculture, forestry and fishing. Whereas, construction industry is regarded the fourth largest employer in Malaysia (CIDB, 2016b). That would help to reduce unemployment rate, poverty and improve income for people (CIDB, 2016a). According to the Department of Statistics (2016), more than 1.2 million workers were involved in this industry with approximately 9% of the total national workforce.

Roads are considered as basic element of Malaysian infrastructure accounting for nine-tenth of all passengers and freight traffic and most widely used mode of domestic transport (Jatarona, Yusof, Ismail & Saar, 2016). Road network in Malaysia has witnessed an expansion of 58% between the period 2010 and 2015 only, providing accessibility, mobility and connectivity. Generally, roads in Malaysia are classified into two main categories, namely: federal roads and states roads. Federal roads link states capitals and lead to the exit from the country. State roads provide internal communication within a certain state. Normally, the construction of roads is handled by Public Work Department

(JKR). The primary goal of JKR is to provide infrastructure serving the increasing needs of the country (Ghenbasha, Sabki, Omar & Ayob, 2018). Thus, it is crucial for such agencies to complete these projects on time for the continuation of the development process.

1.3 Problem Statement

The Malaysian government is considered the largest client in the construction industry. The government has focused on developing basic infrastructure to enhance the economic growth, connectivity and meeting people needs (Ramanathan & Narayanan, 2014). However, a considerable number of construction projects in Malaysia have experienced poor time performance. It was reported that building projects in Malaysia face time or/and cost overruns between 5% and 20% of contract duration (Yap & Skitmore, 2018). This findings are very close to the findings of Haslinda, Xian, Norfarahayu, Hanafi and Fikri (2018) in which 10% to 30% of high rise building projects were completed late as stated by most respondents. Public projects have also been criticized because of failure of meeting project's deadlines. For example, Shehu, Holt, Endut and Akintoye (2015) found that only 25% of Malaysian construction projects were completed within planned period and concluded that public projects in particular experience time overrun more than those implemented by private sector. It was further stated that projects handled by JKR in particular take longer than their original schedule to be completed in planning and design phases (up to 60 extra days) (Ab. Halim & Zin, 2016). Developed countries were also faced by time overrun. According to Olawale and Sun (2010), complex construction projects in the UK are likely to be finished more than six months late. Zhang, Chen and Yuan (2019) concludes that traditional construction projects in Canada were delayed by about 4 months averagely. It was also found that the average schedule overrun in rich counties such UK, USA, Sweden and others was 42.7% (Ansar, Flyvbjerg, Budzier & Lunn, 2016).

The above-mentioned results with regard to Malaysia present the problem of delay faced by general construction projects and those implemented by the government. However, Mohamad, Wafa and Singh (2016) focused on road construction sector by analysing a sample of 10 projects experienced time overrun in the state of Perak. The findings revealed that time overrun could have reached to100 days maximum. As a result, delay in completion was experienced within Malaysian road projects but remains rarely studied.

Repletion of delay in public construction projects indicates that the efforts made to handle this problem are insufficient. Therefore, this study was carried out to investigate causes of delay in Malaysian public projects. More specifically, the focus was given to road projects since research conducted within such field in Malaysia appear to be lacking. Moreover, BNs were utilized to provide a prediction tool particularly for owner and contractor to assess project status in terms of time delay.

1.4 Research Questions

As a result of the issues identified in section 1.3, the following research questions have been formulated:

i What are the causes of delay in road construction projects in Malaysia?

ii Who is causing time delay in road construction projects in Malaysia?

iii Where are the most critical causes of delay affecting road construction projects?

iv How to predict and overcome time delay in road construction projects in Malaysia?

1.5 Research Objectives

To successfully answer the research questions, the following objectives have been formulated:

i To establish risk rating for causes of delay in road construction projects.

ii To develop a model to predict time delay in road construction projects using BNs.

iii To validate the BNs model based on knowledge of road experts.

1.6 Research Scope

This research focuses on federal road projects in Malaysia. The research investigates causes of delay in road construction projects and further identifies key risk indicators that have significant effects on project duration. The focus was given to public projects since the responsibility of the construction of roads in Malaysia lies with the government. All representatives of project parties were considered through data collection process.

1.7 Significance of the Research

This study identifies the most important factors causing delay in road construction projects in Malaysia. These factors should be paid more attention for completing a project within the planned period. As a result, counter measures have been proposed as potential solutions for owner and contractor to avoid project delay. Moreover, a BNs model to predict time delay in road construction projects was developed. The model works as a warning system, particularly for owner and contractor to prevent construction delay. The value of the model is reflected by the ability of providing direct answer about delay percentage of which project progress in terms of time can be examined.

1.8 Limitations

In this research, approaching experts for defining the structure and parameters of BNs model was challenging which hierarchy led to two main assumptions to serve research objectives. The first assumption was made by considering all the delay factors with direct effect on project delay without relationships between each other. This may not be always the case. For example, late delivery of material leads to shortage of material on site. Moreover, the states (variable conditions) which are fundamental components during model development were defined without experts' consultation. These difficulties and limitations have affected the reliability of the estimation of prior and conditional probability tables for the whole network.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents the problems of delay faced by construction projects. The most important factors affecting time delay in road construction worldwide and Malaysian construction are also reviewed. This chapter also presents the concept of risk management (RM), its process and application in construction field. Moreover, an explanation of Bayesian networks (BNs) and some concepts associated with this method are provided. This is followed by some important features by which BNs take advantage over the other methods. Some of the challenges associated with expert-based BNs modelling are also addressed. This chapter ends with some recent research in construction field in which BNs have been employed.

2.2 Overview of Delay and Time Performance in Construction Projects

In construction, delay could be defined as the period of time exceeding the completion date stated in the contract or the agreed time between project parties (Assaf & Al-Hejji, 2006). It is the difference between the actual and original contract duration (Sweis, Sweis, Abu Hammad & Shboul, 2008). It is also described as the situation when owner and contractor together or individually contribute to project completion beyond contract duration (Aibinu & Jagboro, 2002). Construction delay is acknowledged as a global phenomenon and rare projects are completed within planned period (Aziz, 2013).

Construction is generally recognized as complex and high-risk exposed (Tawil et al., 2014). Risks in construction are continuously evolving and occur in all project phases. Despite the different views about which phase is more risky, the effects of risks on project duration could eventually lead the project to total abandonment (Riazi, Skitmore &

Cheung, 2011). The problem of delay may arise due to uncertain environment that the project may encounter in the future. However, unexpected events are not only the source of delay problem. Although the importance of time for both owner and contractor is overriding, many causes of delay are attributed to their poor performance. In fact, owner, contractor and consultants have the greater influence on project delay (Alzara, Kashiwagi, Kashiwagi & Al-Tassan, 2016).

Construction delay has been internationally experienced, especially in developing countries. For instance, 80% and 72% of infrastructure projects in Ethiopia and India were delivered late (Tesfa, 2016; Patil, Gupta, Desai & Sajane, 2013). In Saudi Arabia, the average delay of 39% was found among 49 road and bridge construction. Seboru (2015) studied delays in Kenyan roads based on the fact that 70% of these projects were not completed on time. Furthermore, almost the same percentage as previous has been experienced in bridge construction in Nepal where 16 out of 82 projects exceeded the contract period by more than 100% (Suwal & Shrestha, 2016). In Jordan, 65% of public projects were completed beyond planned period (Sweis, 2013). The magnitude of delay may significantly appear in the former country since the delay could have reached to 455% of contract duration (Al-Hazim & Abu salem, 2015). In Korea, construction projects were averagely delayed by 30.2% of contract duration (Acharya, Im & Lee, 2006).

Malaysian construction industry is also facing such problems. It was emphasized that poor performance associated with project time and cost is no longer acceptable as the plan put Malaysia towards becoming a developed country (Jatarona et al., 2016). However, It was reported that failure in meeting project objectives within planned time and cost in Malaysian construction is a critical issue (Memon, Abdul Rahman & Abdul Azis, 2012). Most Malaysian construction projects have suffered delays in project delivery (Ramanathan, Potty & Idrus, 2012). Memon, Abdul Rahman, Abdullah & Abdul. Azis (2011) investigated 30 large construction projects suffered from delay in completion. The study revealed that over 50% of the projects exceeded contract duration by less than 100 days. In addition to that, 10 projects had additional 100 to 300 days to be completed, and only 3 projects required over 300 extra days to be achieved. Other researchers have also stated that several project clients have experienced either time or/and cost overruns. As cited by Shehu et al. (2014), 15 out of 16 projects undertaken by Ministry of Defence

(MoD) were completed beyond contract duration. It was further concluded that approximately 17% of projects handled by the Malaysian government were regarded sick (Sambasivan & Soon, 2007). Elsewhere, public projects were exposed to criticism as 79.5% of the projects exceeded the original duration (Endut, Akintoye & Kelly, 2009). The aforementioned results confirm that even the government which is the biggest client in the Malaysian construction industry is affected by negative trend of time overrun.

2.3 Causes of Delay in Road Construction Projects

Causes of delay spread through the project from the beginning to the end, regardless of the location, ownerships and type of construction. However, road projects are exposed to higher risk than other construction due to geological issues. Moreover, long span, multiplicity of stockholders involved and huge investment make it challenging to achieve the project within planned period (Vu, Wang, Min, Mai & Nguyen, 2016).

A considerable number of studies within road construction sector worldwide have been carried out to explore the reasons behind delays. However, the number of causes varies from each study to another. Most often, delay factors are classified into groups based on their sources. For example, Mahamid, Bruland and Dmaidi (2012) identified 52 causes of delay affecting Palestinian roads categorized into 8 groups, namely: project, owner, material and equipment, labour, external, design, contractor and consultant. The study found that political situation is the most important factor causing delay in road projects. Al Hadithi (2018) analysed 64 factors causing delay in highway construction projects in Iraq using frequency index and Spearman's rank correlation. It has been also concluded that political decision and political realities is the highest cause affecting high project delay. In both countries (Palestine and Iraq), unstable political situation leads to increase cost of materials, shortage of resources, difficulties in importing material and then delay. Causes of delay have been also investigated within road and bridge projects in Saudi Arabia (Elawi et al., 2016). It has been found that the highest frequent and severe factor contributing to delay was land acquisition. The researchers declared that this finding matched with the research findings of the Gulf Countries Construction (GCC) Industry's literature. Land acquisition was also analysed at the top of factors causing delay in roads over bridges in India (Venkateswaran & Murugasan, 2017). If the project area falls within private lands, it is much more difficult as owners tend to resist land acquisition in several ways. Moreover, in urban locations in India, very few lands are under the control of the government and hence most of these projects require long time for land acquisition. There is also a common problem in other developing countries such as Egypt, Kenya, Zambia, Ghana and Ethiopia where financial difficulties and funding the project was computed the first factor causing road project delay (Aziz & Abdel-Hakam, 2016; Seboru, 2015; Kaliba, Muya & Mumba, 2009; Akomah & Jackson, 2016; Amare, Quezon & Busier, 2017). Delay in payment affects the performance of contractor most construction activities cannot be carried out. (Santoso & Soeng, 2016) concluded that rain and floods are the highest factors causing delay in Cambodian road project and further elaborates road projects are usually constructed in long space which makes it more vulnerable to rain effects. (Kamanga & Steyn, 2013) investigated causes of delay in road construction projects in Malawi. The top five causes were shortage of fuel, insufficient cash flow of contractor, shortage of foreign currency slow payment procedures adopted by client and delay in relocating utilities.

2.4 Causes of Delay in Malaysian Construction Projects

In Malaysia, the research conducted in this country has covered many types of construction, and the same factors were found to be significant in different studies. For example, financial difficulties of contractor was prioritized the cause number one of delay many times in addition to poor site management and improper planning of contractor which have been ranked among top five causes repeatedly (Abdullah et al., 2010; Shehu et al., 2014; Memon, Rahman, Akram & Ali, 2014; Hasmori et al., 2018). Owner was also found to be significant contributor to project delay where financial and late payment to contractor was analysed in critical position through Malaysian literature (Memon, 2014; Memon et al., 2014; Shah, 2016). This is an indication of poor performance of both owner and contractor in construction and the important role they play in project success. Tahir et al., (2019) conducted a study within Malaysian construction projects in which the most critical causes of delay were delay in preparation of design document, poor schedule and control of time, delay in delivery of material to site, lack of knowledge about the different defined execution methods, shortage of labour and material in market, and changes in scope of work. Setting aside from project professionals, there are other uncontrollable factors interrupting project progress such as rain effect or weather conditions. This factor has been prioritized as the most important factor causing delay remarkably (Mydin, Sani, Taib & Alias, 2014; Ramanathan & Narayanan, 2014;

Ramanathan et al., 2012). In this research, literature review was carried out to identify the most important delay factors affecting road projects worldwide and Malaysian construction (see Appendix A).

2.5 Construction Risk Management

Risk management (RM) is used in many industries including construction sector. Several organizations and institutes have developed their own RM standards such as Project Management Institute (PMI) (PMI, 2017), Office of Government Commerce in UK (OGC) (OGC, 2002) and others. In the context of construction project management, RM is defined as "the process of conducting RM planning, identification, analysis, response planning, response implementation, and monitoring risk on a project" (PMI, 2017). As cited by Zou, Zhang and Wang (2007), it is one of the ten areas acknowledged by the former institute and all are equally important. Although RM is claimed to be as a complex process that is very difficult to perform, its application is recommended in all projects to avert adverse consequences (Adnan, Jusoff & Salim, 2008).

RM is one of the vital issues which is strongly associated with project success. It is regarded as mandatory task for fulfilling project objectives (Sharma & Swain, 2011). It was reported that the application of RM is even more important than decision making process within the organizations (Fatemi & Glaum, 2000). In construction, risks are dynamic and constantly changing. Therefore, RM is applied during the lifetime of the project by determining the probability of occurrence and addressing proper treatment if they materialized (Thevendran & Mawdesley, 2004). However, it was argued that more benefits of RM are derived in the conceptual phase because of high degree of uncertainty in such phase (Uher & Toakley, 1999), and consequently supporting decisions taken by project professionals. For instance, decisions related to contractor's work can be optimized in consideration of risk events that might occur. Such decisions can be derived from applying RM beginning from identifying risks linked to the project reaching to the proper actions to reduce them (Kembłowski, Grzyl, Kristowski & Siemaszko, 2017). It was further explained that managing risks does not only involve identifying threats, but also the associated opportunities (Szymański, 2017). Eventually, it should be emphasized that the aim of RM is not to remove all risks rather than increasing the chance of achieving success (Zou et al., 2007).

Implementation of RM in construction requires going through several processes. These include RM planning, risk identification, qualitative risk analysis, quantitative risk analysis, plan risk response, implement risk response and risk monitoring (PMI, 2017). Each process has inputs, techniques and outputs, and heavily dependent on of the outcomes coming from previous processes. Therefore, each process should be adequately performed to ensure high-quality flow of information. That is why the earlier stages are acknowledged as a fundamental for effective RM. Jia et al. (2013) compared between RM processes in different organizations and found many common processes. It has been found that RM planning is the beginning of the whole RM and helpful for the success of the next processes through the life cycle of the project. The researcher also declared that RM reporting is the end of RM. It is generally useful to summarize the RM with regular outputs with regard to predefined risk control points, and helps organizations to understand current situations and take corresponding measures in their RM practice. Table 2.1 shows a comparison of RM process in different organizations.

Table 2.1 Comparison of risk management process in different organizations

RM process	**Professional recognition**				
	PMI	**OGC**	**ISO**	**IRM**	**HM treasury**
Risk planning	*		*		
Risk identification	*	*	*		*
Risk analysis	*		*		
Risk assessment		*	*	*	*
Risk responses	*	*	*	*	
Risk monitoring	*	*	*	*	
Risk control	*				*
Risk review and reporting			*	*	*

Source: Jia et al. (2013)

2.5.1 Risk Identification

RM begins with risk identification as a starting point in which risks that could affect the project and their characteristics are recorded (Mojtahedi, Mousavi & Makui, 2010). They could be repeatedly materialized in one or multiple project phases. Therefore, risk identification is carried out continuously through all project phases and should be an ongoing process through the whole life cycle of the project (Kasap & Kaymak, 2007). However, a study carried out in Malaysia revealed that contractors prefer to identify risks during third part of project duration because risks are controllable in this period (Adnan et al., 2008). In contrary, it was concluded that identification of risks is better over the bidding stage, that is, effective estimation of overruns in time and cost can be derived (Renuka, Umarani & Kamal, 2014). The result of this process is a list of potential risks to one or more of project objectives and further to be managed.

Several techniques can be employed for risk identification purpose. These mainly include experts consultation, interviews, meetings or revising historical data and records (Choudhry & Iqbal, 2013). Hillson (2002) argues that no specific technique is more favourable over the others. Therefore, multiple techniques should be applied for more effective risk identification. Adnan et al. (2008) further explains that choosing proper technique is dependent on the environment and conditions that the project is subject to as different risk factors can be found in different projects. However, these techniques should be carried out with care, that is, identifying potential risks posing a threat to the project, so that efficient RM can be performed. This offers many alternatives strategies that could be utilized for establishing risk reduction (Cazorla, Luque & Dieguez, 2017)

Identifying risks is not the responsibility of the project manager only. All stakeholders and project team members have a responsibility to identify project risks. Engaging all stakeholders maximize the effectiveness of the outcome of this process and leads to avoiding negative impacts that may affect the project in the future. Here, the experience and knowledge of stakeholders are of great importance towards project success (Kotb & Ghattas, 2017). Risk identification activities involve wide range of participants. They can be project managers, team members, customers, experts, end users, operations managers, stakeholders and others (PMI, 2017).

2.5.2 Risk Analysis

In the RM process, all steps are interconnected, and each is regarded as a part of a system. Therefore, each step should be adequately handled to guarantee the effectiveness of the system as a whole from planning stage to completion (Baloi, 2012). This indicates how important risk identification step is as it constitutes the basis for the next stages. Once the risks are identified, risk analysis is then applied. The main purpose of risk analysis is to evaluate possible consequences of the major risks that have been identified earlier (Aven, 2012). Therefore, many alternatives can be provided by performing this procedure and would promote the process of decision making (Dziadosz & Rejment, 2015).

The process of project risk analysis demands efficient and appropriate techniques. These techniques are usually supported by tools that assist in the process of gathering and managing the data in the various project phases (Renuka et al., 2014). Each risk analysis technique has its strengths and weaknesses. In principle, two categories of risk analysis have been developed, qualitative and quantitative. In construction projects, all methods can be applied. However, applying a certain technique should be carried out in accordance with some considerations, i.e. the nature of risk, project scope and the requirements that should be satisfied (Gajewska & Ropel, 2011). It was stated that "the right analysis technique is the one capable of adequately capturing and handling uncertainty" (Baloi, 2012). Finally, whether using qualitative or quantitative method, the results of the analysis should be reliable.

A qualitative risk analysis is based on descriptive scale to prioritize and identify project risks. It depends on the estimation of risk probability and corresponding impact on project objectives should they occur (time, cost, quality) (Brown, 2012). Subsequently, deciding which action is needed after integrating the probability of occurrence and impact (Marco & Thaheem, 2014). More often, qualitative analysis is performed first and forms the basis for quantitative analysis. In general, this type of analysis can be accomplished where risks can be addressed on a nominal scale (Serpella et al., 2014).

A quantitative risk analysis numerically analyses data and the effect of the identified risks on project objectives. In this category, the risks with high priority are further analysed by assigning numerical rating in order to develop a probabilistic analysis of a project (Choudhry & Iqbal, 2013). Hence, a clearer picture of the problem may be presented by figures or graphs (Szymański, 2017). As mentioned earlier, the right techniques to be chosen depends on the type of the project and its characteristics. Table 2.2 shows the main differences between qualitative and quantitative risk analysis.

Table 2.2 Comparison between qualitative and quantitative risk analysis

Qualitative risk analysis	Quantitative risk analysis	Source
Nominal scale	Numerical scale	(Marco & Thaheem, 2014)
Perform first	Perform after qualitative analysis is accomplished	(Szymański, 2017)
Applied in small companies	Applied in medium and large companies the can afford the requirements for these methods	(Lyons & Skitmore, 2004)
No software required	May require specialized tools because of the large amount of data	(Adnan et al., 2008)

Note that the CIDB categorizes the contractors in Malaysia that register with them using grades from G1 to G7 based on the contractor's tendering capacity and their paid-up capital. Contractors that are registered with CIDB are awarded grades of registration from G1 to G7. These grades reflect the tendering capacity of the construction company and its capacity to accept a range of construction projects of different values. Moreover, A construction company is structured based on their grades of registration, which reflects their financial capabilities, tendering capacity and size of the company. When the company expands and increases their financial capabilities, a contractor can apply to upgrade to a higher registration grade and increase their tendering capacity (Kamal & Flanagan, 2014). Table 2.3 shows the grades of registration of the contractors and the difference between small, medium and large companies, as set by the CIDB.

Table 2.3 Grades of registration of contractors by the CIDB

Contractor grades of registration	**Tendering capacity**	**Paid-up capital**	**Size of company**
G7	No limit	RM 750,000 (USD 247,500)	Large construction company
G6	Not exceeding RM10 million (USD 3.3 million)	RM 500,000 (USD 165,000)	
G5	Not exceeding RM 5 million (USD 1.65 million)	RM 250,000 (USD 82,500)	Medium construction company
G4	Not exceeding RM 3 million (USD 990,000)	RM 150,000 (USD 49,500)	
G3	Not exceeding RM 1 million (USD 330,000)	RM 50,000 (USD 16,500)	Small construction company
G2	Not exceeding RM500,000 (USD 165,000)	RM 25,000 (USD 8,250)	
G1	Not exceeding RM200,000 (USD 66,000)	RM 5,000 (USD 1,650)	

Source: Kamal and Flanagan (2014)

2.6 Bayesian Networks

Bayesian belief networks or Belief networks (BNs) are probabilistic graphical and mathematical model that combined graphical theory and probability to interpret the dependency relationships between the variables (Brown, 2012). They are directed acyclic graph (DAG) consisting of two parts. The first part, so called qualitative part, implies development of the BNs structure in which a set of random variables in a certain domain is represented. These variables are connected by arrows by which the dependence relationships between the variables are captured beginning from influencing variables towards influenced variables (Khodakarami & Abdi, 2014). When two variables are not connected, that is, the probability of one variable does not depend directly upon the other. The variable with no incoming arrow is called root node, and the probability corresponds to this variable before observing any evidence is called prior probability. The variables can be discrete which is defined by finite number of states such as balloon (yes or no), categorical (low, medium, high) and others. On the other hand, continuous variable implies probability definition in continuous scale such as height and temperature (Misirli & Bener, 2014). The second part, so called quantitative part, deals with numerical aspect of the network which implies defining prior probabilities for independent variables and conditional probabilities for dependent variables whether being discrete or continuous. The whole system describes how the variables interact and can be useful for problem-solving in decisions that involve uncertainty (Iqbal, Yin, Hao, Ilyas & Ali, 2015). Luu, Kim, Tuan and Ogunlana (2009) provides an example of BN constructed mainly to predict delay in construction projects. The researcher illustrates the flow of information and cause-effect relationship between "shortage of material" and "construction delay" as shown in Figure 2.1.

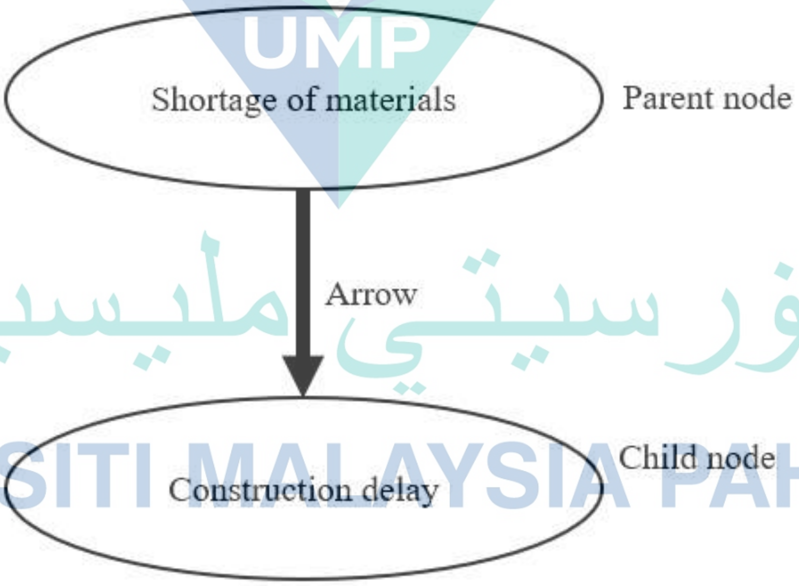

Figure 2.1 A simple Bayesian network of the construction delay
Source: Luu et al., (2009)

Figure 2.1 represents a simple BN constructed mainly for predicting schedule delay in construction project. The node "shortage of material" is denoted as parent node and the node "construction delay" is denoted as child node. The arrow between them indicates that if the project is experiencing shortage of materials, it would cause a delay in project completion. Thus, it can be said that "shortage of materials" is a parent of "construction delay" because "construction delay" depends on the conditions of "shortage of materials", and the arrow represents causal relationship beginning from the cause to the effect. In other word, the probability distribution of construction delay is conditionally dependent upon the occurrence probability of shortage of materials.

