STRATEGIC RISK AND RELIABILITY ASSESSMENT IN THE CONTAINER LINER SHIPPING INDUSTRY UNDER HIGH UNCERTAINTIES

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ABSTRACT

The container liner shipping industry (CLSI) can be defined as one consisting of a fleet of vessels that provides a fixed service at regular intervals between ports of call. It is noteworthy that the CLSI is remarkably acting as an artery in making contributions to the growth of the global economy. However, in an era of unprecedented global changes, the CLSI faces a variety of internal and external risks. Moreover, the reliability and capability of liner shipping operators (LSOs) vary under different environmental conditions. Consequently, it is important for LSOs to ensure that the safety and reliability of their internal operations as well as external environments through proactive assessment of their reliability and capability are intact. The literature indicates that disruptive events have been assessed and investigated by many researchers and practitioners whilst the root causes arising from external risks have not yet been fully identified. The aim of this research was to develop integrated frameworks for assessing risk and reliability in the CLSI under high uncertainties. As a result, three interlocking levels of analysis have been highlighted in this research: 1) business environment-based risk (BEBR), 2) organisational reliability and capability (ORC) of LSOs, and 3) punctuality of containerships. To achieve the aim, *firstly*, this research employed a combination of different decision-making methods (i.e. Analytic Hierarchy Process (AHP), Fuzzy Set Theory (FST) and Evidential Reasoning (ER)) for the assessment of the BEBR. The research outcomes are providing LSOs with a powerful decision-making tool to assess the risk value of a country prior to investment and strategic decisions. In addition, LSOs are also able to regularly assess the overall level of existing BEBR in a host country prior to development of mitigation strategies that can help to minimise financial losses. *Secondly,* this research employs the Fuzzy Bayesian Belief Network (FBBN) method for evaluating the ORC of LSOs. By exploiting the proposed FBBN model, LSOs are able to conduct a self-evaluation of their ORC prior to the selection of a strategy for enhancing their competitive advantages in the CLSI. A significant concern in container liner shipping operations is the punctuality of containerships. Therefore, *thirdly*, this research concentrated on analysing and predicting the arrival punctuality of a liner vessel under dynamic environments by employing a combination of Fuzzy Rule-Base (FRB) and FBBN methods. *Finally*, a probabilistic model for analysing and predicting the departure punctuality of a liner vessel was generated. Accordingly, from the outcomes of this research LSOs are able to forecast their vessels' arrival and departure punctuality and, further, tactical strategies can be implemented if a vessel is expected to be delayed. In addition, both arrival and departure punctuality models are capable of helping academic researchers and industrial practitioners to comprehend the influence of uncertain environments on the service punctuality. In order to demonstrate the practicability of the proposed methodologies and models, several real test cases were conducted by choosing the Malaysian maritime industry as a focus of study. The results obtained from these test cases have provided useful information for recommending preventive measures, improvement strategies and tactical solutions. The frameworks and models that have been proposed in this research for assessing risk and reliability of the CLSI will provide managerial insights for modelling and assessing complex systems dealing with both quantitative and qualitative criteria in a rational, reliable and transparent manner. In addition, these models have been developed in a generic sense so that they can be tailored for application in other industrial sectors.

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ABBREVIATIONS

AHP	Analytic Hierarchy Process
ATA	Actual Time Arrival
ATD	Actual Time Departure
AVA	Advertised Vessel Arrivals
BBN	Bayesian Belief Network
BEBR	Business Environment-Based Risk
BL	Bill of Lading
BN	Bayesian Network
CI	Consistency Index
CLSCM	Cranfield Centre for Logistics and Supply Chain Management
CLSI	Container Liner Shipping Industry
CLSN	Container Liner Shipping Network
COLREG	International Regulations for Preventing Collisions at Sea
CPT	Conditional Probability Table
CR	Consistency Ratio
CRED	Centre for Research on the Epidemiology of Disasters
CSI	Container Security Initiative
DAG	Directed Acyclic Graph
D-S	Dempster-Shafer
EM-DAT	Emergency Disasters Database
ER	Evidential Reasoning
ETA	Estimated Time Arrival
ETD	Estimated Time Departure
EU	European Union
FBBN	Fuzzy Bayesian Belief Network
FER	Fuzzy Evidential Reasoning
FL	Fuzzy Logic
FRB	Fuzzy Rule-Base
FST	Fuzzy Set Theory
FTA	Free Trade Agreement
GATT	General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
HAZID	HAZard IDentification
HAZOP	HAZard and OPerability Analysis
ICRG	International Country Risk Guide
ICS	International Chamber of Shipping
IDS	Intelligent Decision System
IMO	International Maritime Organization
ISPS	International Ship and Port Facility Security Code
JPD	Joint Probability Distribution
LSCI	Liner Shipping Connectivity Index
LSO	Liner Shipping Operator
LSOs	Liner Shipping Operators
MARPOL	International Convention for the Prevention of Pollution from Ships
NOAA	National Oceanic and Atmospheric Administration
OCHA	Office of the Coordination of Humanitarian Affairs
OORC	Overall Organisational Reliability and Capability
ORC	Organisational Reliability and Capability
PIANC	World Association for Waterborne Transport Infrastructure
POD	Port of Destination
POL	Port of Loading

POT	Port of Transhipment
PPPs	Purchasing Power Parities
RONOA	Return on Net Operating Assets
SA	Sensitivity Analysis
SCRM	Supply Chain Risk Management
SI	Shipping Instruction
SOLAS	International Convention for the Safety of Life at Sea
STCW	Standard of Training Certification & Watchkeeping
TEU	Twenty-foot Equivalent Unit
UNCTAD	United Nations Conference on Trade and Development
UNODC	United Nations Office on Drugs and Crime
WHO	World Health Organization
WSC	World Shipping Council
WTO	World Trade Organization

CHAPTER ONE

Introduction

Summary

This chapter discusses the research background and research objectives which have been developed based on an extensive and comprehensive literature review. The justification of the research is highlighted based on the CLSI necessities. Also, the structure of the research is elucidated on a chapter-by-chapter basis. Finally, the scope of the research is presented.

1.1 Definitions of Terms Used in this Research

Accident can be defined as an unintended event involving fatality, injury, property loss or damage and/or environmental damage (Wang and Trbojevic, 2007).

In this study, ***business environment-based risk*** can be defined as a wider scope of external risks including political risks, economic risks, social risks and natural hazards that directly or indirectly influence the LSOs and their business performances.

Container liner shipping industry can be defined as one consisting of a fleet of containerships that provides a fixed service at regular intervals between ports of call.

Decision-making can be defined as the process of sufficiently reducing uncertainty and doubt about alternatives to allow a reasonable choice to be made from among them (Harris, 1998).

Delay can be defined as the recurrent changes displayed by performance of the service and the cancellation of previous planning by its institutions (Wright, 2008).

Hazard is a physical situation with the potential for human injury, damage to property, damage to the environment or some combination of these (Kumamoto and Henley, 1992).

Knowledge can be defined as judgements about the general tendency of things to happen; ***evidence*** signifies the impact of that which actually occurred, while ***belief*** combines these two terms; it consists of an assertion about a specific situation inferred by applying generic knowledge to a set of evidence sentences (Aleliunas, 1988).

In this study, ***liner shipping operator*** can be defined as a shipping organisation or company that provides containerised shipping line services. A number of these shipping organisations are called ***liner shipping operators***.

In this study, ***organisational reliability and capability*** can be defined as the performance of the internal reliability and capability factors within a liner shipping organisation that contribute to the service improvement and the effectiveness of these functions in meeting the reliability requirements of shippers.

Probability distribution can be defined as the characteristic of an item expressed by the probability that it will perform a required function under stated conditions for a stated period (Kumamoto and Henley, 1992).

Reliability can be defined either as the probability that a system or a component performs its specified function as intended within a given time horizon and environment, or as the probability of the absence failures affecting the performance of the system over a given time interval and under given environmental conditions (Andrew and Moss, 2002).

Risk can be defined as the potential negative impact that may arise from an adverse situation (Adhitya *et al*., 2009).

Risk assessment can be defined as an estimation of the probability and the degree of the possible consequences in a hazardous situation in order to select appropriate safety measures (Wang and Trbojevic, 2007).