The concept of d-separation is very important and respected during BNs construction. The structure of BNs represents the (in)dependencies among a set of random variables. Therefore, it is possible to identify the relevant and irrelevant relationships of the variables without any calculations. Three fundamental connections are found in the network topology, namely: serial connections, diverging connection and converging connection explained with consideration of Figure 2.2 as follows:

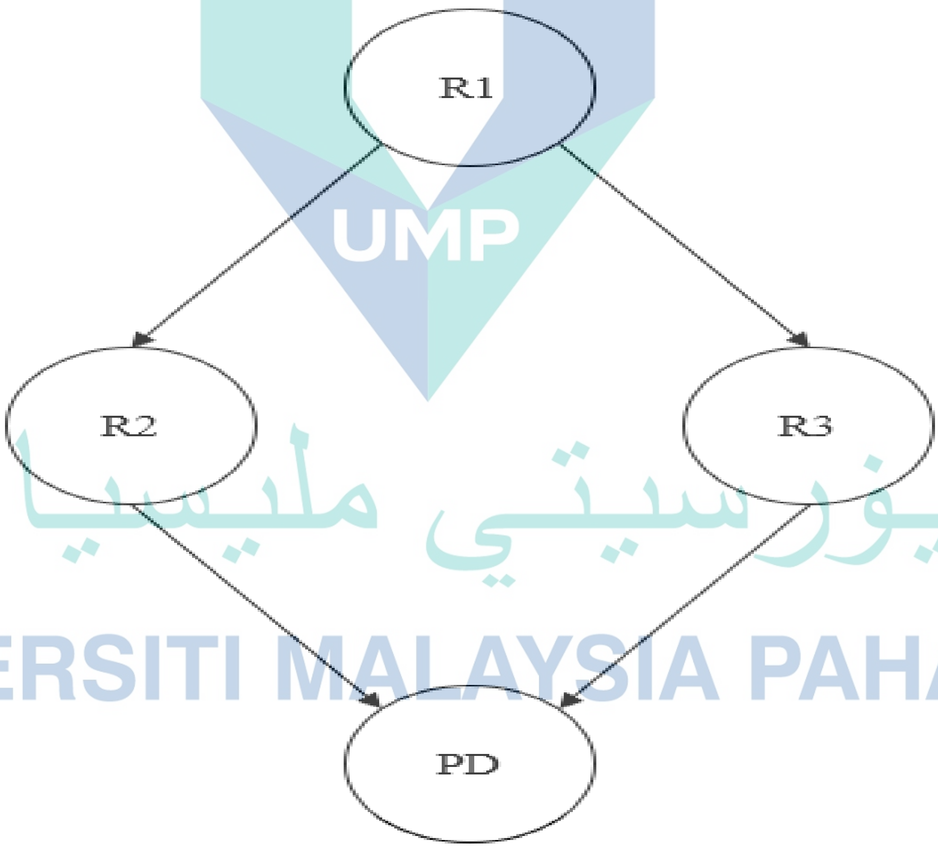

Figure 2.2 Types of connections in BNs
Source: Rafiq, Chryssanthopoulos and Sathananthan (2015)

i Serial connections:

As shown in Figure 2.2, the information may be transmitted from $R1$ to PD through $R2$. If evidence in $R2$ is observed, the information is blocked making $R1$ and PD conditionally independent. For instance, suppose $R1$ represents financial status of contractor, $R2$ represents labour productivity, $R3$ represents sub-contractor's performance and PD represents project delay. The encoded conditional independence statement implies that if there is no information about labour productivity, the project delay can be informed by financial status of contractor. Thus, $R1$ and PD are not independent. However, when labour productivity is known, any knowledge about financial status of contractor becomes irrelevant to any beliefs about project delay. Therefore, $R1$ and PD are independent given $R2$.

ii Diverging connections:

Consider the situation when $R1$ has an influence on both $R2$ and $R3$. This connection encodes that $R2$ and $R3$ are independent given $R1$. However, they are not independent marginally. For example, the knowledge about labour productivity can support and inference about financial status of contractor which in turn makes it possible to infer about sub-contractor's performance. On the other hand, if a condition of financial status of contractor is observed, then labour productivity and sub-contractor's performance are considered independent. Hence, $R2$ and $R3$ are independent given $R1$.

iii Converging connections:

Consider the situation when both $R2$ and $R3$ have an influence on PD. This connection encodes that if these is no information observed about PD, then $R2$ and $R3$ are marginally independent. In other words, the evidence on $R2$ or $R3$ has no influence on the other. However, they not independent given PD. For example, labour productivity and sub-contractor's performance are independent. However, if knowledge about project delay arrives, the conditions of labour productivity can be inferred from knowledge about sub-contractor's performance and vice versa. Hence, $R2$ and $R3$ are not independent given PD.

2.6.1 Bayes' Rule

BNs are based on conditional probability theory which was developed in the late 1700s by Thomas Bayes. Bayes' rule can be expressed as follows (Khodakarami & Abdi, 2014):

$$P(B \mid A) = \frac{P(A \mid B)P(B)}{P(A)} \qquad 2.1$$

Where $P(B)$ is prior probability, which represents the probability or belief about B before observing any evidence. $P(A)$ represents the probability of evidence A that has been observed. $P(A \mid B)$ is the conditional probability or the likelihood of event A given that the event B has occurred. $P(B \mid A)$ is called the posterior probability of B after making observation about A. As can be noted, the probability of B appears in both sides of Equation 2.1. Bayes' rule describes how the probability of an event B changes given new knowledge about event A that has been obtained. Thus, Bayes' rule can also be written as:

$$Posterior = \frac{Likelihood * Prior}{Evidence}$$

By applying this rule, the probability distribution of some variables taking certain values can be revised with respect to new data arrives (Liu, 2010).

2.6.2 Conditional Probability

Conditional probability is the probability of variable being on a certain state that is dependent on the states of another variable. Given two variables, A and B, a conditional probability is denoted as $P(A \mid B)$. $P(A \mid B)$ is the probability of variable A occurring given that B has already occurred. Mathematically, conditional probability can be written as shown in Equation 2.2:

$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)} \quad 2.2$$

Where $P(B) > 0$.

If A and B are independent, then:

$$P(A \cap B) = P(A)P(B) \quad 2.3$$

Based on Bayes theorem we have:

$$P(A \cap B) = P(A \mid B)P(B) \quad 2.4$$

By comparing Equation 2.3 and Equation 2.4 then:

$$P(A \mid B) = P(A)$$

2.6.3 Joint Probability Distribution

Suppose a number of variables, $A = \{A1, A2, \ldots, An\}$, are involved in BNs construction and the dependence relationships between the variables are defined. Given that the BNs structure is fully created, the joint probability can be written as follows (Misirli & Bener, 2014):

$$P(A) = \prod_{i=1}^{n} P(A_i \mid parents(A_i)) \quad 2.5$$

Where $parents(Ai)$ are the parent nodes of the variable (Ai), $P(A)$ is the joint probability distribution of A, which represents the product of conditional probabilities of the node Ai, given all its parent nodes. Thus, both prior and conditional probabilities are required to calculate joint probability for a certain variable. For more illustration, consider the example shown in Figure 2.3.

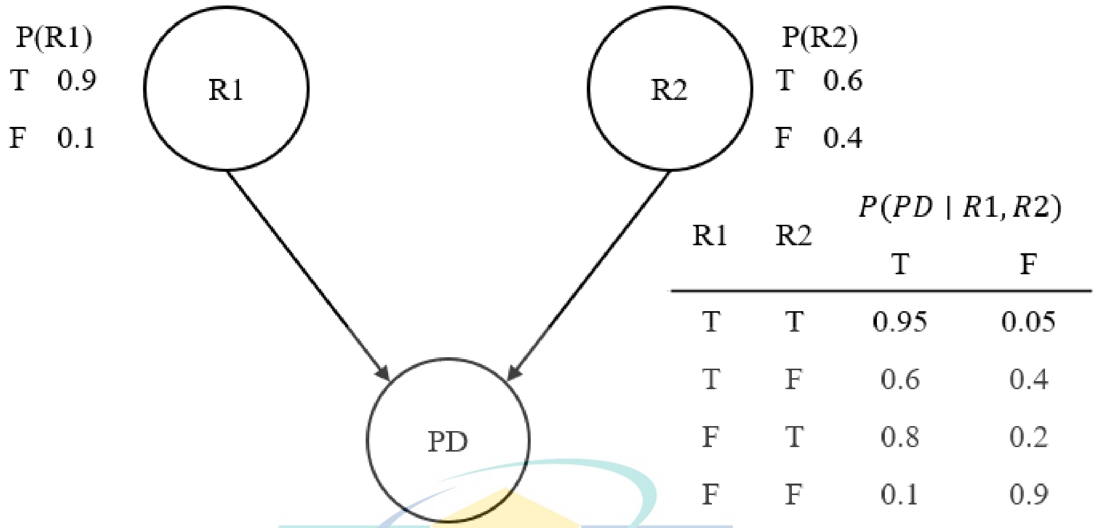

Figure 2.3 Example of BNs with full probabilites definition

Suppose a BNs model is constructed to evaluate project delay (PD) in construction project with respect to two independent risk factors, $R1$ and $R2$. Each risk is assigned two states, "T" denotes the occurrence and "F" denotes the complement. Since the states of the variable PD are discrete, the conditional probabilities for this specific variable are expressed by a probability table. The corresponding table shows conditional probabilities which are defined for the node PD given each possible combination of $R1$ and $R2$. For example, given two risk events $(R1 = T, R2 = T)$, the occurrence probability of project delay $(PD = T)$ is 0.95. On the other hand, considering the second case when only $R1$ occurs $(R1 = T, R2 = F)$, the probability of the project experiencing delay is 0.6. The joint distribution for PD with respect to Equation 2.5 can be written as:

$$P(PD, R1, R2) = P(\, PD \mid R1, R2 \,)P(R1)P(R2)$$

As such, consider the situation when $(PD = T)$, $(R1 = T)$ and $(R2 = F)$, the joint distribution for this specific combination is:

$$\begin{aligned} P(PD = T, R1 = T, R2 = F) &= P(\, PD = T \mid R1 = T, R2 = F \,)P(R1 = T)P(R2 = F) \\ &= 0.6 * 0.9 * 0.4 = 0.216 \end{aligned}$$

Therefore, the probability distribution over variable PD can be computed as the following:

$$P(PD = T) = P(PD = T \mid R1 = T, R2 = T) * P(R1 = T) * P(R2 = T)$$
$$+ P(PD = T \mid R1 = T, R2 = F) * P(R1 = T) * P(R2 = F)$$
$$+ P(PD = T \mid R1 = F, R2 = T) * P(R1 = F) * P(R2 = T)$$
$$+ P(PD = T \mid R1 = F, R2 = F) * P(R1 = F) * P(R2 = F)$$
$$= 0.95 * 0.9 * 0.6 + 0.6 * 0.9 * 0.4 + 0.8 * 0.1 * 0.6 + 0.1 * 0.1 * 0.4$$
$$= 0.781$$

And

$$P(PD = F) = 1 - 0.781 = 0.219$$

2.7 BNs Advantages

Recently, BNs have gained widespread popularity due to its potential of performing multiple tasks. The main tasks and advantages of BNs can be summarized as the following:

i BNs have the ability to accomplish two main types of inference, namely: predictive inference and diagnostic inference (Odimabo, Oduoza & Suresh, 2017). Prediction functionality allows to calculate the probability distribution of a child given the data relevant to its parent nodes. On the other hand, BNs can reverse its logic, that is, inferring about the probability of the parent nodes in the light of new information arrived at its child nodes (Kembłowski et al., 2017). Therefore, observing any evidence at one or more variables would enable the model to be used for top-down and bottom-up reasoning (Misirli & Bener, 2014). Consequently, forecasting of future events as well as identifying the most common cause of the problem. Also, there is another type of reasoning called intercausal reasoning which involves reasoning about common causes of the same effect (Fenton, Neil, & Caballero, 2007). For example, consider "weather" and "late payment" are two causes of "project delay". In situation where evidence is set in "project delay" and in one cause, the belief about the other cause will change. Although the two causes are marginally independent, knowledge about one cause gives information about the other.

ii BNs are visual representation of dependence relationships between the variables. Although risks in construction in some cases are considered isolated (Cheng & Hamzah, 2013), in reality the dependencies are commonly existed between risks. However, most methods ignore such aspect. For example, fuzzy methods assess risks separately (Kuo & Lu, 2013). Moreover, the relationships between the inputs and outputs in Artificial Neural Networks (ANNs) are difficult to interpret and it is difficult to find out why and how the network come up with such results once trained (Bakhshi & Touran, 2014). In contrast, BNs address causal relationships among a set of random variables which in turn enhance risk analysis (Luu et al., 2009).

iii BNs can be built by historical data, expert knowledge or integration of both. When the data are reachable, both structural and parameter learning can be obtained using one of many algorithms available for such purposes (Usitalo, 2007). However, insufficient statistics is not a barrier for BNs construction. In fact, expert judgment is commonly used for defining BNs variables, their relationships and eliciting their probabilities (Misirli & Bener, 2014). In conjunction with ANNs, large amount of data is required and expert knowledge cannot be incorporated (Sivarajah, Kamal, Irani & Weerakkody, 2017). This feature is very important in BNs within construction field since the data regarding construction risks are historically lacking (Zhang, Wu, Zhong & Lu, 2014).

iv BNs provide flexibility in modelling. The nature of BNs allows to remove or add any variable with no significant changes on the remainder of the network. The only required modifications are associated with defining CPTs for child node with respect to new data relevant to additional parent nodes (Khodakarami & Abdi, 2014). Therefore, BNs accept new variables and evidence at any point (Usitalo, 2007). Comparatively with ANNs, adding or removing any variable demands a newly reconstructed network (Bakhshi & Touran, 2014). The usefulness of this feature lies in the fact that the same model can be used and refined by experts in a certain field to serve their interests.

v Finally, BNs are capable of answering what-if questions (Rafiq et al., 2015). Once the model is created, multiple scenarios can be examined. As a result, providing a test tool for most likely consequence of risk events, that is, looking at the future with present data. What-if analysis can be carried out to explore the impact of changes of certain nodes on the other nodes and the performance of a system (Zhang et al., 2014). Therefore, BNs optimize decisions taken by decision makers and a set of preventive actions to minimize adverse consequences can be established (Grande, Castillo, Mora & Lo, 2017).

2.8 Challenges in Expert-based BNs Modelling

As mentioned earlier, when data for constructing a BNs model is insufficient or irrelevant, the development of BNs can continue using subjective beliefs and expert knowledge. Thus, the use of expert judgment plays a critical role in every aspect of the network. However, many issues arise when deriving probabilities required for the network from expert opinions. The first problem in estimating the probability of project risks is in the term itself. Many people even experts are not familiar with probability theory and find it difficult to transfer their perceptions into probability (Hillson, 2005). Therefore, previous research have attempted to offer some definitional techniques in which meaningful description of probability is presented by scales. These scales are divided into multiple points using phrases (such as probable, expected, or almost certain), labels (such as low, medium, or high), ranges (e.g. 1-10%, 10%-30%, or 30%-70%), or percentages (for example 10%, 20%, or 30%). These techniques are helpful for construction practitioners since the representation of probability becomes less ambiguous. However, even when the words are well defined, another issue is arisen when individuals trying to interpret the terms positioned on the scales (Hillson & Hulett, 2004). For instance, one might interpret a “likely” risk to occur with 50%, while it might be taken as 70% for another. Therefore, the efficiency of expert-based BNs depends on how difficult and efficient the model inputs are derived from expert domain. As a potential solution, a combination of ordinal phrases with numeric definition of probability using numbers or ranges is recommended. For example, linking the probability ranges 0.15-0.25 and 0.25-0.5 to the phrases “once in a while” and “sometimes”, respectively (Jensen et al., 2009).

The second challenge in expert-based BNs is probability estimation for child nodes. For discrete variable, probabilities are estimated by tables in which each row represents each possible combination of the states of parent variables. However, when a child has a large number of parent nodes, the process of eliciting probabilities by experts becomes complex and time consuming because the size of CPTs increases exponentially (Rafiq et al., 2015). For example, if a child node has 10 parent nodes, considering all variables have two states, the number of probabilities required to elicit would be 2^{10}=1024. Such large number of probabilities is very difficult to obtain using expert domain. One alternative to reduce the number of CPTs is by introducing so called intermediate nodes. Intermediate nodes categorize a BN into logical sub-sections or levels, and their probabilities are aggregated to the target output (Pollino & Henderson, 2010). For example, consider 5 delay factors reflect resources problems and the same number of factors reflect design problems. Instead of project delay is directly influenced by 10 factors, two intermediate variables are initiated, resources and design. For intermediate nodes, the number of CPTs equals to $2^5+2^5=64$, in addition to 4 conditional probabilities for poject delay node. Therefore, the total CPTs for entire network equals to 68. In this case, the CPTs entries are considerably reduced from 1024 to 68. There are other methods that can generate full CPTs such as ranked nodes (Fenton et al., 2007). In this method, five point Likert-scale is employed ranging from "very low" to "very high" corresponding to the interval "0.-0.2" and "0.8-1", respectively. Experts are then requested to give weights for parent nodes to its child nodes. Consequently, one of algorithms such as the mean average, the Minimum, the Maximum and the MixMinMax is then used. Therefore, if there are m ranked nodes with n states for each, experts will only supply $m + 1$.

2.9 Some Limitations of BNs

Due to the acyclic nature of a BN's graphical structure, it is not possible to model cyclic loops, such as feedbacks, within a static BN. In other words, if node A affects node B, but is in turn affected by node B, this cannot be represented in a static BN. This represents a major problem for the adoption of BNs as feedbacks are an inherent component of many complex systems (Lee, Park & Shin, 2009). Another problem in BNs modelling is represented by the fact that Many parameters modelled in BNs have continuous values. However, most commercial BN programming shells can only deal with these continuous variables through discretisation. By choosing too few states, this can result in information loss, whereas too many states can over-complicate the model. Resolution of distribution should reflect the quality of information available and the degree of complexity to describe the system efficiently (Barton et al., 2012). As mentioned earlier, BNs use conditional independence to simplify the computational power required to run models. However, where the node in a BN has a large number of parent nodes, the conditional probability table can become overly complex, which increases the computational power to update a BN. This can increase the data requirements to parameterize the model and leads to difficulties in parameterising CPTs that are derived using expert elicitation. As parent nodes are linked to child nodes, the size of the CPTs increase exponentially (Khodakarami & Abdi, 2014).

2.10 BNs Applications in Construction Field

The applications of BNs have been extended to several domains including construction sector. A sample of publications using BNs method have been presented in the next sections.

Sharma and Chanda (2017) proposed a BNs model to assess the performance of Research and Development projects. The researchers identified seven triggers, four main risk factors and three consequences represented by time, cost and quality. The study established the dependence relationships based on expert knowledge. In addition, a total of 30 participants were approached for determining the probabilities for risk triggers, and expectation-maximization algorithm was further used to calculate the CPTs. The developed BNs model benefits the user by examining the project status through different occurrence of risk factors. Furthermore, the most influential causes of project failure in term of time, cost and quality were determined.

Sarasanty, Adi and Wiguna (2017) concentrated on accidents problems in Indonesian construction projects as they are expected to escalate by 5% per a year. Thus, a BNs-based model was constructed to predict accidents during construction that can enhance labour safety. The most significant risk factors affecting construction accidents were identified. Then, the required data and the strengthen between the variables of the model were defined using expert knowledge. The validation was then carried out after the model was completed using four case studies. Model accurecy was then measured using Absolute Percentage Error (APE) which should be less than 30. The BNs model showed googd accuracy with APE mean of 4.564 and can be used to reduce the number of accidents during construction activities.

Xia, Wang, Wang, Yang and Liu (2017) developed a BNs model to analyse causes of cost overruns affecting infrastructure projects in China. First, systematic review of previous works, questionnaire survey and discussion with experts in the field revealed 35 relevant risk factors. Then, another questionnaire was designed and sent to professionals to solicit three pieces of information: general information of respondents, frequency of occurrence and the degree of impact of each risk, and in which stage each risk occurs. After receiving data from targeted population, the relationships between risk items were identified based on a second questionnaire requesting participants to assess the relationship ranging from 1 (no relationship) to 5 (strong relationship). The researchers further used the benefit of questionnaire technique for learning the parameters for the network. The main contribution of this research is that the BNs model provides risk assessment methodology for construction practitioners throughout all stages of the project.

Odimabo et al. (2017) studied risk factors affecting time, cost and quality of Nigerian building projects. Literature-based findings of other researchers were reviewed, and the most relevant risks were further confirmed by experts. A questionnaire was utilized as a data collection method and the answers were then analysed by computing the frequency and impact for each risk. A total of 650 copies were sent to clients, contractors, sub-contractors, and 343 ones only were received comprising 53% response rate. Risk acceptability matrix was further established based on risk frequency and impact allowing to identify whether risk is high, medium or low representing variables states. A BNs model was then constructed using Netica software. The findings revealed the most important factors affecting time, cost and quality of building projects. Furthermore, it was observed that cost- related issues were less important than those associated with time and quality.

Luu et al. (2009) proposed a BNs model aiming to predict project delay in Vietnamese construction. A total of 42 causes of delay were initially outlined and further validated through interview with highly-qualified practitioners. The importance of the risk factors was obtained through questionnaire survey and 16 risk factors representing the most influential factors on project delay were remained and considered for BNs modelling stage. The researchers then identified the dependency relationships between the risk factors by analysing 88 answers received by questionnaire. Similarly, the CPTs were specified through analysing eight expert assessments by means of questionnaire. The proposed Model provided a predicted delay percentage being in three ranges, namely: less than 10%, between 10% and 20% and between 20% to 30%. The model was then refined and tested by two case studies. It was found that the delay percentage occurred in both case studies are located in the ranges predicted by the BNs model.

Nguyen, Tran and Chandrawinata (2016) used BNs approach to predict safety risk of working at heights in construction industry in California in the Unites States. A total of 36 risk factors were identified and their relationships were determined based on influence diagram taken from previous research. A case study of a condo-hotel in San Francisco was used to test the capabilities of the model. Construction practitioners with high experience were consulted to customize and conceptualize the model, and to provide data required for the model. The results of the proposed approach provide probabilities associated with different states of safety risk. Additionally, sensitivity analysis allows practitioners to identify appropriate preventive actions and safety strategies to reduce risk of fall.

(Rafiq et al., 2015) developed a BNs model to represent bridge condition deterioration within UK railway infrastructure network. The network was constructed with two major elements: support condition including wing walls and abutments and deck condition including the barrel arch, spandrel walls, face rings and parapets. The model was verified using 50 samples of nationally masonry arch bridges. It has been found that the BNs model is capable of handling complex relationships between bridge elements and the system by means of conditional probabilities specified on a fixed model structure. What-if scenario was conducted which showed the usefulness of the BNs model in the context of structural health monitoring through the prioritization and assessment of maintenance activities.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the research design including the general methodology undertaken is introduced. The procedures of identifying the variables adopted for this study are illustrated. This chapter also presents the methods utilized for sample selection, data collection and analysis. This is followed by Bayesian networks model development based on selected variables and the assumptions made to serve research objectives.

3.2 Theoretical Framework Establishment

A theoretical framework has been developed based on the existing literature. The most important causes of delay divided into 12 groups were highlighted. Validation of this framework should be conducted with qualified individuals who have the experience and background with the subject. Therefore, semi-structured interviews with three expert panels nominated by JKR have been conducted to evaluate the identified risks. This group of panels was represented by group 1. The role of this group was to validate the theoretical framework of causes of delay only (as another different group was approached for BNs model development). Expert panels were given the framework of causes of delay identified earlier from the literature and asked to select the factors that may cause delay in road construction. They were also given a chance to check for any possible ambiguity or misunderstanding in the description of each delay factor. It has been explained to them that they have full control of the list. In other word, risks can be included, excluded or positioned on its proper group. Finally, with the aid of the expert panels, potential risks with respect to road construction projects in Malaysia categorized into 12 groups have been identified.

3.3 Research Design

Research design illustrates the framework within which a study is carried out. Research design confirms that research questions serve the purpose of the study and addresses the objectives. In this study, quantitative research was adopted. This study is organized to employ numeric in addition to analyse the data gathered from a sample of population statistically. Quantitative analysis is needed to meet research objectives. The data were collected using questionnaire survey as a data collection instrument for processing and processed by semi-structured interviews of road panels. The data were further analysed using The Statistical Package for Social Sciences (SPSS) and Microsoft Excel. These two softwares were employed to generate the values required for evaluating the risk factors and BNs model development.

3.3.1 Population

Targeted population is the aggregate of entire set of study units that have potential for providing the relevant data for the research study. The research population was drawn from four parties, which are participating in road construction projects. Only public organization was considered since the government is responsible for road construction. These parties are represented by owner, contractor, sub-contractor and consultant. The questionnaire employed targets construction practitioners with various professions such as civil engineers, architecture engineers and those holding positions relevant to construction industry.

3.3.2 Sample and Sampling Technique

As mentioned earlier, the targeted population in this study includes practitioners working in the construction of roads. The sample selection procedure adopted in this research is random sampling technique. This technique gains advantage by considering each respondent within the population has an equal chance of being included in the sample.