Safety is freedom from unacceptable risk or personal harm (Wang and Trbojevic, 2007).

Security can be defined as freedom from vulnerability, and supply chain ***vulnerability*** can be defined as an exposure to serious disturbances, arising from risks within the supply chain as well as risks external to the supply chain (Chapman *et al*., 2002).

Supply chain risk management can be defined as the identification and management of risk for the supply chain, through a coordinated approach amongst supply chain members to reduce supply chain vulnerability as a whole (Jüttner *et al*., 2003).

Uncertainty can be defined as a situation in which a person does not have appropriate quantitative and qualitative information to describe, prescribe or predict deterministically and numerically a system, its behaviour or other characteristics (Zimmermann, 2000).

In this study, ***vessel punctuality*** can be defined as the ability of a liner vessel to arrive at or to depart from a particular port of call before or at the estimated arrival/departure time.

1.2 Background of the Research

The container liner shipping system is the most efficient way of transporting goods globally. This shipping system, which transports goods using metal shipping containers, was invented by Malcolm P. McLean in 1955. It makes the logistics process simpler and quicker, as one container can be lifted from a truck directly onto a vessel without its contents first being unloaded. This idea is a system of "intermodalism", designed based on efficiency theory in which the same containerised goods can be transported with minimum disturbance on their shipping journey.

It is worth mentioning that global operations of the liner shipping system significantly bring obvious benefits to the global economy. However, there are many unexpected risks in extended journeys around the world. These risks arise from unexpected events that might disrupt the flow of materials on their journey from initial suppliers to final customers (Waters, 2007). Some of the unexpected events which arise from external events are beyond a manager's control. These risks include earthquakes, tsunamis, hurricanes, extreme weather conditions, wars, terrorist attacks, outbreaks of disease, financial risks, crime, financial irregularities, industrial action, diversity of languages, different cultures and a whole host of others (Waters, 2007). Since a containership operates from one port to another across the globe, a disruption by these unexpected events can cause delay, deviation, stoppage or loss of service platform (Gurning, 2011).

Risk and reliability management has become a focal interest in container liner shipping operations. Although the earliest history of risk management in maritime transportation was drawn up by Phoenician traders 3,000 years ago and many companies have been nonchalantly dealing with risk for more than a thousand years, academic interest in this area has only begun recently (Mokhtari, 2011). This risk management can be traced back to only the late 1950s when the formal definition of "corporate risk management" was established and widely acknowledged (Williams *et al*., 1995).

There are two types of risk, which are "pure risk" and "speculative risk" (Mokhtari, 2011). Pure risk can be defined as the uncertainty as to whether loss will occur such as fire, flood or premature death caused by accident or illness, where no positive outcome can be produced by this risk. On the other hand, speculative risk can be defined as uncertainty about an event that could produce either profit or loss, such as a business venture or investment decisions. It is worth mentioning that there is plenty of effort being expended on risk management to avoid pure risk; however, the focus on speculative risk still lacks attention from practitioners and academicians.

Since the beginning of the 21st century, the research path of “corporate risk management” has begun to diverge from concentrating on insurance buying or pure risk avoidance to more strategic and integrated approaches. Two key perceptions have been introduced to facilitate risk management development, which are integrated risk management and strategic management approach. Integrated risk management can be achieved when risk management is integrated into all the functions and processes within the organisation (AIRMIC, 1999). This perception addresses all related risks that an organisation may face such as country risk, business risk, organisational risk, operational risk, *etc*. On the other hand, a strategic management approach seeks to identify and assess the causes and effects of risk and uncertainty on an organisation (Johnson and Scholes, 2002).

Recently, supply chain risk management (SCRM) has gained significant attention from practitioners and researchers (Blome and Schoenherr, 2011; Colicchia and Strozzi, 2012). In the CLSI, SCRM has also become a major concern for LSOs to manage risk and uncertainty in their supply chain. In the literature, there are plenty of ways of categorising sources of risk. These sources of risk can be classified into three categories which are environmental, organisational and network-related (CLSCM, 2003; Jüttner *et al*., 2003). Yet, the current trend exposes the fact that, in the CLSI, there is a lack of understanding of how external or environmental risk can influence the organisational performances of LSOs in the context of reliability, capability and service punctuality.

1.3 Justification for the Research

Today, the CLSI is remarkably acting as an artery in making contributions to the growth of the global economy. At present, a large proportion (i.e. 80%) of world commodities by volume are transported by seaborne trade and more than 62% of this seaborne trade is carried by the CLSI (UNCTAD, 2012). A recent study considering 157 countries over the period 1962-1990 provided empirical evidence that the CLSI is the driver of 20^{th}-century economic globalisation (Bernhofen *et al*., 2013). In addition, in the 22 industrialised countries examined, containerisation explains a 320% rise in bilateral trade over the first five years after adoption and 790% over 20 years (Bernhofen *et al*., 2013). As a result, it is important for stakeholders to ensure the safety and reliability of liner shipping's internal operations as well as its external business environments.

The global economic condition has gradually made positive progress after being greatly affected by the global economic recession in the middle of 2008. However, despite the rapid growth in the global maritime trade and transportation, this maritime activity remains fragile as shipping and port operations are vulnerable to many risks (UNCTAD, 2012). There are various external risks threatening to destabilise the maritime industry recovery and stable world economy. These external risks include political unrest, increases in bunker fuel prices and global financial turmoil. In addition, floods and cyclones striking Australia, multi-disasters of earthquake, tsunami and nuclear crisis in Japan, political unrest in Western Asia and North Africa, and global energy insecurity make shipping companies worse off (UNCTAD, 2012). As a result, the necessity to understand and to assess the external risk and its influence on the organisational performance of LSOs is becoming crucial.

The aforementioned external risk (i.e. called BEBR in this research) has a profound influence on the organisational performances of LSOs. An unhealthy business environment will adversely affect LSOs in the context of operational reliability, knowledge management and financial capability (CLSCM, 2003; Riahi *et al*., 2014). For example, natural disaster events (e.g. earthquake and tsunami) are catastrophic events that possibly cause port destruction and marine crew loss; as a result, natural disaster events will have a direct impact on operational reliability. On the other hand, social risks (e.g. demographic changes) in a country where LSOs operate can influence the labour quality and availability in the market, which may lead to insufficient workers or incompetent workers; ultimately, social risks influence the knowledge management of an LSO.

With the growing complexity in liner shipping operations due to uncertain environments, one of the biggest concerns is the punctuality of containerships. Delay, however, not only reduces the reliability value of the liner shipping operations but also incurs logistic costs to the customer as a consequence of additional inventory costs, and in some cases additional production cost (Notteboom, 2006). Vessels may be delayed due to port congestion, port inefficiency, poor vessel conditions, rough weather, incapability and unreliability of an agency that represents the LSO at each port of call. These uncertainties are some of the reasons that may impede LSOs from providing on-time services to their customers.

From a strategic point of view, it is worth mentioning that there is a research gap in both industry and academia on how to assess the BEBR, and how the BEBR can influence the ORC of an LSO. At the operational level, there is a need for more practical research to find out the determination of the punctuality of a liner vessel under uncertain environments by using an appropriate analysis framework.

1.4 The Research Aim and Objectives

The aim of this research is to develop integrated frameworks for assessing risk and reliability in the CLSI under high uncertainties. Three interlocking levels of analysis have been highlighted in this research: 1) the BEBR, 2) the ORC of LSOs, and 3) the punctuality of a liner vessel.

1st sub-objective: To identify problems and challenges faced by LSOs using a systematic management approach.

2nd sub-objective: To develop an appropriate mathematical model and a decision support framework for identifying and assessing the BEBR in the CLSI.

3rd sub-objective: To propose a new mathematical model and a decision support framework for identifying and evaluating the ORC of an LSO.

4th sub-objective: To investigate the influence of the BEBR on the ORC of an LSO.

5th sub-objective: To analyse the arrival punctuality of a liner vessel to a particular port of call under uncertain environments by using a novel probabilistic reasoning approach.

6th sub-objective: To analyse the departure punctuality of a liner vessel from a particular port of call under uncertain environments by using a novel probabilistic reasoning approach.