Once sampling method is selected, the sample size should be determined. Sample size represents a smaller group of the entire population by which the results could be populated. Considering unknown population, the minimum sample size required for this research was calculated using Equation 3.1 (Ullah, Khan, Lakhiar, Vighio & Sohu, 2018):

$$n = \frac{Z^2 * P * (1 - P)}{e^2} = \frac{2.575^2 * 0.5 * (1 - 0.5)}{0.09^2} \approx 205 \qquad 3.1$$

Where n is the minimum sample size, Z is the statistical value for the confidence interval used (2.575 for confidence interval of 99%), P is the population proportion which is being estimated (50%) and e is the sampling error of the point estimate (9%). Therefore, a minimum of 205 practitioners involved in handling road projects is required.

3.4 Data Collection

A questionnaire survey was designed and prepared with causes of delay which were confirmed by expert panels. The construction of roads in Malaysia lies with responsibility of JKR. A communication with above-mentioned department was made seeking greater response rate. Consequently, a hard-copy questionnaire survey was administrated by JKR to ensure the right respondents are approached. Respondents are construction practitioners involved in various road construction. The target population includes road construction practitioners representing four entities, namely: owner, contractor, sub-contractor and consultant. In order to receive reliable responses, further refinement was made by removing the answers obtained by respondents who had less than one year working experience (Aziz, 2013; Odimabo et al., 2017; Ye & Abdul Rahman, 2010). Data analysis was then carried out considering responses received by respondents who had at least one year working experience and above.

3.4.1 Questionnaire Design

The technique of questionnaire survey has been widely used in construction management area. Likewise, this research employed questionnaire as a data collection method to gather professionals' perceptions about risks faced by road construction. The questionnaire was fed with 56 causes of delay validated by expert panels. The developed questionnaire was organized into two parts. The first part solicits general information of respondents including their professions, job title, the entity they are representing and their work experience. In the second part, respondents were asked to answer two questions which are: how frequent this risk occurs, and how much this risk can influence project delay based on five point Likert-scale ranging from 1 (very low) to 5 (very high). The term "degree of impact" was used to represent the second question in the whole thesis for simplicity. Before analysing the data, further refinement was made by removing participants with experience of less than one year as exclusion criteria. The answers received from the questionnaire were then analysed to establish risk rating based on the above-mentioned attributes.

3.4.2 Pilot Study

Before conducting the main survey, the reliability provided by the instrument should be examined. Generally, a pilot study is carried out to test the reliability of the data intended to be gathered. The sample size for pilot study varies from each study to another. For example, the questionnaire was previously pilot tested among 10 respondents in various construction projects (Santoso & Soeng, 2016; Shehu et al., 2015; Cheng & Abdul-Rahman Hamzah, 2013; Ewadh, H. Ali and Aswed, 2007). Whereas, a number of 5 participants was to chosen in other research (Choudhry, Aslam, Hinze & Arain, 2014; Mohamad, Suman, Harun & Hashim, 2018; Van, Sang & Viet, 2016). (Long, Ogunlana, Quang & Lam, 2004) and Le-Hoai, Lee and Lee (2008) carried out a pilot study among 6 professionals in Vietnam construction industry. Elsewhere, a total of 20, 30 and 35 respondents were included in the pilot study in different studies (Serpell, Ferrada, Rubio & Arauzo, 2015; Khoshgoftar, Bakar & Osman, 2010; Yap & Skitmore, 2018; Love, Sing, Wang, Irani & Thwala, 2014). According to Mugenda & Mugenda (2003), a sample of 10% of sample size is adequate for piloting a questionnaire. Hill (1998) suggests a sample between 10 to 30 participants used in piloting. As such, a pilot study among 20 personals representing 10% of sample size was conducted. The questionnaire was piloted among 5,5,6 and 4 personals representing owner, contractor, sub-contractor and consultant, respectively.

3.5 Data Analysis

After data collection is completed, the feedbacks gathered from respondents were analysed. As many techniques are widely used for and ranking the causes of delay, the relative importance index (RII) is the favourable method for ranking the delay causes (Kamanga & Steyn, 2013, Doloi, Sawhney, Iyer & Rentala, 2012). RII was widely used by many researchers such as Faridi and El-Sayegh, (2006), Iyer and Jha (2005) and El-Sayegh (2008). This technique considers two attributes: frequency of occurrence of the risk and the degree of impact if the risk occurs. The RII for risk frequency and impact was then calculated through Equation 3.2:

$$RII = \frac{\sum_{i=1}^{5} WiXi}{\sum_{1}^{5} Xi} \qquad 3.2$$

Where Wi weight assigned to ith response; Wi =1,2,3,4 and 5, Xi frequency of the ith response, i response category index = 1, 2, 3, 4 and 5 for very low, low, medium, high and very high, respectively. The relative importance index for frequency and impact of risk were denoted by FI and IM, respectively. The risk rating (RR) were then computed by multiplication of frequency and impact for each risk using Equation 3.3:

$$RR^{i} = FI^{i} * IM^{i} \qquad 3.3$$

Where RR^{i} represents risk rating for risk i, FI^{i} represents the frequency of risk i, IM^{i} represents the impact for risk i, and i represents risk factors ranging from 1 to 56.

The outcome of the analysis represents the importance of each risk in terms of time delay. This process allows to identify the most effecting risk factors on project delay accounting for the basic for BNs model development.

3.6 BNs Model Construction

The main objective of the model is to assess project delay status. The estimator is given the chance to estimate the probability of occurrence for all risk factors involved in the network. Then, the delay in the project is predicted with respect to the conditions assigned to the project delay node. During the whole process of model development, validation and evaluation, new 6 road experts represented by group 2 were approached. Road experts (group 2) were selected based on the advice of the expert panels (group 1) as they have good relationship with JKR and long history record handling road projects with JKR. The next sections discuss the procedures undertaken for probability and structure definition of the BNs model.

3.6.1 Extraction of BNs Structure

BNs imply visual representation of variables for a problem and their relationships in a certain domain (Chen & Leu, 2014). Since these networks are diagrammatically created, it is much easier to understand the interactions between the variables. As many problems can be presented using this method, one of the concepts that can be captured by BNs is cause and effect which was employed in this research (Stamelos, Angelis, Dimou & Sakellaris, 2003). However, with so many factors affecting project delay, BNs may become very complex. Reducing the complexity of the network makes the BN more easily understood, especially for those who are not involved in the BNs construction and facilitate the computational process of CPTs.

To ensure the network is built with its proper variables, two road experts among group 2 working in road construction field were approached. Road experts were concurrently interviewed to select risk factors that should be considered in modelling as they are not equally important. Based on interview findings, the most important risk factors were selected. These risks comprise the structural components of the network in addition to target node represented by project delay.

The states represent observable values of a variable and can be discrete or continuous. The determination of variable states names is important and should reflect the variable being in a certain condition. However, two states for each node in the network were specified, namely: "True" (T) and "False" (F), representing the occurrence or the opposite. More specifically, the occurrence of risk was represented by the state "T" and the non-occurrence of risk was represented by the "F". However, three states were defined for project delay node. These states were represented by less than 10%, between 10% and 20% and more than 20% of contract duration. These states were carefully determined according to road expert 2 due to the fact that every project exceeds the original duration by 20% is considered sick. According to expert 2, JKR usually record every delay occurred in the project but does not report it until the delay exceeds the original duration by 60 days or more than 20% of contract duration. In this situation, if the delay is caused by contractor, he is required to prepare a recovery plan or JKR has the right to terminate him. The project is then either transferred to another contractor or assigned to the same contractor with new contract.

After defining the variables and their states, the dependence relationships are to be determined. The links represent that the probabilities of child nodes are dependent on probabilities accompanied with parent nodes. As many links can be existed between the variables, the calculation of CPTs of child nodes may become time consuming. This is because the CPTs of child node increase with the increase of the number of parent nodes and its states. One common approach proposed to reduce the computation process is by introducing intermediate nodes (Rafiq et al., 2015; Bayraktar & Hastak, 2009). Such nodes have both parent and child nodes and gather the same variables that are usually referred to the same category. Seeking to achieve this goal, the BNs structure has been mainly built by means of answering the main following question: which project party is responsible for risk causing delay? In other word, road experts were asked to identify which party takes responsibility for the occurrence of risk factors. By generating intermediate nodes, the structure and CPTs calculations were then simplified.

Although it would be argued that many risks can be interrelated, the computation process may become a daunting task, especially when constructing the network manually. Therefore, the network was constructed based on the singly-connected concept, that is, only one path between two variables is existed. Therefore, the effect of each factor on the project delay node is transmitted through its relevant group only. Furthermore, it was assumed that the factors within the same risk group are independent, that is, the relationships between them were ignored (Xia et al., 2017). To this point, the BNs structure is considered complete and prepared for quantitative stage.

3.6.2 Probabilities Definition

Quantitative level was undertaken after the structure of the network was defined. This stage implies the definition of probability distribution for the delay factors in addition to intermediate nodes by means of CPTs. The data received from the questionnaire were employed here. Shen, Wu and Ng (2001) proposed a conversion scale used in the questionnaire into numerical values. In other word, the scale associated with frequency and impact of risks ranging from 1 (very low) to 5 (very high) is converted to new numerical values to be used for computation. Statistical analysis by means of mean, standard deviation and variance was then applied.

The initial probabilities for the risk factors were defined based on the answers gathered from participants regarding risk frequency. Moreover, the CPTs for intermediate nodes were defined based on the second question assigned for respondents (how much this risk can influence project delay). The method undertaken by Khalafallah (2002) was then employed for CPTs estimation. First, the mean value of degree of impact for each risk was calculated. Next, the degree of impact of each risk factor was regarded as metric to represent the occurrence probability of the intermediate node which implies defining the contribution percentage of each risk on its intermediate node. Moreover, it was assumed that the degree of impact of the risk factors are mutually exclusive within a certain intermediate node and exhaustively represent this node. Probability mass function (PMF) for discrete variable was then calculated to estimate the CPTs. This process was applied to all intermediation nodes in the network.

The only CPTs that have been estimated differently are those associated with project delay node. Five road experts were invited to participate in this task. The estimation was conducted in two rounds to reach consensus on expert opinions with the aid of a moderator. The role of the moderator is to elaborate to other experts what they are going to estimate. Round one included probability estimation by each individual expert. Road experts were asked “how often do you expect a project delay with less than 10%, between 10% and 20%, and more than 20% of contract duration based on your personal experience”. Road experts were given a chance to estimate the relevant probabilities from 0% to 100%. A probability scale used by Renooij (2001) including numbers and phrases was also attached. Again, the size of CPT for project delay node would be the number of its states multiplied by the number of states in each separate delay factor. Since project delay node had three states and three binary parent nodes, only 24 probabilities were required (3*2*2*2=24). These probabilities were then combined mathematically for each state by means of average, and further normalized for each combination. In the second round, a summary of the results including new probabilities was returned to road experts by the moderator. These probabilities were then revised and further confirmed as a final version of the estimation.

3.7 Validation of the Structure and Outputs of the BNs Model

Validation is a fundamental aspect of the model development process which enhances confidence in using the model and makes it more valuable. With respect to this

concept, the model should be correct whatever the inputs or entries are. The goal of the validation is to identify whether the research results sound and reliable. (Lucko &

Rojas, 2010). In line with unsatisfactory results of the BNs model, the structure or/and the parameters should be revised. When the data are not available, the model can be validated using expert opinions which was the method used in this research.

It should be noted that the BNs model will not be modified any further due to time and efforts needed for approaching road experts. However, we could approach multiple experts individually seeking their opinions about the model and its results using questionnaire survey. The structure of the model was validated by asking road experts about the number of delay factors, their labels and the arrows between them (Pitchforth & Mengersen, 2013). In this context, road experts were delivered the model as a graph and asked to evaluate the model structure based on five point Likert-scale with respect to the following points:

i The delay factors shown in the model represent the most influential factors causing delay in road construction projects.

ii The label of each delay factor is clear and easy to understand.

iii The delay factors are connected to its proper group.

Regarding the third question, road experts should have been asked about the relationships between the delay factors. Since the delay factors were assumed independent, this question as well as all questions was verified with the aid of expert 2 for more clarity.

Numerical validation was then carried out among four road experts. Road experts were asked to estimate the probability of occurrence of the delay factors. These probabilities were then set as evidence in the model, and the outputs should satisfy experts' expectations since the model is validated based on expert opinions not based on empirical data. Otherwise, there might be a problem in the model parameters, or the parameters can be revised through sensitivity analysis using expert opinions. The outputs of the model should behave as expected when manipulating the inputs provided by experts.

Moreover, the same road experts who validated the BNs model outputs were asked to give their opinions about the usefulness, benefits and advantages of the BNs model based on five points Likert-scale. Again, all questions were established and validated by expert 2. Finally, road experts were given a chance to give general comments and difficulties that have been encountered during model validation. The flowchart for research methodology is shown in **Error! Reference source not found.**.

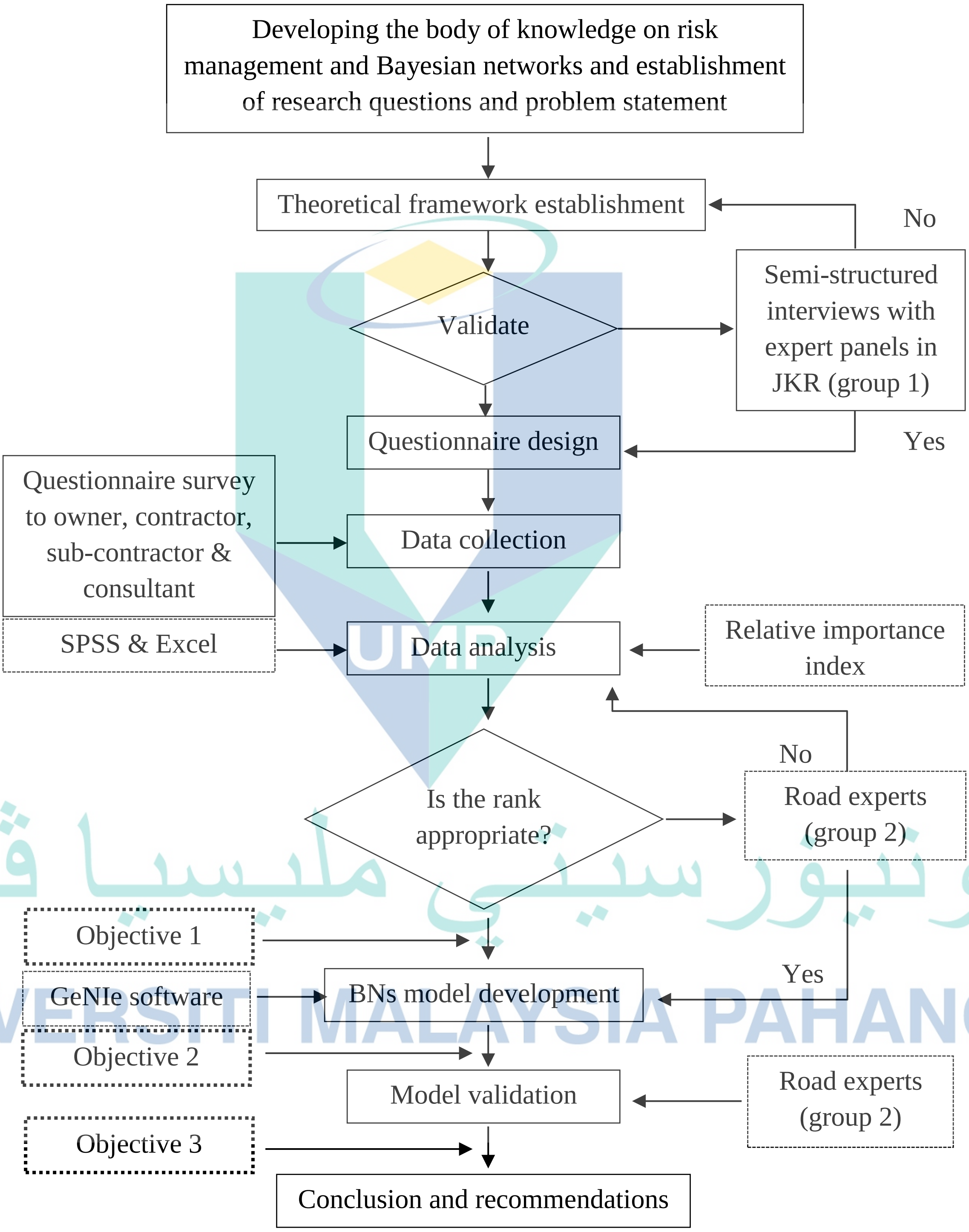

Figure 3.1 Flowchart for research methodology

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the main findings of the research. The procedures of identifying the relevant delay factors to road construction in Malaysia are illustrated. This is followed by analysing the results obtained from the questionnaire and comparing the current findings with previous works. The elaboration of the methodology undertaken for Bayesian networks model development based on expert perceptions is also presented. This chapter further presents the results and feedbacks form experts by which the model was validated and can be used in the future.

4.2 Identification of Causes of Delay in Road Construction Projects

Different number of factors causing project delay was previously identified worldwide. Previous works have attempted to identify causes of delay in various construction projects differently. For example, some studies identified the factors causing delay by considering different number of causes (5, 10 or more than 15 causes) from different sources (Venkateswaran & Murugasan, 2017; Van et al., 2016; Fallahnejad, 2013; Akinsiku & Akinsulire, 2013). While others conducted extensive literature review of causes of delay in various construction projects worldwide (Mahamid et al., 2012; Kazaz, Ulubeyli & Tuncbilekli, 2012; Rachid, Toufik & Mohammed, 2018; Santoso & Soeng, 2016; Akomah & Jackson, 2016; Aziz, 2013). Other scholars such as Tahir et al., (2019), Hamzah, Khoiry, Arshad, Badaruzzaman and Tawil (2012) and El-Sayegh (2008) established theoretical framework of causes of delay from 12, 12 and 5 research papers for their studies, respectively. Whereas Gardezi, Manarvi and Gardezi (2014) identified causes of delay from past records of 50 construction projects. Moreover, Aziz and Abdel-

Hakam (2016) conducted frequency of causes of delay in the literature and identified 293 factors.

In this research, reviewing the literature was undertaken covering a period of decade. The initial delay causes were listed in consideration of top 15 causes of delay in general Malaysian construction and road projects worldwide. However, some factors such as "segmentation of the West Bank" in Palestine (Mahamid et al., 2012), "Conflict, war, revolution, riot, and public enemy" in Egypt (Aziz & Abdel-Hakam, 2016), and others were located among top 15 highest causes but removed directly from the list because they are country specific. Moreover, factors that reflect the same problem such as "poor sub-contractor's performance" (Bagaya & Song, 2016) and "delays in sub-contractor's work" (Marzouk & El-Rasas, 2014) have been considered as a single factor. Through this process, a total of 67 delay factors have been identified and further grouped into 12 categories based on the source of delay. Of the 12 groups, 10 have been established based on a recent review of causes of delay in construction projects (Almohammad & Jamaludin, 2018). The remainder of groups, namely: contractual, and scheduling and controlling were observed with frequency of 7 and 4 based on the reviewed publications. These two groups represent the least frequent groups utilized for causes of delay categorization. The frequency of causes of delay in construction projects within the top 15 rank is available in Appendix A. Finally, the causes of delay were grouped into 12 groups based on the source of delay as follows:

Financial group includes 7 factors which are financial difficulties faced by owner/ client (Aziz & Abdel-Hakam, 2016; Shah, 2016; Memon et al., 2014), delay in payment for completed work by owner (Seboru, 2015; Al-Hazim & Abu salem, 2015; Shehu et al., 2014), cash flow of contractor is insufficient (Akomah & Jackson, 2016; Amare, et al., 2017; Tesfa, 2016), exchange rate fluctuations (Mahamid, 2011; Amare et al., 2017; Tesfa, 2016), material price fluctuations/ increase (Hamzah et al., 2012; Ramanathan, Potty & Idrus, 2011; Abdullah et al., 2010), economic problems/ inflation (Kaliba et al., 2009; Tesfa, 2016) and delay in honouring payment certificate (Kaliba et al., 2009; Akomah & Jackson, 2016).

Contractor group includes 5 factors which are inadequate contractor's experience (Sambasivan & Soon, 2007; Abdullah et al., 2010; Aziz & Abdel-Hakam, 2016), poor sub-contractor's performance (Ramanathan et al., 2012; Abdullah, Alaloul, Liew & Mohammed, 2018; Memon et al., 2014), poor site management and supervision by contractor (Mydin et al., 2014; Kaliba et al., 2009; Akomah & Jackson, 2016), delay in commencement by contractor (Mahamid, 2011b; Mahamid et al., 2012; Tesfa, 2016) and inadequate contractor's workers (Ramanathan & Narayanan, 2014; Ramanathan et al., 2012).

Owner group includes 7 delay factors. These factors are slow decision making (Seboru, 2015; Shehu et al., 2014; Mahamid et al., 2012), slow payment progress and procedures adopted by owner/ client (Kamanga & Steyn, 2013; Shehu et al., 2014; Mahamid et al., 2012), late in revising and approving design documents (Mahamid et al., 2012; Hamzah et al., 2012; Ramanathan & Narayanan, 2014), postponement of project by owner (Mahamid et al., 2012), change in the scope of the project by owner (Tesfa, 2016; Memon et al., 2014; Memon, 2014), change order (Akomah & Jackson, 2016; Pai & Bharath, 2013; Ramanathan et al., 2012) and delay due to land acquisition (Venkateswaran & Murugasan, 2017; Patil et al., 2013; Ramanathan et al., 2011).

Consultant group includes 6 factors which are insufficient inspectors (Mahamid, 2011b; Mahamid et al., 2012), late in reviewing and approving design documents by consultant (Pai & Bharath, 2013; Ramanathan et al., 2012), incomplete documents by consultant (Mydin et al., 2014; Kaliba et al., 2009), lack of experience of consultants' staff (Mydin et al., 2014), lack of application of construction management tools and techniques by consultants' staff (Amare et al., 2017) and delay in performing inspection and testing by consultant (Mahamid et al., 2012 ;Ramanathan et al., 2012).

Equipment group includes the 5 following delay factors: shortage in equipment/ insufficient number (Sharaf & Abdelwahab, 2015; Aziz & Abdel-Hakam, 2016), equipment failure (breakdown) (Shah, 2016; Santoso & Soeng, 2016; Sambasivan & Soon, 2007), late delivery of equipment (Kamanga & Steyn, 2013; Amare et al., 2017), slow equipment movement (Tesfa, 2016) and lack of equipment efficiency (Al-Hazim & Abu salem, 2015; Mahamid, 2013; Thapanont, Santi & Pruethipong, 2018).

Material group includes 4 delay factors which are shortage in construction material (Thapanont et al., 2018; Tahir et al., 2019), quality of materials (Mahamid, 2011b; Sambasivan & Soon, 2007; Al-Hazim & Abu salem, 2015), late procurement of materials (Kaliba et al., 2009; Abdullah et al., 2010) late delivery of materials (Pai & Bharath, 2013; Nawi, Deraman, Hasmori, Azimi & Lee, 2016).

Labour group contains 5 causes of delay. These factors are low productivity of labour (Hasan, Suliman & Al Malki, 2014; Santoso & Soeng, 2016; Memon et al., 2011), insufficient labour/ shortage of labour (Hasan et al., 2014; Sambasivan & Soon, 2007; Tahir et al., 2019), shortage of skilled labour (Patil et al., 2013; Mahamid et al., 2012; Aziz, 2013), staffing problems (Kaliba et al., 2009) and labour disputes and strikes (Suwal & Shrestha, 2016; Kaliba et al., 2009).

Design group includes 5 factors which are inappropriate or incomplete design (Ramanathan et al., 2012; Van et al., 2016; Mahamid, 2013), changes of design (Seboru, 2015; Hasan et al., 2014; Tawil et al., 2013), different/ unfavourable site conditions (Seboru, 2015; Ab. Halim & Zin, 2016; Ramanathan & Narayanan, 2014), conflicting design information (Seboru, 2015) and changes in drawings and specifications (Khair, Farouk, Mohamed & Mohammad, 2016; Kaliba et al., 2009; Hasan et al., 2014).

Site group includes 6 delay factors which are mistake in soil investigation (Aziz & Abdel-Hakam, 2016), disturbance of public activities (Mahamid, 2011a; Mahamid et al., 2012), limited construction area (Mahamid, 2011a; Mahamid et al., 2012), unexpected ground and underground conditions (Memon et al., 2014; Tesfa, 2016; Abdullah et al., 2010), slow site clearance (Tesfa, 2016) and delay in relocating utilities (Kamanga & Steyn, 2013; Thapanont et al., 2018).

Scheduling and controlling group includes 4 causes of delay which are ineffective scheduling and controlling of project by contractor (Abdullah et al., 2018; Haslinda et al., 2018; Hasmori et al., 2018), improper or wrong cost estimation (Al Hadithi, 2018; Akomah & Jackson, 2016; Al-Hazim & Abu salem, 2015), poor estimate of project duration (Memon, 2014; Abdullah et al., 2010; Memon et al., 2011) and closure (Mahamid, 2011a; Patil et al., 2013).

Contractual group includes 7 causes of delay. These factors are represented by claims (Seboru, 2015; Al Hadithi, 2018), necessary variations (Akomah & Jackson, 2016; Seboru, 2015; Mydin et al., 2014), contract modification (Kaliba et al., 2009), conflict between contractor and other parties (Mahamid et al., 2012; Santoso & Soeng, 2016), lack of communication between parties (Shah, 2016; Mahamid, 2013; Ramanathan et al., 2012), practice of assigning contract to the lowest bidder (Santoso & Soeng, 2016; Mahamid et al., 2012; Abdullah et al., 2010) and high competition in bids (Mahamid, 2013).