7th sub-objective: To demonstrate the practicability of the methodological frameworks and models using a number of real case studies.

1.5 The Structure of the Thesis

The structure of the thesis is laid out in Figure 1.1. There are seven chapters, and each chapter is explained as follows:

1.5.1 Chapter One: Introduction

This chapter has discussed the research background and objectives which have been developed based on an extensive and comprehensive literature review. The justification of the research is highlighted based on the CLSI needs. Also, the outline of the research is elucidated on a chapter-by-chapter basis. Finally, the scope of the research is presented.

1.5.2 Chapter Two: Literature Review

This chapter reviews the significant literature related to the current study. It begins with an overview of the CLSI and the planning levels in the container liner shipping systems. Then, the SCRM and a critical review of the current research are deliberated. Finally, the methodological frameworks and methods that are used in the current research are discussed. The aim of this chapter is to achieve the 1st sub-objective as described in Section 1.4.

1.5.3 Chapter Three: Business Environment-Based Risk Assessment in the Container Liner Shipping Industry by Using a Fuzzy Evidential Reasoning Methodology

This chapter proposes an appropriate mathematical model and a decision support framework for assessing the BEBR in the CLSI. A combination of different decision-making techniques such as AHP, FST and ER (i.e. called FER in this study) is employed. Based on the proposed methodology, LSOs will be able to assess the risk value of a country or a port prior to investment and strategic decisions. In addition, with the help of the proposed methodology, LSOs will be able to regularly assess the overall level of existing BEBR in a host country. The aim of this chapter is to achieve the 2nd and 7th sub-objectives as described in Section 1.4.

1.5.4 Chapter Four: A Proposed Fuzzy Bayesian Belief Network for Evaluating the Value of the Organisational Reliability and Capability of a Liner Shipping Operator

This chapter evaluates the value of ORC of an LSO by considering five main criteria, namely 1) operational reliability, 2) financial capability, 3) knowledge management, 4) compliance with regulations and 5) service quality capability. Furthermore, the influence of the BEBR on the organisational functions is investigated in this study. This chapter employs an FBBN to evaluate the value ORC of an LSO. This method of evaluation is capable of helping LSOs to conduct self-evaluation of their ORC for enhancing business sustainability and competitive advantage in the CLSI. The aim of this chapter is to achieve the 3rd, 4th and 7th sub-objectives as described in Section 1.4.

1.5.5 Chapter Five: Adopting a Fuzzy Rule-Base in the Fuzzy Bayesian Belief Network Model for Analysing and Predicting Vessel Punctuality in Liner Operations: Arrival Punctuality

The major concern in the container liner shipping at operational level is the punctuality of a liner vessel. This chapter analyses the probability of arrival punctuality of a liner vessel at a port of call under uncertain environments, by considering port conditions, vessel conditions, process management efficiency (i.e. agency) and knock-on effects of delays. This study adopts an FRB in the FBBN model. This method is capable of helping LSOs to forecast the arrival punctuality of their vessel prior to its actual arrival at a particular port of call. The aim of this chapter is to achieve the 5th and 7th sub-objectives as described in Section 1.4.

1.5.6 Chapter Six: Adopting a Fuzzy Rule-Base in the Fuzzy Bayesian Belief Network Model for Analysing and Predicting Vessel Punctuality in Liner Operations: Departure Punctuality

Within this chapter, a second aspect of punctuality analysis, which is departure punctuality of a liner vessel, is modelled and analysed. This study makes a full use of the FBBN incorporated with an FRB approach. Accordingly, from the outcomes of this study, LSOs will be able to forecast their departure punctuality and, further, tactical strategies can be implemented if a vessel is expected to be delayed. In addition, the departure punctuality models are capable of helping academic researchers and industrial practitioners to comprehend the influence of uncertain environments on departure punctuality. The aim of this chapter is to achieve the 6th and 7th sub-objectives as described in Section 1.4.

1.5.7 Chapter Seven: Conclusions and Further Research

This chapter concludes the studies that have been conducted in this thesis. The contribution of the research to risk and reliability assessment and decision-making approaches to the CLSI and knowledge is outlined. Furthermore, the research limitations and suggestions for future research which requires more effort to be paid to the enhancement of the developed model are summarised.

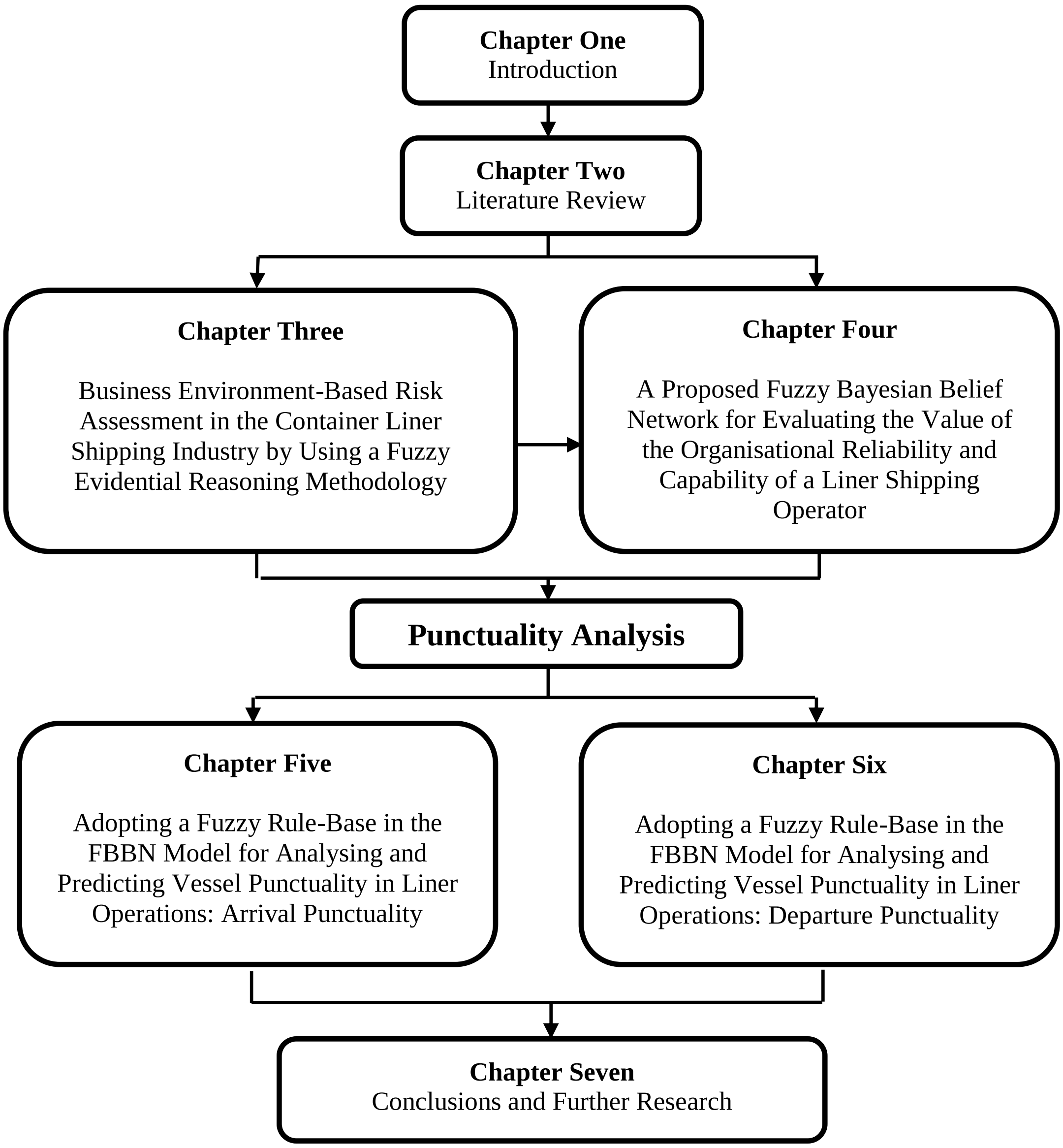

Figure 1.1: The generic structure of the thesis

1.6 Scope of the Research

A brief explanation about the scope of the research in this study is presented in Figure 1.2. In the maritime transportation industry, broadly there are three types of shipping system, which are tramp, industrial and liner. The tramp system, for example, bulk cargo ships, is not operated on a fixed sailing schedule, but merely trades in all ports of the world. Industrial ships such as oil tankers and gas tankers are designed to carry a particular commodity. Liner shipping refers to a vessel that operates on a regular scheduled service between groups of ports. Many types of vessels operate under the liner shipping system, such as ferries, vehicle carriers and containerships. In this research, the specific CLSI, which only provides containerised shipping services, is considered.