External group includes 6 delay factors which are bad weather conditions (Santoso & Soeng, 2016; Ramanathan et al., 2012; Ramli et al., 2017), rework due to errors in execution (Sambasivan & Soon, 2007; Kaliba et al., 2009; Mydin et al., 2014), political situation (Mahamid et al., 2012; Al-Hazim & Abu salem, 2015; Al Hadithi, 2018), government requirements (Al-Hazim & Abu salem, 2015), slow land expropriation due to resistance from occupants (Aziz & Abdel-Hakam, 2016) and delay in paying compensation (land owners) (Kamanga & Steyn, 2013).

The initial delay factors considered in this research were identified from many previous studies. Originally, 67 causes of delay were identified. To validate whether these 67 delay factors were applicable to Malaysian road construction projects, three expert panels involved in road development in Malaysia with at least seven years working experience were consulted to provide verification or comments about the delay factors. The expert panels were nominated by JKR working in road division in JKR in Kuantan. Of three expert panels, two are civil engineers and one is mechanical engineer. The list of factors was then amended based on the results and comments received from the panels. As a result, only risks selected by two or three panels has been chosen for the next stage (see Appendix B). A total of 12 risk factors were dropped and removed from the list. In addition to that, two modifications were proposed as the following: modify equipment group into equipment and machineries group and add the cause “change the government of the day” to the list. This factor was probability added because of change of the government due to 14th Malaysian general election. Eventually, the final version of causes of delay and their corresponding groups have been established and further coded. Table 4.1 shows the validated 56 causes of delay categorized into 12 groups.

Table 4.1 The validated 56 causes of delay in road construction projects

Group	No	ID	Delay factors
Financial (FI)	1	FI-1	Financial difficulties faced by owner/client
	2	FI-2	Delay in payment for completed work by owner
	3	FI-3	Cash flow of contractor is insufficient
	4	FI-4	Material price fluctuations/ increase
Contractor (CT)	5	CT-1	Inadequate contractor's experience
	6	CT-2	Poor sub-contractor's performance
	7	CT-3	Poor site management and supervision by contractor
	8	CT-4	Delay in commencement by contractor
	9	CT-5	Inadequate contractor's workers
Owner (ON)	10	ON-1	Slow decision making
	11	ON-2	Slow payment progress and procedures adopted by client/ owner
	12	ON-3	Late in revising and approving design documents
	13	ON-4	Change in the scope of the project by owner
	14	ON-5	Change order
	15	ON-6	Delay due to land Acquisition
Consultant (CS)	16	CS-1	Late in reviewing and approving design documents by consultant
	17	CS-2	Lack of application of construction management tools and techniques by consultant's staff
	18	CS-3	Delay in performing inspection and testing by consultant
Equipment and machineries (EM)	19	EM-1	Equipment failure (breakdown)
	20	EM-2	Late delivery of equipment
	21	EM-3	Slow equipment movement
	22	EM-4	Lack of equipment efficiency
Material (MT)	23	MT-1	Shortage in construction materials
	24	MT-2	Quality of material
	25	MT-3	Late procurement of material
	26	MT-4	Late delivery of materials
Labour (LR)	27	LR-1	Low productivity of labour
	28	LR-2	Shortage of skilled labour
	29	LR-3	Staffing problems
	30	LR-4	Labour disputes & strikes
Design (DN)	31	DN-1	Inappropriate or incomplete design
	32	DN-2	Changes of design
	33	DN-3	Different/ unfavourable site conditions
	34	DN-4	Conflicting design information
Site (SI)	35	SI-1	Mistakes in soil investigation
	36	SI-2	Limited construction area
	37	SI-3	Unexpected ground & underground condition
	38	SI-4	Delay in relocating utilities
Scheduling and controlling (SC)	39	SC-1	Ineffective scheduling & planning of project by contractor
	40	SC-2	Improper or wrong cost estimation
	41	SC-3	Poor estimate of project duration
	42	SC-4	Closure

Table 4.1 continued

Group		ID	Delay factors
Contractual (CL)	43	CL-1	Claims
	44	CL-2	Necessary variations
	45	CL-3	Contract modification
	46	CL-4	Conflict between contractor and other parties
	47	CL-5	Lack of communication between parties
	48	CL-6	Practice of assigning contract to lowest bidder
	49	CL-7	High competition in bids
External (EX)	50	EX-1	Bad weather conditions
	51	EX-2	Rework due to errors in execution
	52	EX-3	Political situation
	53	EX-4	Government requirements
	54	EX-5	Slow land expropriation due to resistance from occupants
	55	EX-6	Delay in paying compensations (land owners)
	56	EX-7	Change of the government of the day

Before distributing the main questionnaire, a pilot survey among 20 professionals accounting for 5 owners, 5 contractors, 6 sub-contractors and 4 consultants was conducted. The responses were gathered and analysed using SPSS. The reliability of the research instrument was evaluated through Cronbach's coefficient alpha which was used to test the consistency of data collection method. The test showed that Cronbach's alpha equals to 0.979 and 0.962 for risk frequency and impact, respectively. According to Prasad, Vasugi, Venkatesan and Bhat (2019), the value of above 0.7 is considered sufficient. Therefore, the data were considered acceptable and proceeded for analysis.

4.3 Demographic Characteristics of Respondents

The main questionnaire was sent to targeted population to assess the frequency of occurrence and degree of impact of risk factors. A total of 500 questionnaires were distributed and 256 were returned, 37 copies were discarded because they were improperly completed (Xia et al., 2017, Choudhry et al., 2014). This leaves 219 valid responses which is more than sample size (minimum of 205 responses). Table 4.2 shows the demographic characteristic of respondents.

Table 4.2 Demogrphic characteristic of respondents

Type of distribution		Frequency	Percentage	Cumulative
Distribution based on profession	Civil engineer	150	68.5	68.5
	Electrical engineer	27	12.3	80.8
	Mechanical engineer	9	4.1	84.9
	Architecture engineer	18	8.2	93.1
	Quantity surveyor	15	6.9	100
	Total	219		
Distribution based on jot title	Project manager	47	21.5	21.5
	Project supervisor	88	40.2	61.7
	Safety officer	15	6.9	68.6
	Clerk of works	57	26.0	94.6
	Construction manager	6	2.7	97.3
	Construction officer	6	2.7	100
	Total	219		
Distribution based on entity	Owner/ Client	24	11.0	11.0
	Contractor	57	26.0	37.0
	Sub-contractor	69	31.5	68.5
	Consultant	69	31.5	100
	Total	219		
Distribution based on experience	Less than one year	33	15.1	15.1
	1 to less than 5 years	77	35.2	50.3
	5 to 10 years	72	32.9	83.2
	More than 10 years	37	16.8	100
	Total	219		

As shown on Table 4.2, civil engineers have contributed the most representing 68.5%. About 12.3% of responses were received from electrical engineers and 8.2% from those who are architectural. Quantity surveyors and mechanical engineers occupied fourth and fifth place based on their participations (6.9% and 4.1%, respectively). Table 4.2 also shows the distribution frequency of respondents based on their job title. Majority of samples were project supervisors, followed by clerk of works (40.2% and 26%, respectively). Project managers were third in participation (21.5%) and safety officers have given a share of 6.9%. Those who are construction manager and construction officer contributed equally with a share of 2.7% form each. With respect to representative entity, sub-contractors and consultants were represented the most with equal responses from each (31.5%). Questionnaires that have been filled by contractors represent 26%, and the least response rate was obtained from owner side (11%). Furthermore, most of respondents had 1 to less than 5 years of experience (35.2%), followed by those with experience of 5 to 10 years (32.9%) with slight difference (5 responses). The questionnaire collected from those who had more than 10 years and less than one year of experience accounted for 16.8% and 15.1%, which the later have given the least number of feedbacks.

4.4 Ranking of Causes of Delay in Road Construction Projects

The factors causing time delay in road projects were initially identified and divided into 12 groups. The validation of the framework was conducted through semi-structured interviews with three expert panels selected by JKR. A questionnaire survey was sent to owners, contractors, sub-contractors and consultants to evaluate risk factors based on their frequency and impact (see Appendix C). Five-point Likert-scale was used to assess risks ranging from 1 (very low) to 5 (very high) for both attributes. The answers were collected, and the risk rating was established based on the product of frequency and impact for each risk.

Data analysis was then carried out considering credible respondents only. In other words, the answers received from those who had less than one-year work experience were excluded from the analysis. As a result, out of 219 responses, 33 ones were removed and only 186 ones were considered for analysis. Although the number of analysed answers is less than sample size, it would lead to more reliable results. The ranking of the delay factors was validated and confirmed through face-to-face interview with two road experts (expert 1 and expert 2). Table 4.3 presents the overall ranking of causes of delay in Malaysian road projects based on combined views of owner, contractor and consultant.

Table 4.3 Overall ranking of causes of delay

ID	Delay factors	FI	IM	RR	Rank
FI-1	Financial difficulties faced by owner/ client	3.774	3.661	13.818	1
EX-1	Bad weather conditions	3.645	3.419	12.464	2
FI-2	Delay in payment for completed work by owner	3.645	3.290	11.994	3
FI-4	Material price fluctuations/ increase	3.468	3.274	11.354	4
FI-3	Cash flow of contractor is insufficient	3.371	3.339	11.255	5
EM-1	Equipment failure (breakdown)	3.290	3.194	10.508	6
CT-1	Inadequate contractor's experience	3.145	3.274	10.298	7
SC-1	Ineffective scheduling & planning of project by contractor	3.145	3.226	10.146	8
EM-3	Slow equipment movement	3.242	3.129	10.144	9
ON-1	Slow decision making	3.129	3.194	9.993	10
CT-5	Inadequate contractor's workers	3.177	3.129	9.942	11
CT-3	Poor site management and supervision by contractor	3.194	3.097	9.890	12
MT-1	Shortage in construction materials	3.032	3.258	9.879	13
DN-3	Different/ unfavourable site conditions	3.081	3.194	9.838	14
CT-4	Delay in commencement by contractor	3.097	3.129	9.690	15
EM-4	Lack of equipment efficiency	3.194	3.032	9.684	16
CT-2	Poor subcontractor's performance	3.000	3.226	9.677	17
SI-2	Limited construction area	3.097	3.097	9.590	18
DN-2	Changes of design	3.113	3.081	9.590	19
ON-2	Slow payment progress and procedures adopted by owner	3.129	3.065	9.589	20
SI-3	Unexpected ground & underground conditions	3.048	3.145	9.588	21
EM-2	Late delivery of equipment	3.177	3.016	9.584	22
DN-1	Inappropriate or incomplete design	2.952	3.226	9.521	23
MT-2	Quality of material	3.081	3.081	9.490	24
DN-4	Conflicting design information	3.097	3.065	9.490	25
EX-2	Rework due to errors in execution	3.129	3.032	9.488	26
SI-1	Mistakes in soil investigation	3.065	3.081	9.441	27
MT-3	Late procurement of materials	2.984	3.161	9.433	28
SI-4	Delay in relocating utilities	3.048	3.081	9.391	29
EX-3	Political situation	3.048	3.081	9.391	30
MT-4	Late delivery of materials	3.000	3.065	9.194	31
SC-2	Inaccurate cost estimation	3.016	3.032	9.146	32
EX-5	Slow land expropriation due to resistance from occupants	3.097	2.952	9.140	33
LR-2	Shortage of skilled labour	3.065	2.968	9.095	34
LR-1	Low productivity of labour	3.032	2.984	9.048	35
EX-6	Delay in paying compensations (land owners)	3.016	2.984	9.000	36
ON-3	Late in revising and approving design documents	3.032	2.968	8.999	37
SC-4	Closure	2.952	3.032	8.950	38
CL-4	Conflict between contractor and other parties	3.048	2.935	8.948	39
SC-3	Poor estimate of project duration	2.952	3.016	8.902	40
CS-1	Late in reviewing and approving design documents by consultant	3.097	2.871	8.891	41
ON-5	change order	3.081	2.839	8.745	42
CL-6	Practice of assigning contract to lowest bidder	3.048	2.855	8.703	43
CL-3	Contract modification	2.935	2.952	8.664	44
CL-2	Necessary variations	3.048	2.839	8.653	45
ON-4	Changes in the scope of the project by owner	2.871	3.000	8.613	46

Table 4.3 continued

ID	Delay factors	FI	IM	RR	Rank
LR-4	Labour disputes & strikes	2.839	3.016	8.562	47
EX-7	Change of government of the day	2.823	3.032	8.559	48
CL-5	Lack of communication between parties	2.935	2.903	8.522	49
CS-3	Lack of application of construction management tools and techniques by consultant's staff	2.968	2.871	8.520	50
LR-3	Staffing problems	2.871	2.968	8.520	51
CL-1	Claims	2.887	2.935	8.475	52
CS-2	Delay in performing inspection and testing by consultant	2.984	2.839	8.470	53
ON-6	Delay due to land acquisition	2.855	2.919	8.334	54
EX-4	Government requirements	2.903	2.855	8.288	55
CL-7	High competition in bids	2.919	2.839	8.287	56

Table 4.3 indicates that the top ten causes of delay in road construction projects in Malaysia are: financial difficulties faced by owner/ client (RR=13.818), bad weather conditions (RR=12.464), delay in payment for completed work by owner (RR=11.994), material price fluctuations/ increase (RR=11.354), cash flow of contractor is insufficient (RR=11.255), equipment failure (breakdown) (RR=10.508), inadequate contractor's experience (RR=10.298), ineffective scheduling and planning of project by contractor (RR=10.146), slow equipment movement (10.144) and slow decision making (RR=9.993). Of top ten causes, four are related to financial group, two related to equipment and machineries, and only one factor is related to external, scheduling and controlling, contractor and owner groups separately.

4.4.1 Discussion of Top Ten Delay Causes

Table 4.3 indicates that participants have ranked financial difficulties faced by owner is the most significant factor causing delay in Malaysian road construction. This factor was previously listed in 5th rank within Malaysian construction (Memon et al., 2014). Memon (2014) found that financial difficulties of owner is the 3rd delay cause in Malaysia, and the top four causes are attributed to owner performance. It is not surprising because the former study focused on contractors' perception only. It was reported that a "blame game" is played out between project parties once the project exceeds its duration (Riazi et al., 2011). Such problem was also confirmed by Azman, Dzulkalnine, Hamid and Beng (2014). The researchers declare that poor finance by owner is one of the most important causes of delay in Malaysian construction. The rank of financial difficulties of owner in the current study is in line with other studies in which this factor was addressed in first place within road projects in Egypt and general construction in Nigeria and Saudi Arabia (Aziz & Abdel-Hakam, 2016; Akinsiku & Akinsulire, 2013; Khatib, Poh & El-Shafie, 2018). Furthermore, financial difficulties of owner was given a rank among top five causes of delay in public construction projects (Akhund, Imad & Memon, 2018; Van et al., 2016; Sweis, 2013; Bagaya & Song, 2016). In contrast to this, construction projects funded by advanced countries such Japan and Korea seem to have adequate funding which did not affect project duration significantly (Kavuma, Ock & Jang, 2019; Maemura, Kim & Ozawa, 2018). It was reported that financial issues of owner may impact project individuals, especially the contractor (Ye & Abdul Rahman, 2010). For example, cash flow and funding the project by contractor may be negatively affected which in turn leads to late payment to manpower, suppliers and sub-contractors, and influence construction progress.

The second most important factor causing delay in Malaysian roads is bad weather conditions. This factor was previously ranked the highest cause of delay in Design and Build (D&B) projects and general construction in Malaysia (Ramanathan, 2014; Mydin et al., 2014). It was further reported that rain effect in particular on construction activities is the 1st and 2nd highest factor causing delay in D&B projects and rural area in Malaysia, respectively (Ramanathan et al., 2012; Ramli et al., 2017). Likewise, Cambodian roads have been faced by adverse weather conditions where rain and floods was analysed as the most significant factors causing delay (Santoso et al., 2016). Moreover, the same importance of weather conditions found in this research was observed within road sector in both Jordan and Ghana (Al-Hazim, 2015; Akomah, 2016). Environmental disasters such as floods, tornados, hurricanes, volcanic eruptions, earthquakes, and landslides are recognized to have a major impact on a construction project, especially a road construction project, evident by Kim and Choi (2013) of the recent natural disasters and extreme weather events that have caused widespread devastation are the Tohoku Earthquake and the Tsunami in Japan in March 2011. However, such factor was not assessed as critical in other type of construction such as pipeline, building and general construction (Fallahnejad, 2013; Aziz, 2013; Doloi, Sawhney, Iyer, & Rentala, 2012; Sweis, 2013; Arantes et al., 2016; Yafai, Hassan, Balubaid, Zin, & Hainin, 2014). Memon et al. (2014) explains that some construction activities cannot be performed during bad weather which in turn may affect the quality of works and contribute to project delay. Santoso (2016) supports previous statement and further elaborates that road projects particularly involves open-space construction work making these projects more vulnerable to rain. As a result, it is reasonable for weather conditions factor to be in first or second rank for countries like Malaysia and Cambodia as they are usually exposed to heavy rain.

Table 4.3 also shows that delay in payment for completed work by owner is the 3rd factor causing delay in road construction projects in Malaysia. This result is in line with many studies conducted in different countries including Malaysia such as Algeria, Sudan and Iraq in which late payment for completed work was prioritized the 4th delay factor in road and general construction (Rachid et al., 2018; Khair et al., 2018; Al Hadithi, 2018; Akhund et al., 2018). The second place was also given to this factor in Malaysian and Oman construction projects (Shehu et al., 2014; Yafai et al., 2014). Moreover, the highest rank was found in Tanzania, Ghana and Egypt in which delay in payment for completed work occupied the 1st factor affecting project delay in various construction projects (Sambasivan, Deepak, Salim & Ponniah, 2017; Amoatey & Ankrah, 2017; Marzouk & El-Rasas, 2014). Payment by owner is heavily dependent on financial status within owner's organization. Therefore, it is reasonable for such factor to be among top three causes of delay as well as financial difficulties faced by owner.

Material price fluctuation possessed the 4th rank according to overall results. This factor was not recognized as significant in Malaysian construction, especially within 2014 in which it was prioritized the 15th,16th and 24th according to overall results (Memon et al., 2014; Memon, 2014; Shehu et al., 2014). However, material price fluctuation was identified as a major risk in 2015 (Kang, Fazlie, Goh, Song & Zhang, 2015), and evaluated in 7th place within Malaysian construction in 2017 (Ramli et al., 2017). Hasmori et al. (2018) demonstrates that Malaysia is experiencing the economy downturn with decreasing value of Ringgit against major world currencies. The importance given to material price fluctuation in the current study may also due to 14th Malaysian general election which was hold on May 2018. The data were collected after 3 months of general selection date which may have affected respondents' attributes. Haslinda et al. (2018) explains that material price fluctuation is heavily dependent on the project country, economic conditions and neighbouring countries. In other developing counties, the increase of material price does not seem to influence project delay significantly since it was given 22nd and 19th position in Iraq and Ghana (Al Hadithi, 2018; Akomah, 2016), and assessed as medium risk factor in Egypt within road construction sector (Sharaf & Abdelwahab, 2015). Likewise, this factor received low rank in studies conducted within Vietnamese and Pakistani government projects (Akhund et al., 2018; Van et al., 2016). The priority possessed by this factor was 22nd and 30th, respectively. Kuo and Lu (2013) reports that when construction material prices suddenly escalate, policies for materials procurement may change and affect the progress of work. Therefore, contractors may postpone some construction activities until the prices decrease and become stable.

Cash flow of contractor is insufficient occupied the 5th highest cause of delay in road construction projects in Malaysia. Inadequate cash flow and financial difficulties faced by contractor have been cited in 1st place twice in Malaysian construction and 6th place in private housing development projects within the same country (Hasmori et al., 2018; Shehu et al., 2014; Mydin et al., 2014). There might be a situation when contractors have many concurrent projects and adequate fund is required to cover project expenses. However, it was reported that the major reason behind poor project funding by contractor in Malaysia is deficiencies in client’s management capacity (Azman et al., 2014). There seem to be a common pattern of such problem not only in Malaysia, but also in developing countries. For instance, financial and cash flow difficulties was ranked the 1st factor affecting project delay in different types of construction and ownership in Pakistan, Sudan, Saudi Arabia, Burkina Faso and Nigeria (Hussain, Zhu, Ali, Aslam, & Hussain, 2018; Akhund et al., 2018; Khair et al., 2018; Al-Emad, Abdul Rahman, Nagapan, & Gamil, 2017; Bagaya & Song, 2016; Akinsiku & Akinsulire, 2013). This finding is also in parallel with other studies carried out in other developing countries in which this factor was frequently assessed between 2nd and 6th most contributor factor to project delay (Prasad et al., 2019; Thapanont et al., 2018; Amoatey & Ankrah, 2017; Marzouk & El-Rasas, 2014; Khabisi, Aigbavboa & Thwala, 2016; Kamanga & Steyn, 2013; Doloi et al., 2012). However, advanced countries such as Korea did not suffer from such problem where financing the project by contractor was not assessed as critical (Acharya et al., 2006; Kavuma et al., 2019). As can be noticed, the availability of cash flow for contractor is of great important in keeping construction progress as planned. However, many contractors find themselves unable to provide the funds, especially for large projects where huge amount of money is needed. Therefore, contractor should ensure adequate project finance even before the payment by owner can be distributed.

Overall results show that equipment failure (breakdown) is the 6th factor affecting delay in Malaysian roads. This result is in line with other studies where equipment failure has been placed in 8th and 4th position in Malaysian construction (Shah, 2016; Ramli et al., 2017; Hasmori et al., 2018). This also is in coinciding with the findings of other research works where equipment breakdown was assessed as one of the most important problems causing delay particularly in road projects (Thapanont et al., 2018; (Santoso & Soeng, 2016; Aziz & Abdel-Hakam, 2016; Akomah & Jackson, 2016). However, failure of equipment seemingly does not have considerable influence on project delay in other types of construction (Jahanger, 2013; Mpofu, Ochieng, Moobela & Pretorius, 2017; Arantes et al., 2016; Gündüz, Nielsen & Özdemir, 2012). Santoso and Soeng (2016) state that contractors with medium-sized companies tend to rent equipment and rely on second-hand machineries because of insufficient capital. Using these equipment for long time requires continuous maintenance and may lead to equipment breakdown. Aziz and Abdel-Hakam (2016) add that road construction requires heavy equipment and its spare parts might be imported overseas. This would cause late delivery and affect project deadlines. The researchers also emphasize that large road projects should be given to large contractors whose financial resources are enough to cover road project expenses.

The 7th most significant cause of delay in road projects in Malaysia is inadequate contractor's experience. This cause was found in 3rd rank based on two studies carried out within Malaysia (Shah, 2016; Tawil et al., 2014). However, a study conducted by Memon (2014) revealed that lack of experience is the 26th delay factor according to Malaysian contractors' perception. In contrary, owner feels this factor is more critical as being addressed the second in Saudi Arabia (Elawi et al., 2016). The study claims that inexperienced contractor is a critical problem in all Gulf Countries Construction and recommends improving the criteria by which the contractor is selected. It is normal since project parties usually avoid blaming themselves for project delay. Other countries such as Egypt, Pakistan and Turkey have also experienced such problem which was analysed in 3rd, 7th and 1st place, respectively (Aziz & Abdel-Hakam, 2016; Hussain et al., 2018; Gündüz et al., 2012). Experience of contractor is of great importance since it affects every aspect related to resources, site management and communication with other parties. Therefore, contractor should not be awarded the contract with poor experience because they cannot manage and plan the project adequately. Otherwise, it would result in deleterious consequences.

Ineffective scheduling and planning of project by contractor occupied 8th rank according to combined views. Several studies have shown that inadequate planning by contractor is a major problem in construction projects in Malaysia. For instance, Shah (2016) and Haslinda et al. (2018) have found this factor in 1st place, while Abdullah, Alaloul, Liew and Mohammed (2018) and Hasmori et al. (2018) have prioritized it the 3rd and 8th, respectively. Scheduling and planning issue may be the most common cause of delay not only in Malaysia, but also in developing countries in various construction projects. Many studies have ranked this problem among top ten delay causes. Therefore, it is not reasonable to address all previous works. However, the most critical rank through literature was observed in Pakistan, Tanzania and Iraq where the 2nd highest score was given to this cause (Akhund et al., 2018; Sambasivan et al., 2017; Jahanger, 2013). Hussain et al. (2018) attributes this factor to tight timeframes faced by contractor due to pressure from other competitors which may lead to improper planning during tendering phase. Ruqaishi and Bashir (2013) concludes that this cause is attributed to lack of systematic site management and poor contractor's experience in construction.

The 9th most significant cause of delay in Malaysian roads is slow equipment movement. This factor was previously addressed as the 6th most significant cause of delay in road construction in Ethiopia (Tesfa, 2016). However, it was not even identified in other research. Since the equipment used in road construction are heavy equipment and pricey, it may affect project schedule because of long time for maintenance.

The 10th highest factor affecting project delay as shown in Table 4.3 is slow decision making. This cause might have the most consistent rank within Malaysian construction projects where it was prioritized the 10th factor causing delay frequently (Abdullah et al., 2018; Chidambaram & Potty, 2016; Shehu et al., 2014; Ramanathan et al., 2012). Likewise, slowness in decision making was also computed among the highest ten causes in many developing countries such as India, Tanzania, Ghana and South Africa (Prasad et al., 2019; Sambasivan et al., 2017; Amoatey & Ankrah, 2017; Khabisi et al., 2016). Mpofu et al. (2017) claim that delay in decision making is linked to excessive bureaucracy in client's organisation. Alamri, Amoudi and Njie (2017) declare that this problem occurs because owner's representatives may not have the rights to make decisions on a timely manner. The researchers also clarify that decision makers may have poor technical experience and there is a gap between managerial and technical qualifications.

4.5 Ranking of Groups of Delay in Road Construction Projects

Based on the ranking of the delay factors shown in Table 4.3, the mean RR of the top three factors within each group was computed to represent the importance of delay group since consultant group had the lowest number of factors (three delay factors). The delay groups are discussed from the most to least important as follows:

Financial group (RR=12.389): the financial-related group of delay factors is the most important group causing delay. This is mainly due to the factors financial difficulties faced by owner/ client (RR=13.818), delay in payment for completed work by owner (RR=11.994) and material price fluctuations/ increase (RR=11.354).

External group (RR=10.448): the second most important group causing delay is external group in which the top three factors are bad weather conditions (RR=12.464), rework due to errors in execution (RR=9.488) and political situation (RR=9.391).

Equipment and machineries group (RR=10.112): the third most important group is equipment and machineries. The most significant factors in this category are equipment failure (breakdown) (RR=10.508), slow equipment movement (RR=10.144) and lack of equipment efficiency (RR=9.684).

Contractor group (RR=10.043): contractor group is the fourth most important group causing delay. The notable factors are inadequate contractor's experience (RR=10.298), inadequate contractor's workers (RR=9.942) and poor site management and supervision by contractor (RR=9.890).

Design group (RR=9.650): following contractor group, design group is ranked the 5^{th} most important delay group. The top three delay factors are different/ unfavourable site conditions (RR=9.838), changes of design (RR=9.590) and inappropriate or incomplete design (RR=9.521).

Material group (RR=9.601): material group is the 6^{th} most important group to cause delays. This is mainly due to the factors shortage in construction materials

(RR=9.879), quality of materials (RR=9.490) and late procurement of materials (RR=9.433).

Site group (RR=9.540): site group is ranked in the 7th place. The most important factors causing delay in this group are limited construction area (RR=9.590), unexpected ground and underground conditions (RR=9.588) and mistakes in soil investigation (RR=9.441).

Owner group (RR=9.527): the 8th most important group causing delay is owner group whose the most significant factors are slow decision making (RR=9.993), slow payment progress and procedures adopted by owner (RR=9.589) and late in revising and approving design documents by owner (RR=8.999).

Scheduling and controlling (RR=9.414): this group is prioritized as the 9th most important group causing delay. The notable factors are ineffective scheduling and planning of project by contractor (RR=10.146), inaccurate cost estimation (RR=9.146) and closure (RR=8.950).

Labour group (RR=8.902): labour group is the 10th most significant group contribute to delay. This mainly due to shortage of skilled labour (RR=9.095), low productivity of labour (RR=9.048) and labour disputes and strikes (RR=8.562).

Contractual group (RR=8.772): following labour group, the 11th most important group is contractual group in which the top three factors are conflict between contractor and other parties (RR=8.948), practice of assigning contract to the lowest bidder (RR=8.703) and contract modification (RR=8.664).

Consultant group (RR=8.627): the consultant-related group of delay factors is the last and least important group of delay. The notable factors are late in reviewing and approving design documents by consultant (RR=8.891), lack of application of construction management tools and techniques by consultant's staff (RR=8.520) and delay in performing inspection and testing by consultant (RR=8.470). The ranking of delay groups listed from the most to least important is shown in Table 4.4.

Table 4.4 Overall ranking of groups of delay

ID	Group	RR	Rank
FI	Financial	12.389	1
EX	External	10.448	2
EM	Equipment & machineries	10.112	3
CT	Contactor	10.043	4
DN	Design	9.650	5
MT	Material	9.601	6
SI	Site	9.540	7
ON	Owner	9.527	8
SC	Scheduling & controlling	9.414	9
LR	Labour	8.902	10
CL	Contractual	8.772	11
CS	Consultant	8.627	12

Table 4.4 shows that financial group is the highest group affecting project delay (RR=12.38). It is not surprising since all risk factors related to financial category are among the top five causes. External group was ranked second (RR=10.448), followed by equipment and machineries group (RR=10.112). Contractor and design groups had average of RR 10.043 and 9.650 positioned in fourth and fifth place. Material group was 6^{th} in importance (RR=9.601) proceeding site group which was prioritized 7^{th} (RR=9.540). The 8^{th} and 9^{th} most important groups causing delay were owner and scheduling and controlling groups with RR of 9.527 and 9.414, respectively. Labour group was prioritized 10^{th} (RR=8.902), followed by contractual group (RR=8.772). The least score was given to consultant group (RR=8.627) which represents the least important group causing project delay.

4.6 BNs Model Development

The BNs model was created using road experts' consultation. The network structure was defined based on two road expert knowledge which are expert 1 and expert 2. Whereas, the CPTs were estimated using questionnaire survey sent to five road experts representing expert 2 to expert 6. The following factors served as the basis for selecting respondents: profession, working experience and all respondents engaged in model development must have experience in road construction projects. The description of road experts involved in BNs model construction is shown in Table 4.5.

Table 4.5 Description of road experts involved in the BNs model construction

No of Expert	Profession	Job title	Entity	Experience
EX1	Civil	Senior construction project manager	Owner	+30
EX2	Civil	Project manager	Owner	+10
EX3	Civil	Construction manager	Contractor	+10
EX4	Civil	Resident engineer	Consultant	+10
EX5	Civil	Project manager	Contractor	+10
EX6	Civil	Resident engineer	Consultant	+10

As shown in Table 4.5, all road experts have been selected with civil engineering background as civil engineers are the most suitable engineers for road construction. Each of which had at least 10 years working experience. Attempts have been made to approach two representatives from three main project parties (owner, contractor and consultant). During model construction and validation processes, different number of respondents were engaged. Table 4.6 shows contribution of road experts in the model construction, validation and evaluation.

Table 4.6 Contribution of road experts on different satges of the BNs model developmemt

Stage\ No of experts	EX1	EX2	EX3	EX4	EX5	EX6
Definition of the BNs model structure	*	*				
Conditional probabilities estimation for PD node		*	*	*	*	*
Validation of the BNs structure			*	*	*	
Validation of the BNs outputs	*	*	*	*		
Evaluation of the BNs model	*	*	*	*		

As can been noticed from Table 4.6, different number of road experts were in involved in different stages due to time limitation. The data were collected though visits to JKR and not all respondents were available at the time of each visit. For example, the model structure was created based on experience of expert 1 and expert 2 only. Most of respondents excluding expert 1 participated in estimating conditional probabilities for PD node. With regard to validation of the BNs structure, only three experts were approached. Expert 6 was not available for this stage. However, expert 1 and expert 2 was excluded because they were approached to create the BNs model structure. During the BNs outputs validation and BNs model evaluation, the same road experts were consulted representing expert 1 to expert 4.

4.6.1 Selection of the Relevant Delay Factors

The procedures of identifying risks affecting road construction projects in Malaysia started with reviewing the relevant literature. Through this process, a total of 56 risk factors were identified and further confirmed by expert panels. A questionnaire survey was employed to gather professionals' perceptions about the risk factors. The data were collected and analysed in a purpose of ranking these factors based on the score given by respondents.

Previous research identified the variables considered for BNs differently. For example, Odimabo et al., (2017) developed a BNs model based on the most significant factors affecting time, cost and quality of construction projects. A criticality decision cut-off points of 3.0 and above for risk likelihood was the criteria adopted to select the variables for the model. Following this criteria, a total of 38 risk factors will be selected in this research. Luu et al., (2009) distributed a questionnaire to elicit the relative importance of risk factors affecting construction projects based on the influence of the risks on project delay. The study adopted 16 risk factors for the BNs model which had the mean and Cronbach's alpha values higher than 3.5 and 0.7, respectively. Regardless Cronbach's alpha value, the only factor which had a score of degree of influence above 3.5 in this research is financial difficulties faced by owner. Therefore, it is not reasonable to adopt only one factor for BNs model. Xia et al., (2017) identified significance index of risks affecting cost overrun in infrastructure projects by combining likelihood of occurrence of risks and severity of consequence. Thirteen risks of the primary risk list were identified as key factors with having a mean significance value higher than the average score. In this research, the risk factors which have the mean value and above of RR (9.488) were selected for the model resulting in 26 risk factors which is less than the number of risk factors if the method used by Odimabo et al., (2017) was adopted (38 risk factors). The lower number of risks was adopted in order to reduce the complexity of the network. In summary, the method adopted to select the model variables reduced the risk factors from 56 into 26.

In order to verify and determine the most influential factors on Malaysian road projects, two road experts were approached. Expert 1 and expert 2 were engaged in this stage. Experts agreed that all the factors above the average of RR represent the most important factors causing delay. Expert 2 further stated that "the most influential factors come from contractor and sub-contractor. The top 26 factors should be reduced to maximize effective action taken to prevent project delay". Although the delay factors were assumed independent, the delay factors which are highly correlated or not suitable for the model were modified. As such, some risk factors were combined as they fairly represent the same problem and others were removed. Table 4.7 shows the modified delay factors for BNs model.

Table 4.7 Modified risk factors for BNs model

ID	Delay factors	Action	New factor/ remark
FI-1 FI-2 ON-2	Financial difficulties faced by owner/ client Delay in payment for completed work by owner Slow payment progress and procedures adopted by owner	Combine (by road experts)	Financial difficulties and late payment for completed work by owner (FI-5)
EM-1 EM-4	Equipment failure (breakdown) Lack of equipment efficiency	Combine (by road expert)	Lack of equipment efficiency and failure (EM-5)
DN-3 SI-3	Different/ unfavourable site conditions Unexpected ground & underground conditions	Remove (by researcher)	There are two types of road projects conventional projects and Design & Build projects. These factors can be under either owner or contractor responsibility based on type of the project. Since the network is singly-connected, these factors were removed because they cannot be connected to two groups in singly-connected network.
EM-2 MT-4	Late delivery of equipment Late delivery of materials	Combine (by road experts)	Late delivery of material and equipment (EM6)
DN-1 DN-4	Inappropriate or incomplete design Conflicting design information	Remove (by road experts)	These problems are resolved before tender

As can be seen from Table 4.7, 4 out of 26 delay factors were removed. "Different/ unfavourable site conditions" and "unexpected ground and underground conditions" were removed in order to satisfy the assumption associated with singly-connected network. "Inappropriate or incomplete design" and "conflicting design information" were removed because such problems are usually resolved before tender and the proposed BNs model will be used after the construction begins. To this point, the remaining delay factors equals to 22. After removing 4 delay factors, 7 delay factors were remained as shown in Table 4.7. These 7 delay factors were considered to establish three new delay factors, one factor was added to financial group (financial difficulties and late payment for completed work by owner (FI-5)) and two factors were added to equipment and machineries group (lack of equipment efficiency and failure (EM-5) and late delivery of material and equipment (EM-6)). Through this process, a total of 18 delay factors were considered to be included in the BNs model. Figure 4.1 shows an initial network with selected delay factors in addition to project delay node (PD) based on singly-connected concept.

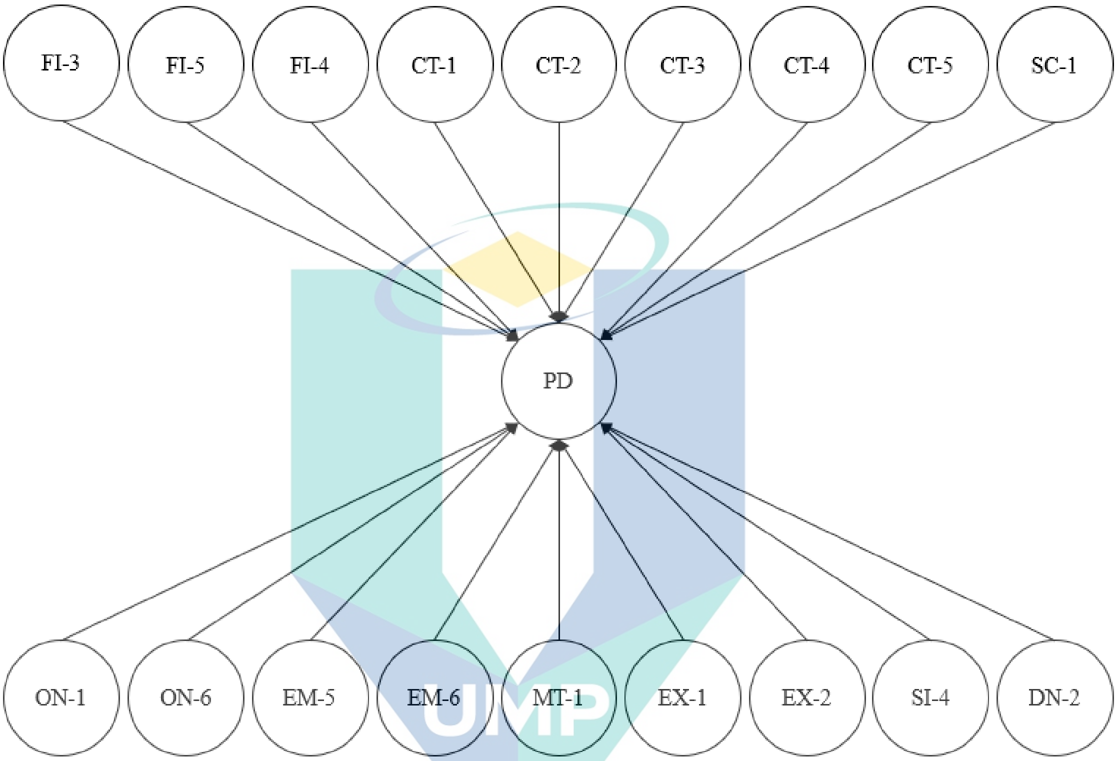

Figure 4.1 An initial BNs model structure

4.6.2 Introduction of Intermediate Nodes

Figure 4.1 presents the initial BNs model with "PD" as a target node and 18 delay factors as influencing nodes. All delay factors are considered with two binary state variables (True or False). It is known that the size of CPT for "PD" node would be the number of its states multiplied by the number of states in each separate delay factor, i.e. the total number of entries in the whole network equals to 2^{18}= 262144, resulting in large number of calculations. Alternatively, several intermediate nodes were initiated based on responsibility of project party on projects risks. These nodes were represented by owner, contractor and beyond control denoted by main groups. It worth mentioning that there were no delay factors considered for modelling are consultant-responsibility. Thus, the BNs model was constructed with respect to the remainder of the main parties (owner and contractor) in addition to non-professionals' responsibility delay factors which were represented by beyond control group.

4.6.2.1 Contractor Responsibility

In consideration of delay factors chosen for model construction, the largest number of risks accounting for 12 out of 18 delay factors were attributed to contractor side. According to Pollino and Henderson (2010), for models constructed partially or completely by experts, it is recommended that a child node should have four parent nodes maximum because most people cannot interpret information beyond four dimensions. Therefore, additional intermediate nodes represented by sub-groups were generated in this category based on experts' consultation, namely: mismanagement, skills and expertise, and resources discussed as the following:

Mismanagement (MIS): five delay factors were linked to this group, namely: cash flow of contractor is insufficient (FI-3), poor site management and supervision by contractor (CT-3), delay in commencement (CT-4), ineffective scheduling and planning of project by contractor (SC-1) and delay in relocating utilities (SI-4). It is noticeable that the delay factors which are parent nodes are more than four. However, experts stated that all these factors are important and should be included in the model.

Skills and expertise (SKE): four delay factors were selected to represent this group namely: inadequate contractor's experience (CT-1), poor sub-contractor's performance (CT-2), Inadequate contractor's workers (CT-5) and rework due to errors in execution (EX-2).

Resources (RE): resources represent material, equipment and labour. However, no labour-related delay factors were found as important. The only three delay factors linked to resources are: lack of equipment efficiency and failure (EM-5), late delivery of equipment and materials (EM-6) and shortage in construction materials (MT-1).

4.6.2.2 Owner Responsibility

Owner takes responsibility for 4 out of 18 delay factors. These factors are: financial difficulties and late payment for completed work by owner (FI-5), slow decision making (ON-1), delay due to land acquisition (ON-6) and changes of design (DN-2).

4.6.2.3 Beyond Control

The variables connected to this node represent delay factors which its occurrence is not caused by contractor or owner activities. These factors are: bad weather conditions (EX1) and material price fluctuations/ increase (FI-4).

The final version of the model was created based on two road expert knowledge. Figure 4.2 shows the conceptual BNs model for predicting construction delay.

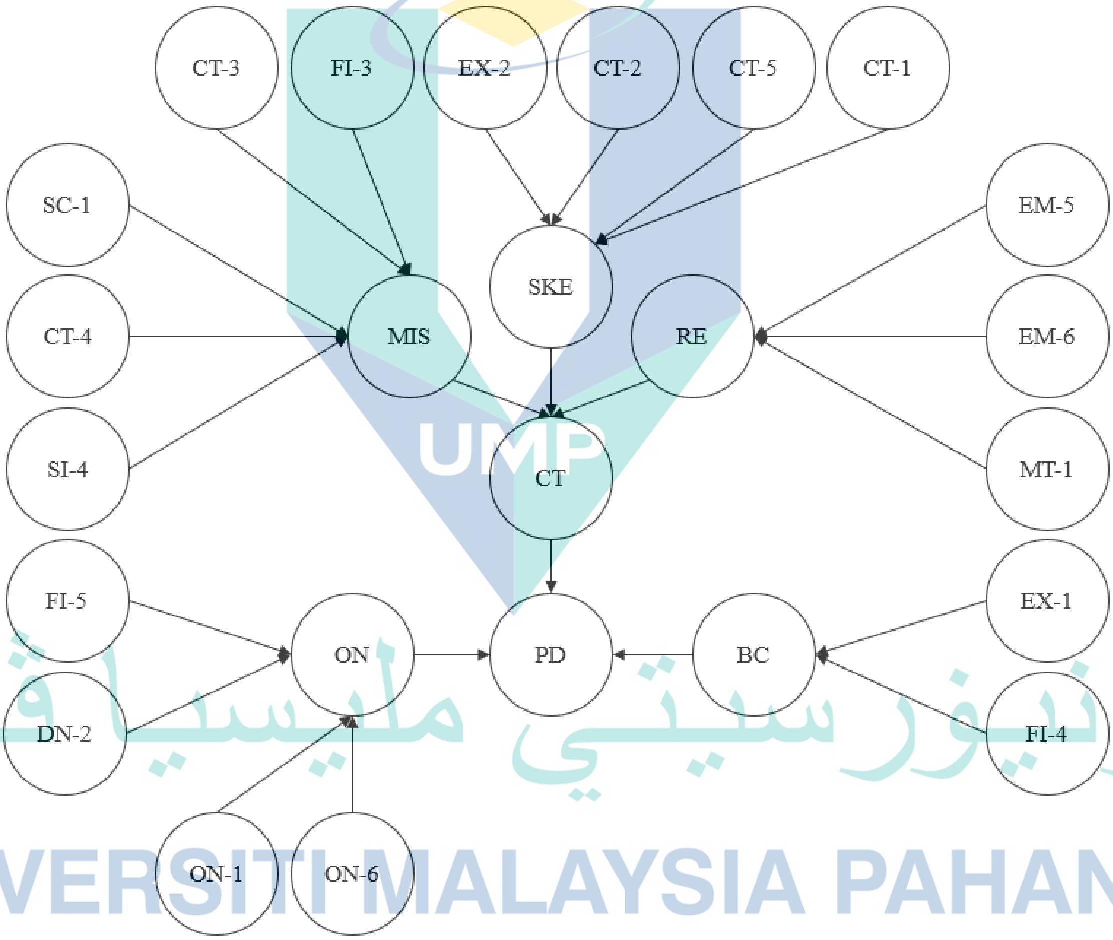

Figure 4.2 The conceptual BNs model for predicting construction delay

4.6.3 Estimation of Prior and Conditional Probabilities

In this stage, the probabilities required for the network were defined based on both risk frequency and impact. The original Liker-scale used in the questionnaire was first converted into numerical scale as shown in Table 4.8.

Table 4.8 Conversion of Liker-scale into numerical scale

Verbal expression	Original scale		Conversion scale	
	Frequency	Impact	Frequency	Impact
Very low	1	1	0.1	1
Low	2	2	0.3	3
Medium	3	3	0.5	5
High	4	4	0.7	7
Very high	5	5	0.9	9

The scores associated with risk frequency were then used to estimate the prior probability for an individual risk, while the degree of impact was used to define the CPTs related to all intermediate nodes. Table 4.9 shows the mean, standard deviation (SD) and variance for the risk factors involved in BNs model.

Table 4.9 Statistical summary of risk frequency and impact

ID	Probability			Impact		
	Mean	SD	Variance	Mean	SD	Variance
FI-5	0.655	0.151	0.023	6.323	1.576	2.484
FI-3	0.574	0.163	0.027	5.677	1.657	2.747
FI-4	0.594	0.148	0.022	5.548	1.363	1.858
CT-1	0.529	0.140	0.019	5.548	1.410	1.989
CT-2	0.500	0.149	0.022	5.452	1.375	1.891
CT-3	0.539	0.125	0.016	5.194	1.389	1.929
CT-4	0.519	0.152	0.023	5.258	1.425	2.031
CT-5	0.535	0.133	0.018	5.258	1.227	1.506
ON-1	0.526	0.151	0.023	5.387	1.395	1.946
ON-6	0.471	0.173	0.030	4.839	1.462	2.137
EM-5	0.558	0.151	0.023	5.387	1.441	2.077
EM-6	0.500	0.177	0.031	5.129	1.531	2.344
MT-1	0.506	0.162	0.026	5.516	1.198	1.434
DN-2	0.523	0.158	0.025	5.161	1.506	2.269
SI-4	0.510	0.183	0.033	5.161	1.549	2.400
SC-1	0.529	0.149	0.022	5.452	1.327	1.760
EX-1	0.629	0.158	0.025	5.839	1.601	2.564
EX-2	0.526	0.156	0.024	5.065	1.658	2.750

The CPTs for all intermediate nodes were defined in the same way. One example of CPTs calculations for group gathering a number of risk factors is presented. The CPTs calculation for CT is also presented since its parent nodes have a group of risk factors. It should be noted that the new factors such as FI-5 was established based on combination of three delay factors which are FI-1, FI-2 and ON-2. The frequency and impact of FI-1 was assigned to FI-5 because FI-1 has higher impact than FI-2 and ON-2. This proposition was considered based on expert opinions as the impact of risk is more important to them than frequency. Similar procedures were applied to EM-5 and EM-6.

Consider RE group which is affected by three influencing risk factors EM-5, EM-6 and MT-1. The mean impact of each risk is 5.387, 5.129 and 5.516, respectively. The sum of impact of these risks would be 16.032. To represent the occurrence probability of RE group, the degree of impact of each risk on its group was regarded as a metric. Therefore, the impact of risks on RE would be the impact of each risk over the total which would be 5.387/16.032, 5.129/16.032 and 5.516/16.032 for EM-5, EM-6 and MT-1, respectively. The contribution percentage of EM-5, EM-6 and MT-1 to RE was then computed as 0.336, 0.3199, and 0.3441, respectively. It was assumed that the degree of impact of the risk factors are mutually exclusive within RE and they exhaustively represent RE. As such, given a number of risk events, the occurrence probability of RE group would be calculated as the sum of the probabilities of events based on probability mass function (PMF). Let X discrete random variable with the values $X(S) = \{x_1, x_2, \dots, x_n\}$. Then, a PMF $P(X)$ is defined as follows:

$$P(X) = \begin{cases} P(X = x)\,;\, x \in X(S) \\ 0\,; \quad otherwise \end{cases} \qquad 4.1$$

Where S is the condition of the variable being "T", x is the values of the variable being "T" and $P(X)$ satisfies the following conditions:

$$0 \leq P(X) \leq 1$$
$$\sum P(X) = 1$$

As such, the calculation of PMF based on Equation 4.1 for RE=T can be computed as the following:

The probability of RE=T when EM-5=T, EM-6=T and MT-1=T equals to:

$$P(EM5 = T, EM6 = T, MT1 = T) = P(EM5 = T) + P(EM6 = T) + P(MT1 = T)$$
$$= 0.336 + 0.3199 + 0.3441 = 1$$

The probability of RE=T when EM-5=T, EM-6=T and MT-1=F equals to:

$$P(EM5 = T, EM6 = T, MT1 = F) = P(EM5 = T) + P(EM6 = T) + P(MT1 = F)$$
$$= 0.336 + 0.3199 + 0 = 0.6559$$

The probability of RE=T when EM-5=T, EM-6=F and MT-1=T equals to:

$$P(EM5 = T, EM6 = F, MT1 = T) = P(EM5 = T) + P(EM6 = F) + P(MT1 = T)$$
$$= 0.336 + 0 + 0.3441 = 0.6801$$

The probability of RE=T when EM-5=T, EM-6=F and MT-1=F equals to:

$$P(EM5 = T, EM6 = F, MT1 = F) = P(EM5 = T) + P(EM6 = F) + P(MT1 = F)$$
$$= 0.336 + 0 + 0 = 0.336$$

The probability of RE=T when EM-5=F, EM-6=T and MT-1=T equals to:

$$P(EM5 = F, EM6 = T, MT1 = T) = P(EM5 = F) + P(EM6 = T) + P(MT1 = T)$$
$$= 0 + 0.3199 + 0.3441 = 0.664$$

The probability of RE=T when EM-5=F, EM-6=T and MT-1=F equals to:

$$P(EM5 = F, EM6 = T, MT1 = F) = P(EM5 = F) + P(EM6 = T) + P(MT1 = F)$$
$$= 0 + 0.3199 + 0 = 0.3199$$

The probability of RE=T when EM-5=F, EM-6=F and MT-1=T equals to:

$$P(EM5 = F, EM6 = F, MT1 = T) = P(EM5 = F) + P(EM6 = F) + P(MT1 = T)$$
$$= 0 + 0 + 0.3441 = 0.3441$$

The probability of RE=T when EM-5=F, EM-6=F and MT-1=F equals to:

$$P(EM5 = F, EM6 = F, MT1 = F) = P(EM5 = F) + P(EM6 = F) + P(MT1 = F)$$
$$= 0 + 0 + 0 = 0$$

Table 4.10 shows the calculation of PMF for RE=T for each possible combination of risk events EM-5, EM6 and MT-1.

Table 4.10 Probability mass function for RE=T

EM-5	EM-6	MT-1	RE=T
P(EM-5=T)=0.336	P(EM-6=T)=0.3199	P(MT-1=T)=0.3441	1
P(EM-5=T)=0.336	P(EM-6=T)=0.3199	P(MT-1=F)=0	0.6559
P(EM-5=T)=0.336	P(EM-6=F)=0	P(MT-1=T)=0.3441	0.6801
P(EM-5=T)=0.336	P(EM-6=F)=0	P(MT-1=F)=0	0.336
P(EM-5=F)=0	P(EM-6=T)=0.3199	P(MT-1=T)=0.3441	0.664
P(EM-5=F)=0	P(EM-6=T)=0.3199	P(MT-1=F)=0	0.3199
P(EM-5=F)=0	P(EM-6=F)=0	P(MT-1=T)=0.3441	0.3441
P(EM-5=F)=0	P(EM-6=F)=0	P(MT-1=F)=0	0

Since RE (as well as other intermediate nodes) has only two states ("T" and "F"), the probability of non-occurrence of RE would be the complement ($P(RE = F) = 1 - P(RE = T)$). Table 4.11 Shows the calculation of PMF for RE=T and RE=F.

Table 4.11 Probability mass function for RE=T and RE=F

EM-5	EM-6	MT-1	RE=T	RE=F
P(EM-5=T)=0.336	P(EM-6=T)=0.3199	P(MT-1=T)=0.3441	1	1-1=0
P(EM-5=T)=0.336	P(EM-6=T)=0.3199	P(MT-1=F)=0	0.6559	1-0.6559=0.3441
P(EM-5=T)=0.336	P(EM-6=F)=0	P(MT-1=T)=0.3441	0.6801	1-0.6801=0.3199
P(EM-5=T)=0.336	P(EM-6=F)=0	P(MT-1=F)=0	0.336	1-0.336=0.664
P(EM-5=F)=0	P(EM-6=T)=0.3199	P(MT-1=T)=0.3441	0.664	1-0.664=0.336
P(EM-5=F)=0	P(EM-6=T)=0.3199	P(MT-1=F)=0	0.3199	1-0.3199=0.6801
P(EM-5=F)=0	P(EM-6=F)=0	P(MT-1=T)=0.3441	0.3441	1-0.3441=0.6559
P(EM-5=F)=0	P(EM-6=F)=0	P(MT-1=F)=0	0	1-0=1

The calculations shown in Table 4.12 presents full definition of conditional probabilities of RE with respect to each potential combination of risk events.

Table 4.12 Conditional probability table for RE node

EM-5 0.336	EM-6 0.3199	MT-1 0.3441	RE T	 F
T	T	T	1	0
T	T	F	0.6559	0.3441
T	F	T	0.6801	0.3199
T	F	F	0.336	0.664
F	T	T	0.664	0.336
F	T	F	0.3199	0.6801
F	F	T	0.3441	0.6559
F	F	F	0	1

Likewise, the same process was applied to estimate the CPTs for the nodes MIS, SKE and BC (see Appendix E), and the contribution percentage of each parent node to its child node is shown in Appendix D.

Regarding CT, there are three influencing groups, namely: MIS, SKE and RE. Each group has 5, 4, and 3 influencing risks, respectively. The impact of MIS, SKE and RE on CT was first calculated by summing the impact of all risks involved in each, i.e. 26.613, 21.323 and 16.032, respectively. The contribution percentage of MIS, SKE and RE to CT were then computed as 0.416, 0.3334, and 0.2506, respectively. Following the aforementioned assumption, the CPTs associated with CT were then simplified as shown in Table 4.13.

Table 4.13 Conditional probability table for CT node

MIS	SKE	RE	CT	
0.416	**0.3334**	**0.2506**	**T**	**F**
T	T	T	1	0
T	T	F	0.7494	0.2506
T	F	T	0.6666	0.3334
T	F	F	0.416	0.584
F	T	T	0.584	0.416
F	T	F	0.3334	0.6666
F	F	T	0.2506	0.7494
F	F	F	0	1

The estimation of CPTs for PD which is the target node has been carried out among five road experts. The concept of conditional probability was explained to the moderator by which the flow of information from the author to experts was quarantined. Experts were allowed to define probabilities associated with project delay from 0 to 100% with the aid of probability scale (see Appendix F). Since the estimation was carried out directly and differently, a second round was undertaken. The second round was necessarily conducted allowing experts to revise their estimation based on each other. Consensus among experts' opinions about CPTs for PD node was then reached as shown in Table 4.14.

Table 4.14 Conditional probability table for PD node

CT	ON	BC	PD		
			<10%	**10%-20%**	**>20%**
T	T	T	0	0	1
T		F	0	0.25	0.75
T	F	T	0.05	0.3	0.65
T	F	F	0.1	0.3	0.6
F	T	T	0.2	0.3	0.5
F	T	F	0.25	0.6	0.15
F	F	T	0.7	0.3	0
F	F	F	1	0	0

The previous step accounts for the final step in BNs model construction. The software used to develop and construct the belief network is "GeNIe 2.2 Academic" which is a free software tool developed at the University of Pittsburgh. Figure 4.3 shows a fully constructed BNs model for construction delay prediction in which the states "<10%", "10%-20%" and ">20%" are represented by "Low", "Medium" and "High", respectively.

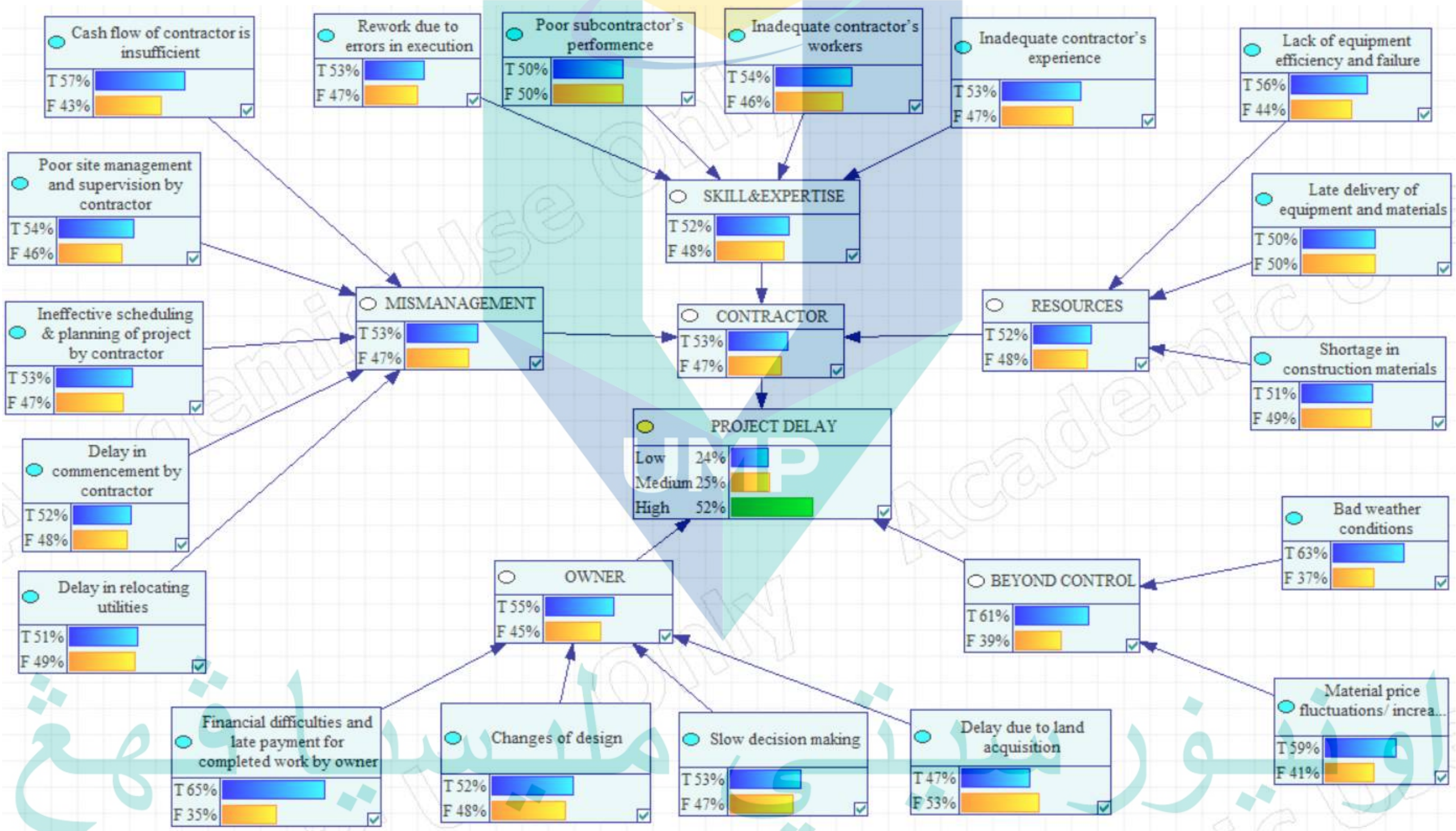

Figure 4.3 The conceptual BNs model for predicting construction delay

Figure 4.3 shows that road construction projects in Malaysia are more likely to exceed contract duration at least by 20% ($P(PD = High) = 0.516$). While it is almost the chance for these projects to delay between 10% and 20% or less than 10% of contract duration ($P(PD = Medium) = 0.247$ and $P(PD = Low) = 0.237$, respectively). Note that the blue bar for all risk factors and intermediate nodes indicates the occurrence probability represented by "T" and the yellow bar indicates the non-occurrence probability represented by "F". For project delay node, the blue, yellow and green bars represent the probability of project delay being "<10%", between "10%" and "20" and more than "20%" of contract duration, respectively. These conditions were represented by "Low", "Medium" and "High" in model because "GeNIe" software does not accept symbols in the state names (for example the symbol "<").

4.6.4 Sensitivity Analysis

4.6.4.1 Sensitivity Analysis for Model Parameters

Sensitivity analysis for model parameters was performed using "GeNIe" software. Sensitivity analysis was conducted to investigate how the variation (or uncertainty) in the output of the model react to different sources of variation in the model parameters. This was done by calculating the posterior probability of PD by systematically changing other probabilities. The results of sensitivity analysis of the first 10 parameters sorted from the most to least sensitive when "$PD = High$" are shown in Figure 4.4.

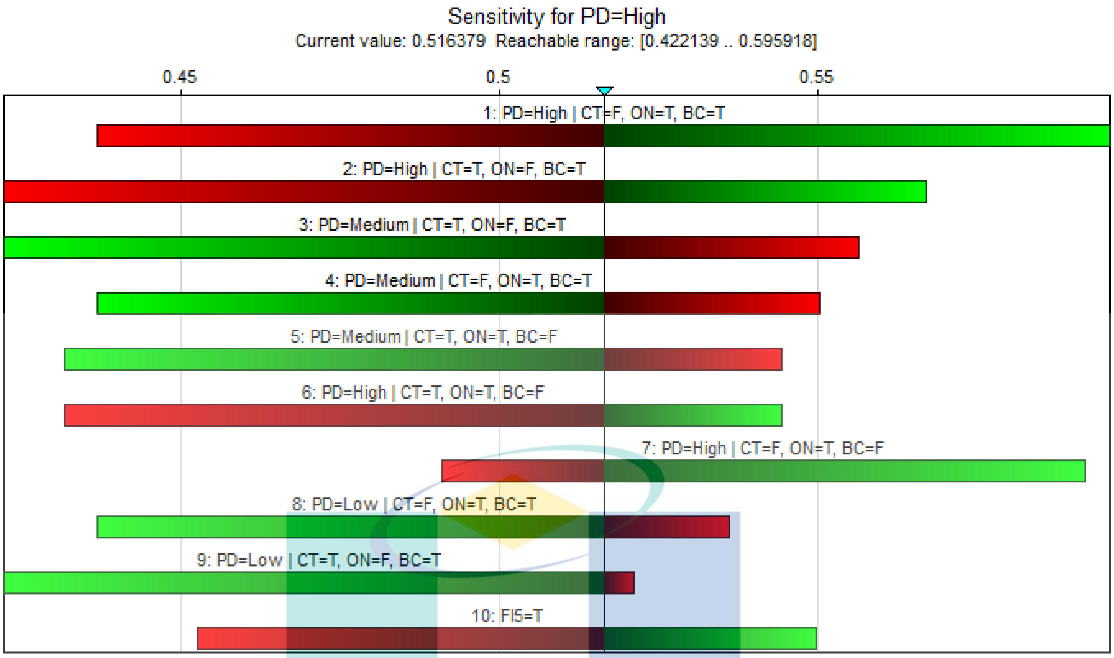

Figure 4.4 Tornado graph for sensitivity analysis of the state PD=High

In the tornado graph shown in Figure 4.4, the extreme state of PD was set as the target state and sensitivity analysis was performed. The probabilities of all other parameters were changed by 100% and the change occurred in the probability of PD in the state "High" was observed. The value (the probability) of "High", "Medium" and "Low" states ranges between 0 to 1, and the sum of these probabilities must be 1. Note that "GeNIe" software automatically creates tornado graph for the effect of single parameter on the target state. Therefore, the tornado graph does not represent the effect of change of two or more parameters on any state at the same time. And the bars represent the change of PD in the state 'High" when the parameters are set between the minimum and maximum. The results indicate that the most sensitive conditional probability on "High" state is "$P(PD = High \mid CT = F, ON = T, BC = T)$". The initial probability of PD in "High" state before any change is 0.516379. By changing the first parameter 100% negatively and positively, the probability of PD in "High" state can be decreased and increased to 0.43684 and 0.595918, respectively. The minimum and maximum probability value of "High" state in case of 100% change is between 0.422139 and 0.595918, respectively. This indicates that the maximum probability of PD being in "High" state can be reached when the probability of the first parameter (first bar) equals to 1. On the other hand, Figure 4.4 shows three parameters (2nd, 3rd and 9th bars) of which full observations can lead to minimum probability of the "High" state of PD. In general, one should consider the length of the bar as a measure of the impact of the parameters on PD (in this case the impact of parameters on “High” state). The longer the bar, the more sensitive of the corresponding parameter on PD. Similarly, the effect of 100% change of parameters on “Medium” states of PD is shown in Figure 4.5.

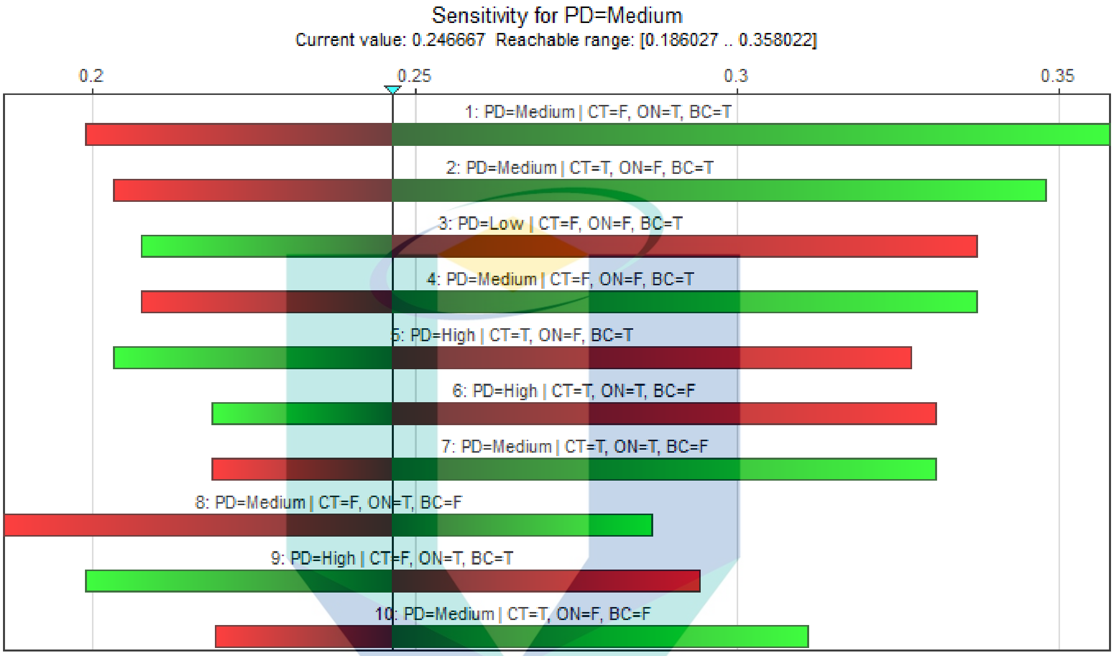

Figure 4.5 Tornado graph for sensitivity analysis of the state PD=Medium

In the tornado graph shown in Figure 4.5, the “Medium” state of PD was set as the target state and sensitivity analysis was performed. The probabilities of all other parameters were changed by 100% and the change occurred in the probability of PD in the state “Medium” was observed. The results indicate that the most sensitive conditional probability on the state “Medium” is “$P(PD = Medium \mid CT = F, ON = T, BC = T)$”. The initial probability of PD in “Medium” state before any change is 0.246667. By changing the first parameter 100% negatively and positively, the probability of PD in “Medium” state can be decreased and increased to 0.198944 and 0.358022, respectively. The minimum and maximum probability value of “Medium” state in case of 100% change is between 0.186027 and 0.358022, respectively. Finally, the effect of 100% change of parameters on “Low” state of PD is shown in Figure 4.6.

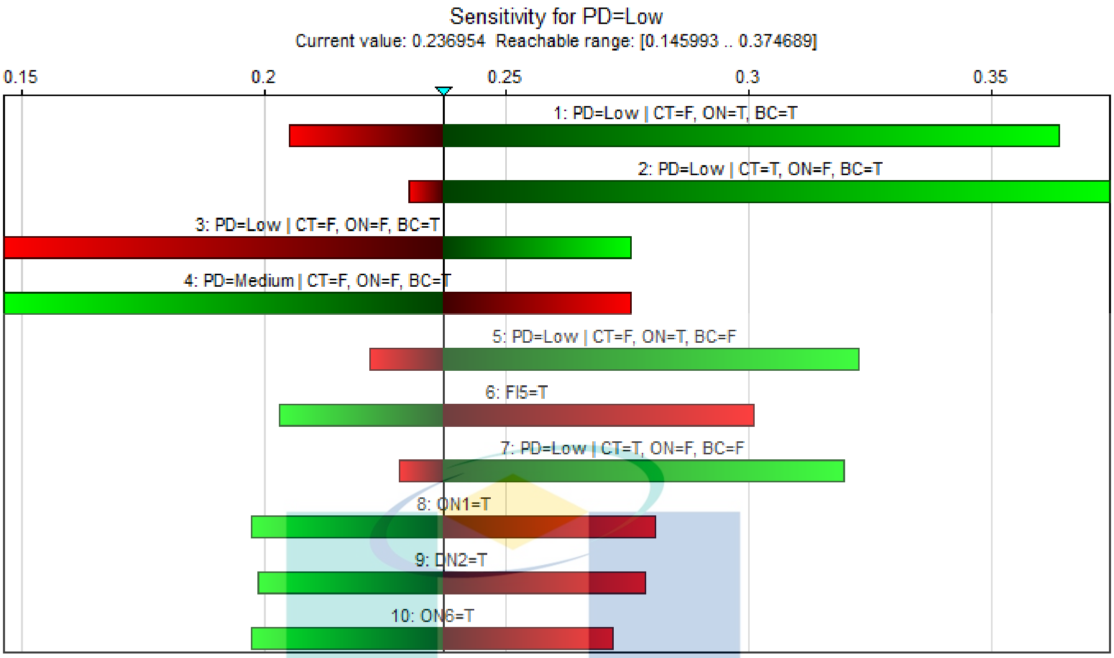

Figure 4.6 Tornado graph for sensitivity analysis of the state PD=Low

In the tornado graph shown in Figure 4.6, the "Low" state of PD was set as the target state and sensitivity analysis was performed. The probabilities of all other parameters were changed by 100% and the change occurred in the probability of PD in the state "Low" was observed. The results indicate that the most sensitive conditional probability on the state "Low" is "$P(PD = Low \mid CT = F, ON = T, BC = T)$". The initial probability of PD in "Low" state before any change is 0.236954. By changing the first parameter 100% negatively and positively, the probability of PD in "Low" state can be decreased and increased to 0.205138 and 0.159078, respectively. The minimum and maximum probability value of "Low" state in case of 100% change is between 0.145993 and 0.347689, respectively.

It is worth mentioning that green and red bars in the tornado graphs reflects positive and negative contribution to the target variable (PD) when specific state is selected ("Low", "Medium" or "High"). In Figure 4.6 for example, the first parameter ($PD = Low \mid CT = F, ON = T, BC = T$) makes positive contribution to "$PD = Low$". This implies that the higher/lower conditional probability of these conditional states the higher/lower probability of "$PD = Low$". Likewise, the fourth parameter ($PD = Medium \mid CT = F, ON = F, BC = T$) makes positive contribution to "$PD = Low$". This implies that the lower/higher conditional probability of these conditional states the higher/lower probability of "$PD = Low$".

4.6.4.2 Sensitivity Analysis for the Delay Factors

Similarly, sensitivity analysis of the delay factors on PD which called root variables sensitivity analysis was conducted. The probability of PD being in "High" state was measured when changing a single root variable state. The change in the probabilities of PD when a single risk will and will not occur was examined (for example, $P(FI5 = T) = 1$ and $P(FI5 = F) = 1$, respectively). Figure 4.7 shows the delay factors from the most to least sensitive on "High" state of PD.

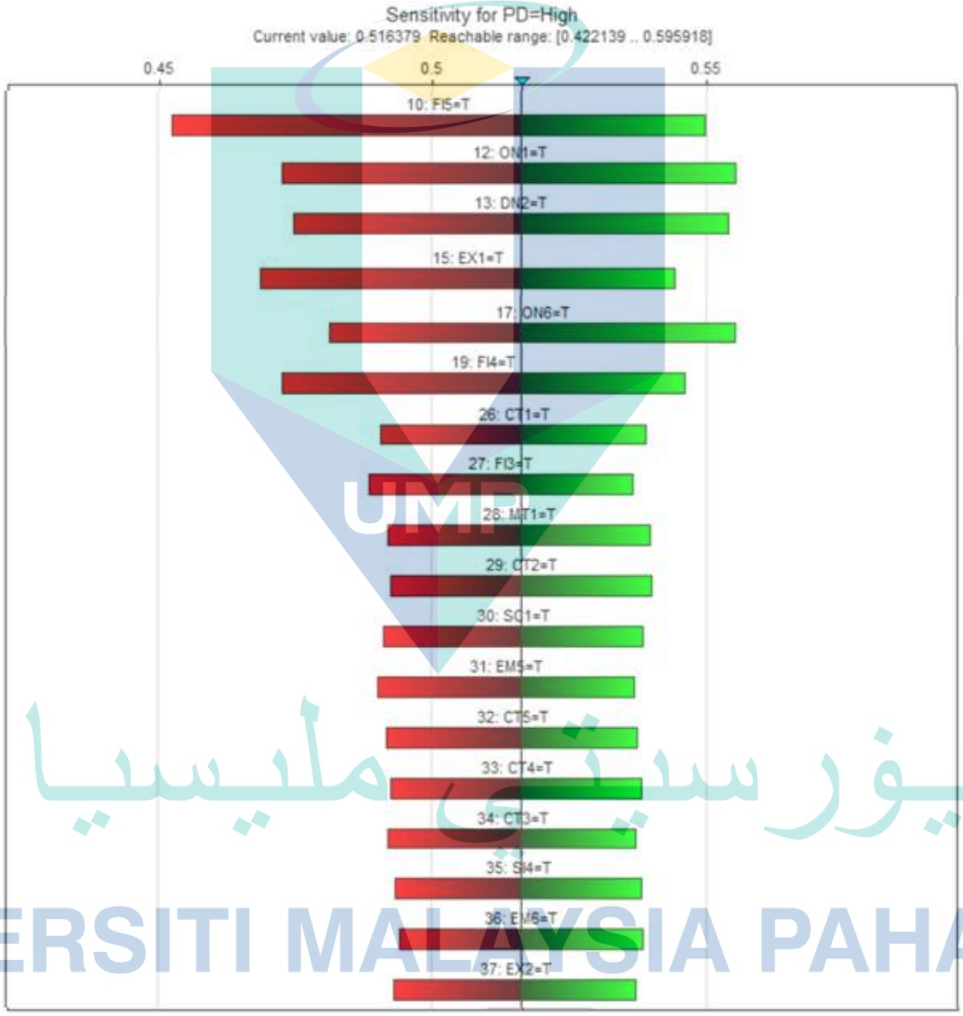

Figure 4.7 Tornado graph for sensitivity analysis of the delay factors on the state PD=High

Figure 4.7 indicates that "FI-5" has the highest effect on the "High" state of PD. The initial probability of PD being in "High" state before any change is 0.516379. When the condition of this factor is set as "F" (the risk will not occur), the posterior probability of PD in "High" state is reduced to 0.452668. On the other hand, when this factor is set as "T" (the risk will occur), the posterior probability of PD in "High" state is increased to 0.549967. The probability range in which the "High" state can be changed in case of both observations is 0.0972987. This is higher than any change can occur when changing the probability of other single delay factor. As a result, reducing this factor is preferable over other risks to eliminate time overrun. Since "FI-F" reflects financial problems of owner, it can be said that owner should understand his responsibility to seek adequate fund and make payment on time to avoid project delay.

Sensitivity analysis is a fundamental aspect in BNs and used as a way for model validation. High sensitivity value of the parameter indicates that the parameter has a high influence on posterior probability of the outcome. Therefore, it is of great importance to evaluate the parameter with high accuracy. Re-estimation of the parameter requires running sensitivity analysis again to examine which other parameters also have high influence on the output. On the other hand, variables with low impact on the network should be combined or even removed to reduce the complexity of the network. Due to limited communication with road experts, the structure and parameters will not be modified any further.

4.7 Model Validation

This stage implies that the parameters and structure of the model have been appropriately defined. The structure was entirely built by interview sessions of two road experts representing expert 1 and expert 2 (see Table 4.5). As a result, a total of 18 delay factors have been chosen for model development. In addition to that, six intermediate nodes were established gathering delay factors related to contactor, owner or beyond groups. The next sections present the validation of the structure and results of the BNs model based on experts' inputs.

4.7.1 Validation of the Structure of the BNs Model

In this stage, three experts (expert 3 to expert 5) were approached to evaluate the structure and components of the model. Expert 1 and expert 2 were excluded in this stage since they were involved in the model construction. Three main points were considered to examine the appropriateness of the model structure. First, experts were required to assess the number of delay factors involved in the model. Experts were also given a chance to mention any additional critical delay factors that should be also considered. As a result, all experts "strongly agreed" that the selected delay factors represent the most critical factors causing delay in road construction projects. This indicates that the model variables were well-defined, and the number of factors was appropriate. Secondly, participants were approached to examine whether the description of each factor is clear or should be rephrased. As a result, two out of three experts "agreed" about the phrases assigned for the delay factors and one "strongly agreed". However, the only factor that has been criticised is bad weather condition. One expert suggested rephrasing this factor into unexpected or unpredictable weather, i.e. heavy rain is normal and expected during rainy season. However, the effect of rain on construction activities during unusual period of the year is more critical. Finally, experts were asked to give their opinions about the connections between intermediate node and its corresponding delay factors. Again, all experts selected "strongly agree" option, indicating that the connections between the delay factors and their intermediate nodes were appropriate.

4.7.2 Validation of the outputs of the BNs Model

In this section, validation of the model outputs was established based on four experts' knowledge. One expert form different project party was approached. Experts were asked to estimate the probability of occurrence of each delay factor. The probabilities were set as evidence in the BNs model (see Appendix G), and the outputs were then returned to experts to validate. Again, the model was validated using expert opinions only due to lack of historical data. The output of BNs model based on estimation of probability of occurrence of the delay factor provided by experts are shown in Figure 4.8, Figure 4.9, Figure 4.10 and Figure 4.11.

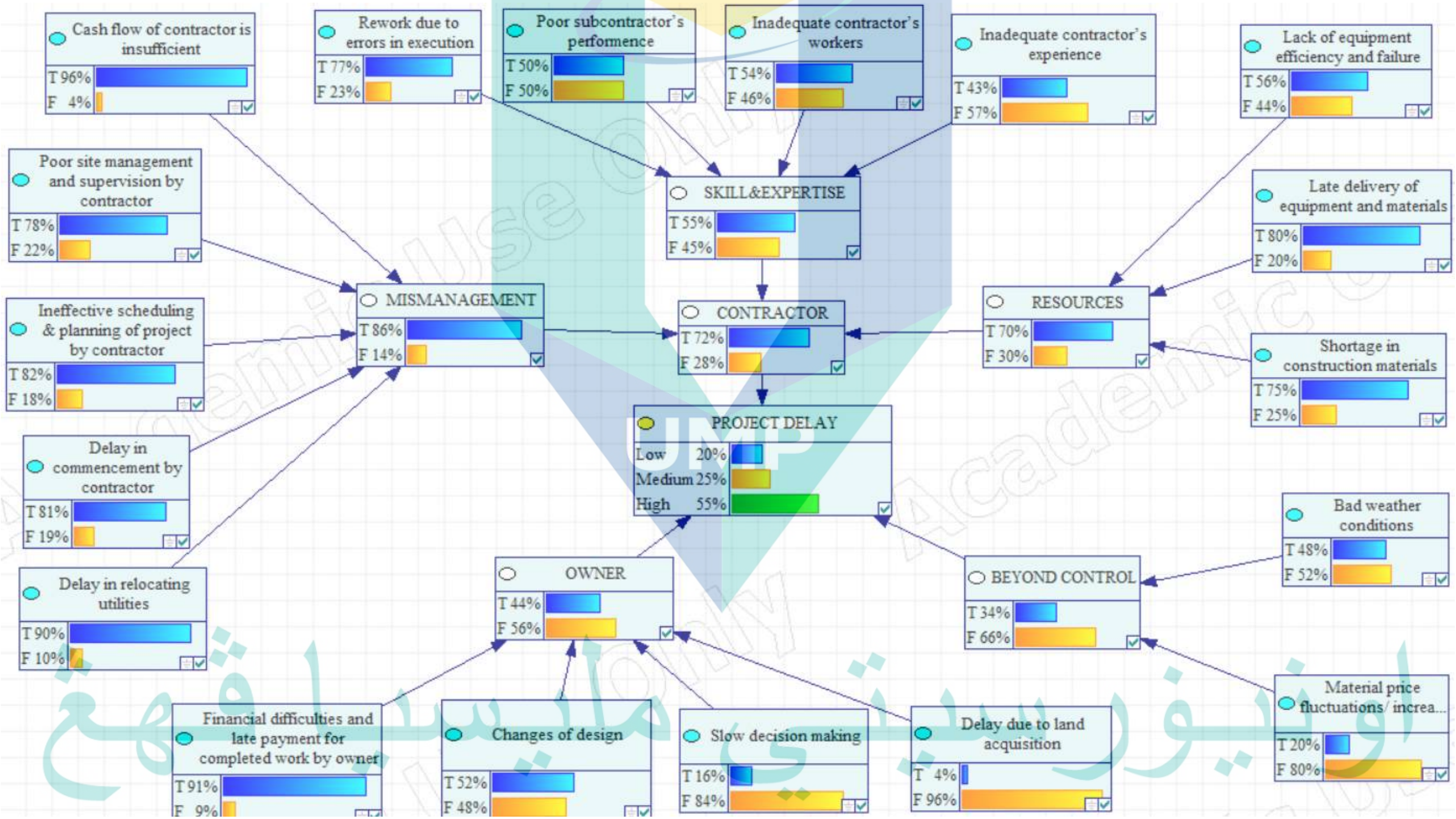

Figure 4.8 The BNs-based model outputs based on expert 1 inputs

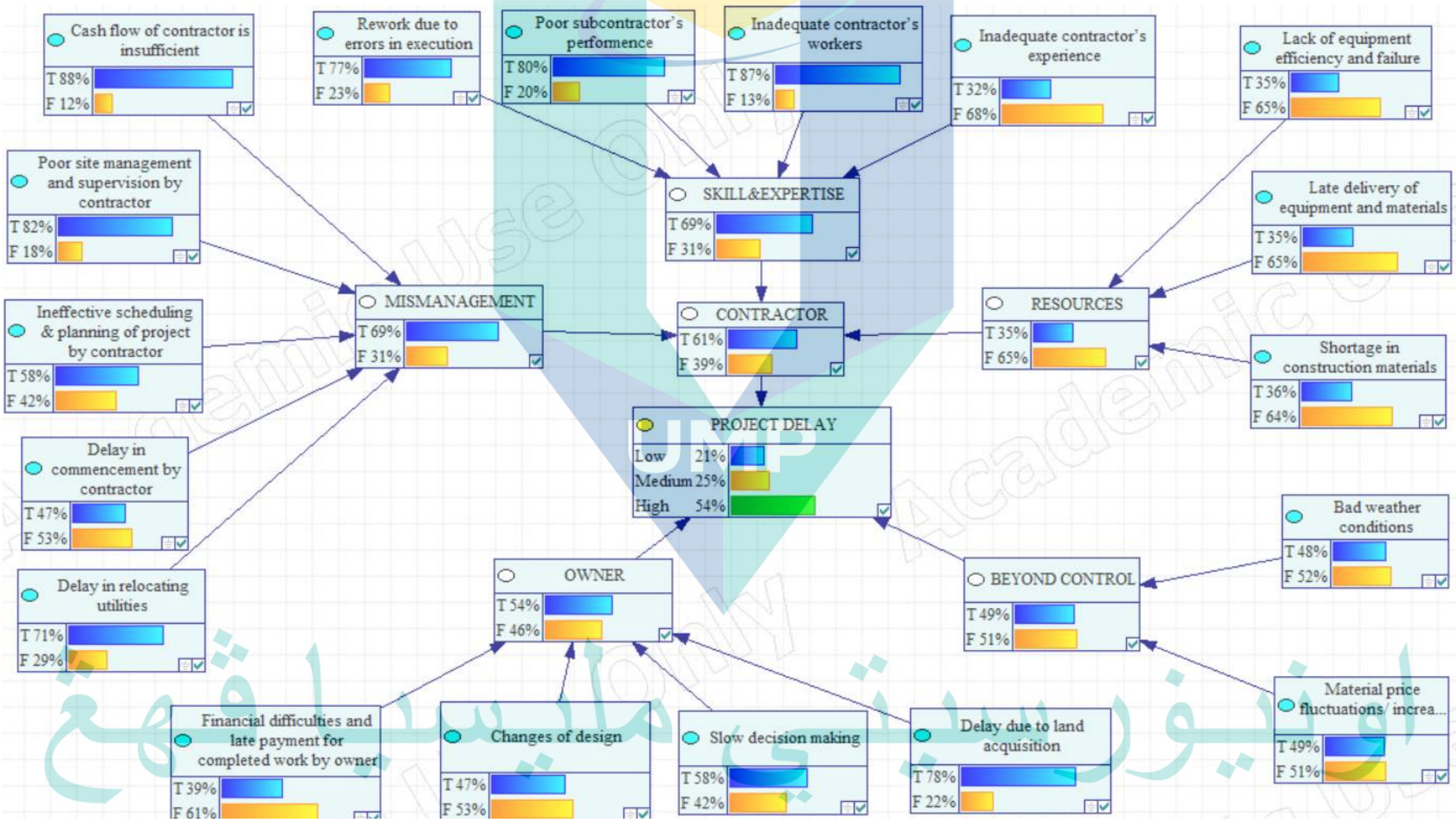

Figure 4.9 The BNs-based model outputs based on expert 2 inputs

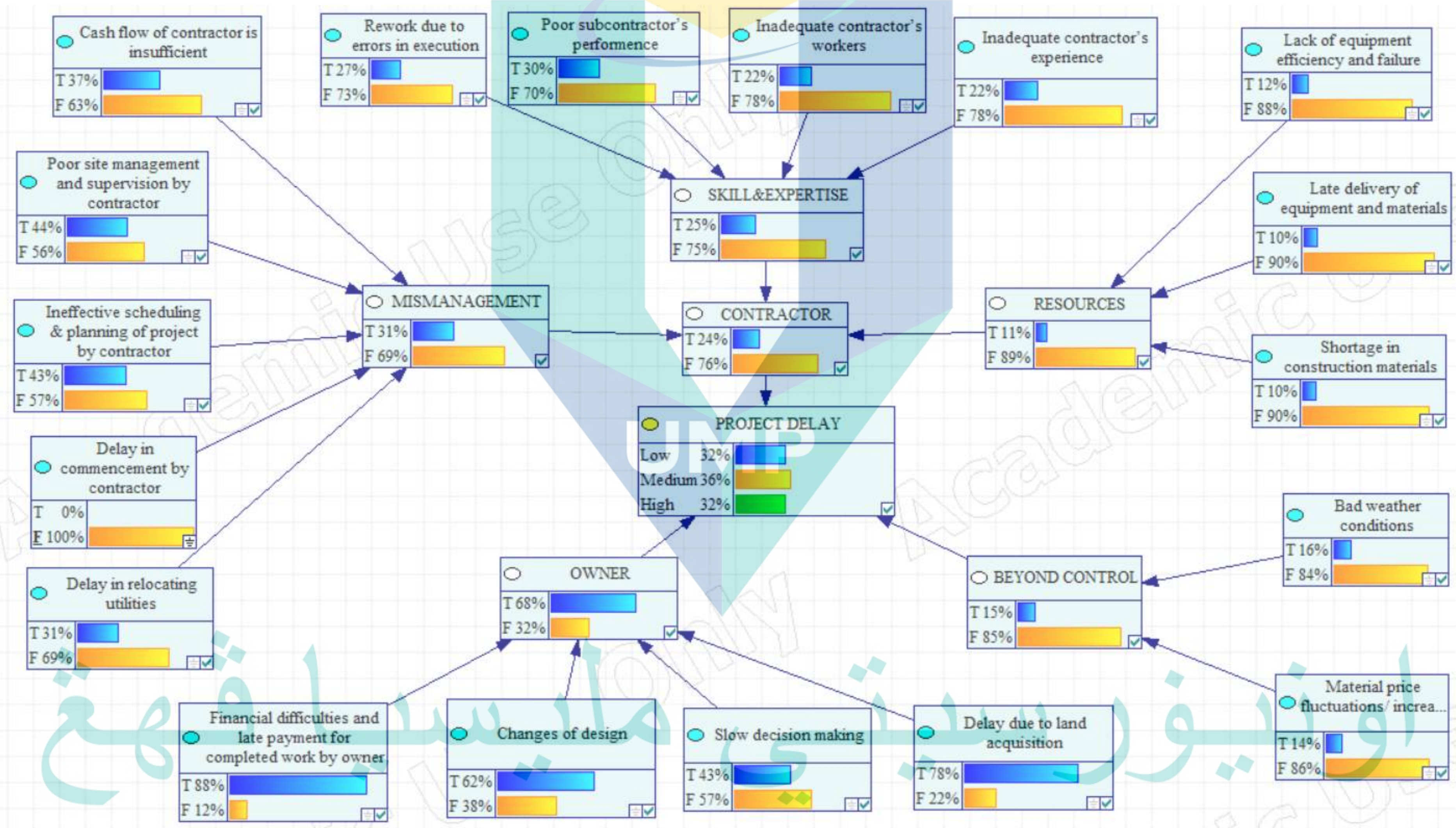

Figure 4.10 The BNs-based model outputs based on expert 3 inputs

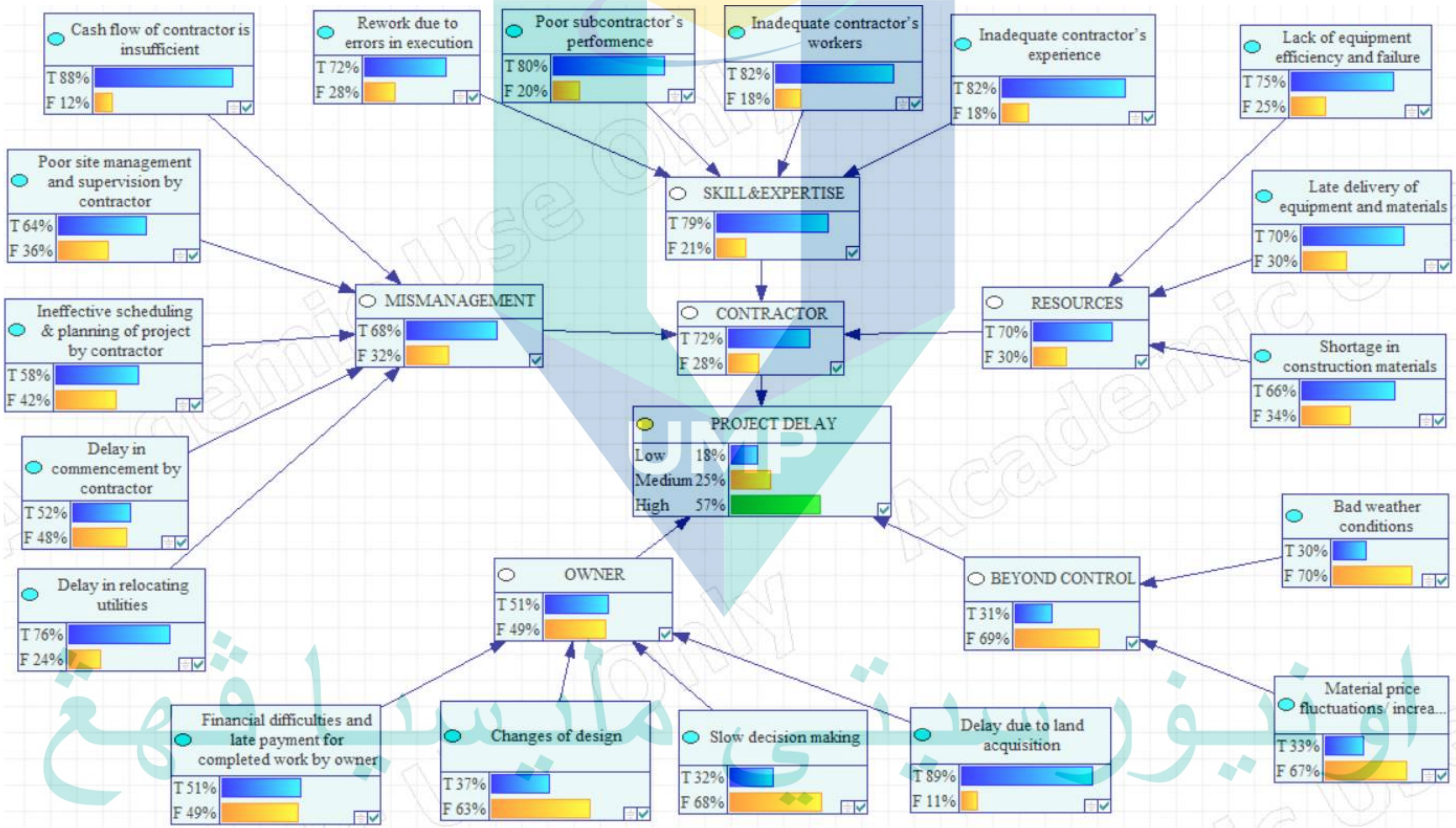

Figure 4.11 The BNs-based model outputs based on expert 4 inputs

The results of the BNs model based on experts' inputs in comparison with original values of the BNs model before observing any evidence are shown in Table 4.15.

Table 4.15 The probability distribution of PD under different experts' inputs

PD probability	Original	Expert 1	Expert 2	Expert 3	Expert 4
Low	0.237	0.2	0.21	0.32	0.18
Medium	0.247	0.25	0.25	0.36	0.25
High	0.516	0.55	0.54	0.32	0.57

As shown in Table 4.15, the project is more likely to delay more than 20% of contract duration ("PD=High") according to expert 1, expert 2 and expert 4, and more likely to delay between 10% and 20% of contract duration ("PD=Medium") according to expert 3. Although different probabilities were set in the model, the probability of *PD* for expert1, expert 2 and expert 4 is very close. The probability of *PD* being in "High" state for expert 1, expert 2 and expert 4 is approximately 55%, 54% and 57%, respectively. The probability of *PD* being in "Medium" state is approximately the same (25% of contract duration). The probability of *PD* being in "Low" state ranges between 18% and 21%. When the model outputs were returned to experts, expert 1 and expert 2 stated that the model correctly predict project delay with the word "yes". Expert 3 and expert 4 provided their opinions with the words "reasonable" and "acceptable", respectively. Here, a common mistake in the questionnaire was made. Experts were free to express their opinions about the model outputs. According to expert 3, "using close-ended question is more convenient for respondents to answer and analysis". Expert 3 also stated that the questionnaire should have asked experts about expected project delay percentage without the BNs results provided. In general, the model correctly predicted project delay in four cases since all experts agreed about the BNs model results.

4.7.3 Evaluation by Experts

In this section, road experts were asked to evaluate the usefulness of the BNs model in time delay prediction for road projects. Three out of four participants stated that the model is "useful" for time delay prediction in road projects. One participant selected "undecided" choice. With regard to model advantages, one expert "strongly agreed" that the BNs model improved the problem understanding, and the remainder of experts "agreed" about this advantage. Half of participants found that the BNs model is "very useful" for problem visualization, and the other half found it "useful". Experts were also approached to examine the applicability of the model in different type of construction. All experts "agreed" that the model is applicable for other types of construction. However, one expert added that "delay in relocating utilities" and "delay due to land acquisition" factors are more critical in road projects than other types of construction. Therefore, these two factors should be removed or replaced by other significant factors considering type of construction projects.

4.8 Counter Measures

In order to increase the chance of completing the project within the planned period, counter measures have been proposed by expert 1. Expert 1 is a senior construction project manager with over 30 years of experience. He is currently working in 6 federal road projects and previously participated in 25 road projects. His responsibility is to manage the construction of road from construction stage to project handing over in terms of time, quality and cost based on four steps: implementation and construction, testing and accreditation, product acceptance and handing over, disability and liability period (DLP). These counter measures were established based on the risk factors included in the BNs model only which represent the most influential factors on project delay.

4.8.1 Owner

i Approve and allocate budget before starting the project quarterly or every year to avoid late payment to contractor.

ii Fixe and specify scope of work and client needs including budget during tender stage.

iii Appoint a competent and energetic superintendent officer or representative team to make fast decision for any issue arises.

iv Understanding and having knowledge about construction contract, procedures, regulation etc.

v Having good relationship with local authority regarding land acquisition issues.

4.8.2 Contractor

4.8.2.1 Mismanagement

i Appoint experienced project manager and key person at site and every person must understand their tasks clearly.

ii Appoint experienced and educated engineer who is capable of liaising with local authorities and utility providers.

iii Top management should monitor their site person works and give trust to them.

iv Discussion and meeting between site persons and top management of the company must be frequently conducted.

v Create an effective planning programme and plan reasonable duration period for each task.

vi Contractor must have good financial resources or bank facilities as a project capital.

4.8.2.2 Skills and Expertise

i Appoint experience engineer and supervisor to monitor the work.

ii Appoint specialist sub-contractors for related works and each should be undergone tender interview.

iii Combine skilled workers and general workers.

iv Follow method statements, procedures, drawings provided and abey instructions provided by consultant.

4.8.2.3 Resources

i Manage stockpile materials properly so that always available at site.

ii Having few providers/ suppliers/ manufacturers in the list as a backup plan if anything happened, not only depend on one supplier.

iii Having completed team to repair and make maintenance works for machineries and transporters.

iv All materials at site should be always sufficient during festival season because lorries are not allowed to be on roads that time (normally for Malaysia 12-15 days each season).

4.8.3 Beyond Control

i Try to complete every work activity earlier than planned and reschedule work programme to cover bad weather occurred with additional resources.

ii Refer to meteorology department to know and get information about weather forecasting and take early action.

iii Discussion between consultant and client should immediately hold if material price fluctuations happened.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter presents the conclusion of the research. It closes the thesis by offering the answers to the research questions including the achievement of the research aim and objectives as they were initially formulated. This chapter further proposes possible recommendations for construction industry practitioners and some recommendations for future research.

5.2 Conclusion

In this thesis, a BNs model for time delay prediction for Malaysian road construction has been developed. The data required for the model were gathered through questionnaire survey and further analysed which led to rank the delay factors according to their importance. These factors were then revised and modified and the most important ones were chosen to build the BNs model. The structure of the proposed model was mainly constructed by expert knowledge and further simplified by creating three main groups responsible for project delay, namely: owner, contractor and beyond control. Model validation was carried out using questionnaire distributed among road experts. Counter measures were further proposed as potential solutions to enhance the performance of owner and contractor which in turn increases the chance of completing the project within the planned period. As a result, the main conclusions of this study are addressed in the next sections.

The first objective of this study was to rank the factors affecting time delay in Malaysian road construction. Risk rating was established in consideration of risk frequency and impact which led to prioritize the delay factors from most to least important. The results revealed that the most significant delay factors affecting road construction projects in Malaysia are: financial difficulties faced by owner/ client, bad weather conditions, delay in payment for completed work by owner, material price fluctuation/ increase, cash flow of contractor is insufficient, equipment failure (breakdown), inadequate contractor's experience, ineffective scheduling and planning of project by contractor, slow equipment movement and slow decision making. Moreover, discussion of the current findings was carried out by focusing on two points which are: causes of delay within Malaysian construction and causes of delay within road sector. Although the comparison of top ten delay causes with other developing countries was made randomly, it revealed the following:

i Most of the delay factors among the highest ten have been frequently determined as significant in Malaysia and other developing countries. These factors were represented by financial difficulties faced by owner, delay in payment for completed work by owner, cash flow of contractor is insufficient, ineffective scheduling and planning of project by contractor, inadequate contractor's experience and slow decision making.

ii Financial and non-payment problems particularly seem to be a common theme in Malaysia and many developing countries. These problems are represented by financial difficulties faced by owner, delay in payment for completed work by owner and cash flow of contractor is insufficient. However, in advanced countries such as Japan and Korea, the performance of construction projects in terms of funding the project is adequate probability due to stable economy.

iii Factors that have more influence on road projects than other types of construction due to nature of road construction projects are: bad weather conditions and equipment failure (breakdown).

iv Bad weather conditions is found to be a major factor affecting project delay in counties exposed to heavy rain and floods such as Malaysia, Japan and Cambodia.

The second objective of this research was to develop a BNs model having the potential to perform prediction inference of time delay faced by Malaysian roads. The model was constructed with consultation of road experts who had the key role of selecting factors to which more attention by project parties should be paid. One of the main advantages of the BNs model is reflected by representing time overrun problem through visual representation. The model was constructed using 18 most significant factors causing delay in road construction projects in Malaysia. Sensitivity analysis was further conducted allowing project parties to identify which delay factor should be reduced first. The results also showed that financial difficulties and late payment by owner is the most sensitive delay factor on project delay. This factor was also analysed in first place according to respondents' answers and further confirmed by road experts as the most significant factor causing delay in road construction projects.

The third and final objective was to validate the proposed BNs model. Road experts were in agreement about the BNs model structure including the selected delay factors, their descriptions and connections to intermediate nodes. In general, the model was appropriate not only for road projects, but also other type of construction. With regard to numerical validation, the BNs model showed its efficiency since the outputs met experts' expectations. The model predicted project delay as expected despite two major drawbacks which will be presented in the next sections to enhance the model.

5.3 Recommendations

Based on the conclusion identified earlier, the following recommendations for project parties and future research are presented in the next sections.

i Project funding should be given high priority. Owner/ client should seek adequate finance in order to make on-time payments to contractor. Likewise, contractor should focus on the same issue as late payment to sub-contractors or others affects their performance and project progress negatively.

ii This research was conducted considering no relationships between the delay factors. In real world there are many correlations between them. Future research should focus on this point and investigate about the dependency relationships between risk factors.

iii The BNs structure was constructed by consultation of two owner representatives which may have led to consider more delay factors attributed to contractor than owner. Engaging personals from different project parties should be considered in order to select proper delay factors for the model. Moreover, the data required to build the BNs model were either collected indirectly using questionnaire or by individual estimation by experts. Expert interviews and workshops for example are preferable for obtaining more reliable data and results.

5.3.1 Further Enhancement to the Model

The usefulness of BNs lies on the reliability of prior knowledge. In this research, prior probabilities were defined based on five point Likert-scale by means of average which resulted in very similar prior probabilities for the delay factors. This problem can be voided by considering more points on Likert-scale or using other methods for probability estimation such as frequency.

As stated by one expert "it is difficult to define probability of occurrence for the delay factors". Here comes the importance of variable states definition. Variables states which were assumed binary should be defined and verified by experts to serve their interests. Consequently, when the model is validated or applicable for use, experts could provide inputs with more confidence.

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APPENDIX A

FREQUENCY OF CAUSES OF DELAY WHITHIN TOP 15 RANK IN THE LITERATURE

No	Causes of delay	Frequency
1	Ineffective scheduling & planning of project by contractor	27
2	Poor site management and supervision by contractor	24
3	Slow decision making	19
4	Lack of communication between parties	19
5	Insufficient labours/ Shortage of labour	17
6	Delay in payment for completed work by owner	15
7	Poor sub-contractor’s performance	14
8	Late delivery of materials	14
9	Bad weather conditions	14
10	Shortage in construction materials	12
11	Slow payment progress and procedures adopted by client/ owner	12
12	Financial difficulties faced by owner/client	11
13	Cash flow of contractor is insufficient	11
14	Shortage in equipment/ Insufficient numbers	11
15	Changes of design	11
16	Low productivity of labour	11
17	Unexpected ground & underground condition	10
18	Change in the scope of the project by owner	10
19	Inappropriate or incomplete design	9
20	Late in reviewing and approving design documents by consultant	9
21	Shortage of skilled labour	9
22	Rework due to errors in execution	9
23	Late delivery of equipment	8
24	Inadequate contractor’s experience	8
25	Poor estimate of project duration	8
26	Late in revising and approving design documents	8
27	Material price fluctuations/increase	7
28	Practice of assigning contract to lowest bidder	7
29	Equipment failure (breakdown)	6
30	Change order	6
31	Necessary variations	6
32	Economic problems/ Inflation	5
33	Different/ unfavourable site conditions	5
34	Delay in honouring payment certificates	4
35	Lack of equipment efficiency	4
36	Changes in drawing & specifications	4
37	Quality of material	4
38	Late procurement of material	4
39	Delay in performing inspection and testing by consultant	4
40	Improper or wrong cost estimation	4
41	Political situation	4
42	Government requirements	4
43	Exchange rate fluctuation	3
44	Inadequate contractor's workers	3
45	Lake of experience in consultants’ staff	3
46	Delay in relocating utilities	3
47	Delay due to land Acquisition	3
48	Claims	3

Continued

No	Causes of delay	Frequency
49	Conflict between contractor and other parties	3
50	Delay in commencement by contractor	2
51	Incomplete documents by the consultant	2
52	Disturbance to public activities	2
53	Closure	2
54	Labour disputes & strikes	2
55	High competition in bids	2
56	Slow equipment movement	1
57	Conflicting design information	1
58	Insufficient inspectors	1
59	Lack of application of construction management tools and techniques by consultant's staff	1
60	Mistakes in soil investigation	1
61	Limited construction area	1
62	Slow cite clearance	1
63	Postponement of project by owner	1
64	Staffing problems	1
65	Slow land expropriation due to resistance from occupants	1
66	Delay in paying compensations (land owners)	1
67	Contract modification	1

APPENDIX B

RESULT OF SEMI-STRUCTURED INTERVIEWS WITH JKR PANELS

Group	No	Causes of delay	Panel 1	Panel 2	Panel 3
Financial	1	Financial difficulties faced by owner/client	√	√	
	2	Delay in payment for completed work by owner	√	√	
	3	Cash flow of contractor is insufficient	√	√	√
	4	Exchange rate fluctuation			√
	5	Material price fluctuations/increase	√	√	√
	6	Economic problems/ Inflation			√
	7	Delay in honouring payment certificates			
Contractor	8	Inadequate contractor's experience		√	√
	9	Poor sub-contractor's performance	√		√
	10	Poor site management and supervision by contractor	√	√	√
	11	Delay in commencement by contractor	√	√	√
	12	Inadequate contractor's workers	√		√
Owner/ client	13	Slow decision making	√	√	
	14	Slow payment progress & procedures adopted by client/ owner	√	√	
	15	Late in revising and approving design documents	√	√	√
	16	Postponement of project by owner			
	17	Change in the scope of the project by owner	√	√	√
	18	Change order	√	√	
	19	Delay due to land Acquisition	√	√	√
Consultant	20	Insufficient inspectors	√		
	21	Late in reviewing and approving design documents by consultant	√	√	
	22	Incomplete documents by the consultant	√		
	23	Lake of experience in consultants' staff	√		
	24	Lack of application of construction management tools and techniques by consultant's staff	√	√	
	25	Delay in performing inspection and testing by consultant	√	√	
Equipment & machineries	26	Shortage in equipment/ Insufficient numbers	√		
	27	Equipment failure (breakdown)	√		√
	28	Late delivery of equipment	√		√
	29	Slow equipment movement		√	√
	30	Lack of equipment efficiency	√	√	√
Material	31	Shortage in construction materials	√		√
	32	Quality of material	√		√
	33	Late procurement of material		√	√
	34	Late delivery of materials	√	√	√
Labour	35	Low productivity of labour	√	√	√
	36	Insufficient labours/ Shortage of labour			√
	37	Shortage of skilled labour	√	√	√
	38	Staffing problems	√		√
	39	Labour disputes & strikes	√	√	√

Continued

Group	No	Causes of delay	Panel 1	Panel 2	Panel 3
Design	40	Inappropriate or incomplete design	√	√	
	41	Changes of design	√		√
	42	Different/ unfavourable site conditions		√	√
	43	Conflicting design information	√	√	√
	44	Changes in drawing & specifications			√
Site	45	Mistakes in soil investigation	√	√	√
	46	Disturbance to public activities			√
	47	Limited construction area		√	√
	48	Unexpected ground & underground condition	√		√
	49	Slow cite clearance			√
	50	Delay in relocating utilities	√	√	√
Scheduling & controlling	51	Ineffective scheduling & planning of project by contractor	√	√	√
	52	Improper or wrong cost estimation	√		√
	53	Poor estimate of project duration	√		√
	54	Closure	√		√
Contractual	55	Claims	√	√	√
	56	Necessary variations	√		√
	57	Contract modification	√		√
	58	Conflict between contractor and other parties	√	√	√
	59	Lack of communication between parties	√	√	√
	60	Practice of assigning contract to lowest bidder	√		√
	61	High competition in bids	√	√	√
External	62	Bad weather conditions	√		√
	63	Rework due to errors in execution	√	√	√
	64	Political situation	√	√	√
	65	Government requirements		√	√
	66	Slow land expropriation due to resistance from occupants	√		√
	67	Delay in paying compensations (land owners)	√	√	√

APPENDIX C

SAMPLE OF UNCOMPLETED QUESTIONNAIRE

Part 1

General Information

Please tick () where appropriate

1. What is your profession?
   - a. Civil engineer
   - b. Electrical engineer
   - c. mechanical engineer
   - d. architecture engineer
   - e. quantity surveyor
   - f. Others,
2. What is your job title?
   - a. Project manager
   - b. Project supervisor
   - c. Safety officer
   - d. Clerk of works
   - e. Others
3. What entity you are representing?
   - a. Owner/ client
   - b. Main contractor
   - c. Sub-contractor
   - d. Consultant
4. What is your work experience?
   - a. Less than one year
   - b. 1 to less than 5 years
   - c. 5 to 10 years
   - d. More than 10 years

Part 2

Please complete the following table according to your personal perception by selecting one among five grades as follows:

1	2	3	4	5
Very low	Low	Medium	High	Very high

Groups	Delay factors	How frequent this risk occurs					How much this risk can influence project delay				
		1	2	3	4	5	1	2	3	4	5
Financial	Financial difficulties faced by owner/client				*					*	
	Delay in payment for completed work by owner				*					*	
	Cash flow of contractor is insufficient				*						*
	Material price fluctuations/ increase			*						*	
Contractor	Inadequate contractor's experience				*					*	
	Poor sub-contractor's performance				*					*	
	Poor site management and supervision by contractor			*						*	
	Delay in commencement by contractor				*				*		
	Inadequate contractor's workers								*		
Owner/ client	Slow decision making				*					*	
	Slow payment progress and procedures adopted by client/ owner				*					*	
	Late in revising and approving design documents				*					*	
	Change in the scope of the project by owner			*					*		
	Change order				*				*		
	Delay due to land Acquisition			*						*	
Consultant	Late in reviewing and approving design documents by consultant				*				*		
	Lack of application of construction management tools and techniques by consultant's staff				*				*		
	Delay in performing inspection and testing by consultant			*					*		
Equipment & machineries	Equipment failure (breakdown)			*				*			
	Late delivery of equipment			*					*		
	Slow equipment movement			*					*		
	Lack of equipment efficiency							*			
Material	Shortage in construction materials			*					*		
	Quality of material			*					*		
	Late procurement of material			*						*	
	Late delivery of materials		*						*		

Continued

Groups	Delay factors	How frequent this risk occurs					How much this risk can influence project delay				
		1	2	3	4	5	1	2	3	4	5
Labour	Low productivity of labour		*						*		
	Shortage of skilled labour		*							*	
	Staffing problems			*						*	
	Labour disputes & strikes		*						*		
Design	Inappropriate or incomplete design			*					*		
	Changes of design		*					*			
	Different/ unfavourable site conditions		*						*		
	Conflicting design information			*					*		
Site	Mistakes in soil investigation		*					*			
	Limited construction area		*						*		
	Unexpected ground & underground condition			*					*		
	Delay in relocating utilities		*					*			
Scheduling &controlling	Ineffective scheduling & planning of project by contractor			*					*		
	Improper or wrong cost estimation			*						*	
	Poor estimate of project duration				*					*	
	Closure			*						*	
Contractual	Claims				*					*	
	Necessary variations			*					*		
	Contract modification			*						*	
	Conflict between contractor and other parties			*						*	
	Lack of communication between parties		*							*	
	Practice of assigning contract to lowest bidder		*						*		
	High competition in bids			*						*	
External	Bad weather conditions			*						*	
	Rework due to errors in execution				*					*	
	Political situation									*	
	Government requirements		*							*	
	Slow land expropriation due to resistance from occupants			*					*		
	Delay in paying compensations (land owners)			*						*	
	Change of the government of the day				*				*		

APPENDIX D

CONTRIBUTION PERCENTAGE OF PARENT NODES TO ITS CHILD NODES

Child node	Parent node	Impact	Percentage	Cumulative
MIS	SI-4	5.161	19.39%	19.39%
	CT-4	5.258	19.76%	39.15%
	SC-1	5.452	20.49%	59.64%
	CT-3	5.194	19.52%	79.16%
	FI-3	5.548	20.84%	100.00%
SKE	CT-2	5.452	25.57%	25.57%
	CT-5	5.258	24.66%	50.23%
	CT-1	5.548	26.02%	76.25%
	EX-2	5.065	23.75%	100.00%
RE	EM-5	5.387	33.60%	33.60%
	EM-6	5.129	31.99%	65.59%
	MT-1	5.516	34.41%	100.00%
CT	MIS	26.613	41.60%	41.60%
	SKE	21.323	33.34%	74.94%
	RE	16.032	25.06%	100.00%
ON	ON-6	4.839	22.29%	22.29%
	ON-1	5.387	24.81%	47.10%
	DN-2	5.161	23.77%	70.87%
	FI-5	6.323	29.13%	100.00%
BC	EX-1	5.839	50.70%	50.70%
	FI-4	5.677	49.30%	100.00%

APPENDIX E

CONDITIONAL PROBABILITY TABLES

Table C.1 CPTs for MIS

SI-4 0.1939	CT-4 0.1976	SC-1 0.2049	CT-3 0.1952	FI-3 0.2084	MIS T	 F
T	T	T	T	T	1	0
T	T	T	T	F	0.7916	0.2084
T	T	T	F	T	0.8048	0.1952
T	T	T	F	F	0.5964	0.4036
T	T	F	T	T	0.7951	0.2049
T	T	F	T	F	0.5867	0.4133
T	T	F	F	T	0.5999	0.4001
T	T	F	F	F	0.3915	0.6085
T	F	T	T	T	0.8024	0.1976
T	F	T	T	F	0.594	0.406
T	F	T	F	T	0.6072	0.3928
T	F	T	F	F	0.3988	0.6012
T	F	F	T	T	0.5975	0.4025
T	F	F	T	F	0.3891	0.6109
T	F	F	F	T	0.4023	0.5977
T	F	F	F	F	0.1939	0.8061
F	T	T	T	T	0.8061	0.1939
F	T	T	T	F	0.5977	0.4023
F	T	T	F	T	0.6109	0.3891
F	T	T	F	F	0.4025	0.5975
F	T	F	T	T	0.6012	0.3988
F	T	F	T	F	0.3928	0.6072
F	T	F	F	T	0.406	0.594
F	T	F	F	F	0.1976	0.8024
F	F	T	T	T	0.6085	0.3915
F	F	T	T	F	0.4001	0.5999
F	F	T	F	T	0.4133	0.5867
F	F	T	F	F	0.2049	0.7951
F	F	F	T	T	0.4036	0.5964
F	F	F	T	F	0.1952	0.8048
F	F	F	F	T	0.2084	0.7916
F	F	F	F	F	0	1

Table C.2 CPTs for SKE

CT-2 0.2557	CT-5 0.2466	CT-1 0.2602	EX-2 0.2375	SKE T	 F
T	T	T	T	1	0
T	T	T	F	0.7625	0.2375
T	T	F	T	0.7398	0.2602
T	T	F	F	0.5023	0.4977
T	F	T	T	0.7534	0.2466
T	F	T	F	0.5159	0.4841
T	F	F	T	0.4932	0.5068
T	F	F	F	0.2557	0.7443
F	T	T	T	0.7443	0.2557
F	T	T	F	0.5068	0.4932
F	T	F	T	0.4841	0.5159
F	T	F	F	0.2466	0.7534
F	F	T	T	0.4977	0.5023
F	F	T	F	0.2602	0.7398
F	F	F	T	0.2375	0.7625
F	F	F	F	0	1

Table C.3 CPTs for ON

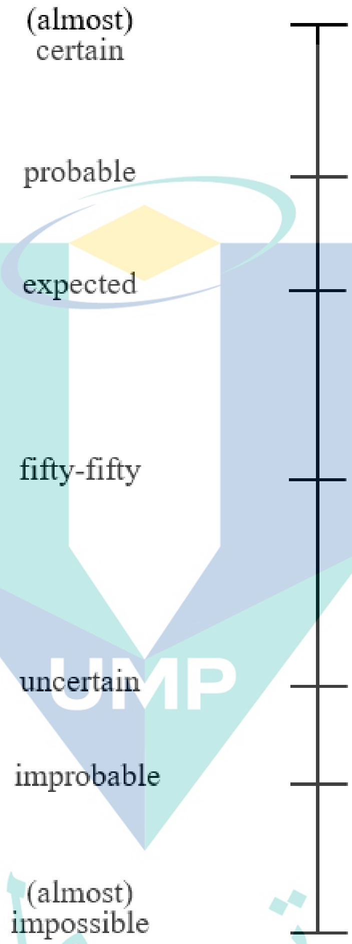
ON-6 0.2229	ON-1 0.2481	DN-2 0.2377	FI-5 0.2913	ON T	 F
T	T	T	T	1	0
T	T	T	F	0.7087	0.2913
T	T	F	T	0.7623	0.2377
T	T	F	F	0.471	0.529
T	F	T	T	0.7519	0.2481
T	F	T	F	0.4606	0.5394
T	F	F	T	0.5142	0.4858
T	F	F	F	0.2229	0.7771
F	T	T	T	0.7771	0.2229
F	T	T	F	0.4858	0.5142
F	T	F	T	0.5394	0.4606
F	T	F	F	0.2481	0.7519
F	F	T	T	0.529	0.471
F	F	T	F	0.2377	0.7623
F	F	F	T	0.2913	0.7087
F	F	F	F	0	1

Table C.4 CPTs for BC

EX-1 0.507	FI-4 0.493	BC T	 F
T	T	1	0
T	F	0.507	0.493
F	T	0.493	0.507
F	F	0	1

APPENDIX F

A PROBABILITY SCALE WITH BOTH NUMERICAL AND VERBAL EXPRESSIONS



APPENDIX G

ESTIMATION OF PROBABILITY OF OCCURRENCE OF CAUSES OF DELAY AS INPUTS FOR THE BNS MODEL

Delay factors	Expert 1	Expert 2	Expert 3	Expert 4
SI-4	0.9	0.7	0.3	0.75
CT-4	0.8	0.45	0	0.5
SC-1	0.8	0.55	0.4	0.55
CT-3	0.75	0.8	0.4	0.6
FI-3	0.95	0.85	0.3	0.85
EX-2	0.75	0.5	0.25	0.7
CT-2	0.5	0.75	0.3	0.8
CT-5	0.5	0.8	0.2	0.8
CT-1	0.4	0.85	0.2	0.8
EM-5	0.5	0.3	0.1	0.7
EM-6	0.8	0.35	0.1	0.7
MT-1	0.75	0.35	0.1	0.65
EX-1	0.35	0.35	0.1	0.2
FI-4	0.15	0.4	0.1	0.25
ON-6	0.05	0.8	0.8	0.9
ON-1	0.15	0.55	0.4	0.3
DN-2	0.5	0.45	0.6	0.35
FI-5	0.85	0.25	0.8	0.35

APPENDIX H

COVER LETTER

Universiti Malaysia PAHANG

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Ruj. Kami : UMP.13.01/22.10 Jld 2
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Bahagian Jalan
Tingkat 10, Kompleks Tun Razak
Bandar Indera Mahkota
25582 Kuanta, Pahang Darul Makmur

Assalamualaikum Tuan Haji,

KEPAKARAN JKR NEGERI PAHANG (BAHAGIAN JALAN) BAGI PENYELIDIKAN SARJANA "DEVELOPING A MODEL TO PREDICT TIME DELAY IN ROAD CONSTRUCTION PROJECTS USING BAYESIAN BELIEF NETWORKS"

Dengan segala hormatnya perkara di atas adalah dipohon kepada pihak tuan

Untuk maklumat tuan, saya adalah penyelia kepada Mohammad Al-Mohammad, (MAC17008) dari Syria, bagi penyelidikan Sarjana di atas. Saya dengan ini memohon khidmat kerjasama TIGA (3) tenaga pakar dari pihak tuan bagi mendapatkan input, pandangan, komen, nasihat dan penambah baikan, ke atas kerangka penyelidikan (*'literature framework'*) yang telah dihasilkan. Pandangan pakar dari pihak tuan merupakan keperluan utama methodologi kajian penyelidikan sarjana ini. Selanjutnya, saya amatlah berharap agar pihak tuan dapat membantu dalam melengkapkan pengaturcaraan soal-selidik kepada kontraktor-kontraktor yang relevan mengikut kluster keutamaan-impak dan kesesuaian kajian kes bagi melengkapkan dapatan *'survey'* penyelidikan ini.

Keperihatinan dan kerjasama pihak tuan ke atas permohonan ini adalah amat dihargai.

Sekian, terima kasih.

"BERKHIDMAT UNTUK NEGARA"

Saya yang menjalankan tugas,

DR. OMAR BIN JAMALUDIN
Penyelia, Penyelidikan Sarjana (MAC17008)
Fakulti kejuruteraan Awam dan Sumber Alam

APPENDIX I

LIST OF EXPERT PANELS SELECTED BY JKR

JABATAN KERJA RAYA NEGERI PAHANG
Tingkat 9-12, Kompleks Tun Razak,
Bandar Indera Mahkota
25582 Kuantan,
PAHANG

Tel : 09 5717000
Faks : 09 5732837
Portal Rasmi : http://jkr.pahang.gov.my

Ruj.Kami : PKR.PHG.R/20/1/1/1. Jld I (61)
Tarikh : 22 Oktober 2019.

Fakulti Kejuruteraan Awam dan Sumber Alam,
Universiti Malaysia Pahang,
Lebuhraya Tun Razak,
26300 Gambang, Kuantan.
(U/P: Dr Omar Bin Jamaludin)

Tuan,
KEPAKARAN JKR NEGERI PAHANG (BAHAGIAN JALAN BAGI PENYELIDIKAN SARJANA *"DEVELOPING A MODEL TO PREDICT TIME DELAY IN ROAD CONSTRUCTION PROJECTS USING BAYESIAN BELIEF NETWORKS'.*

- Senarai nama bagi khidmat kepakaran.

Adalah saya dengan segala hormatnya merujuk kepada perkara di atas dan surat rujukan tuan UMP.13.01/22.10 Jld 2 bertarikh 30 Mei 2018 adalah berkaitan.

2. Sehubungan itu, berikut adalah senarai nama dari pejabat ini seperti yang dikehendaki oleh pihak tuan:

i. Mohd Zaffry Zainal Kamrin Tel: 09 5717191 email: zaffry@jkr.gov.my
ii.Muhammad Faizal Mahadi. Tel: 09 5717185 email: mdfaizal@jkr.gov.my
iii.Nur Hafizah Bt Zakaria Tel: 09 5717187 email: nurhafizahz@jkr.gov.my

Sekian terima kasih.

"BERKHIDMAT UNTUK NEGARA "

Saya yang menjalankan amanah,

(Ir HAJI ROSNAN BIN HUSSIN, AAP., AMP.)
Jurutera Awam Penguasa (Jalan),
b.p: PENGARAH KERJA RAYA
JABATAN KERJA RAYA PAHANG.

Sk: 1. Mohd Zaffry Zainal Kamrin
2. Muhammad Faizal Mahadi.
3. Nur Hafizah Bt Zakaria

(Sila sebutkan nombor pejabat ini apabila menjawab)

CERTIFIED TO ISO 9001:2008 CERT. NO. : AR 4281
CERTIFIED TO ISO 14001:2004 CERT. NO. : ER 0281
CERTIFIED TO OHSAS 18001:2007 CERT. NO. : SR 0602

JOURNALS PUBLISHED

Almohammad, M., & Jamaludin, O. Bin. (2018). A review of causes of delay in construction projects. *International Journal of Engineering & Technology*, *7*(4), 5078–5083. https://doi.org/10.14419/ijet.v7i4.19506