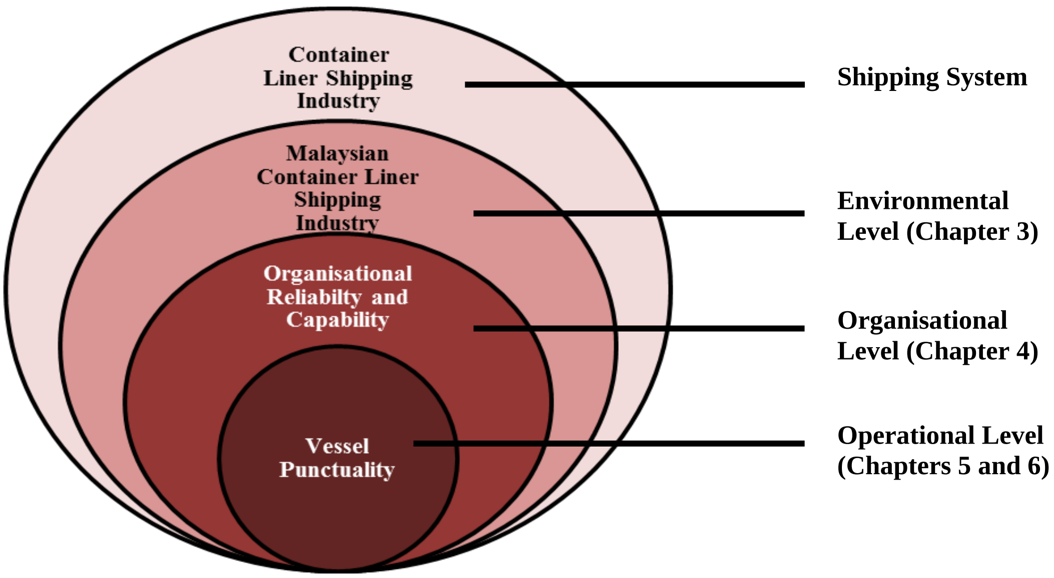

Figure 1.2: The scope of the research study

The CLSI operates across the globe, connecting many countries around its service networks. In order to demonstrate the practicability of the proposed methodologies and models within a specific boundary, the Malaysian CLSI is chosen as the focus of study. The reasons behind the selection of the Malaysian CLSI is because of the remarkable growth of shipping activities in Malaysia, especially the CLSI, which indicates the value of this industry as a core economic activity for the country's outcomes.

The aforementioned three interlocking levels of analysis have been highlighted in this research: 1) the BEBR, 2) the ORC of an LSO, and 3) the punctuality of a liner vessel. *Firstly*, a model of the BEBR is developed and modelled in order to assess the riskiness of the business environment in the country under consideration. The BEBR assessment is focused on the Malaysian CLSI based on the local LSO's judgements. *Secondly*, a model of the ORC is developed and modelled in order to evaluate the performance of internal reliability and capability factors within the LSO's organisation. One Malaysian LSO has been chosen as a test case for this study. *Thirdly*, at the operational level the arrival and departure punctuality models are developed for analysing and predicting the punctuality of a vessel under uncertain environments. Each model is tested by using three real case operations to/from one of the Malaysian ports.

The details of LSOs, vessels and ports involved in these test cases are concealed in order to honour and respect their confidentiality.

1.7 Publications from this Thesis

1. Salleh, N. H. M., Riahi, R., Yang, Z., Wang, J. (2014) Risk Assessment of Liner Shipping from a Business Environment Perspective. *Proc. of the 2nd International Conference on Vulnerability and Risk Analysis and Management and the 6th International Symposium on Uncertainty, Modelling, and Analysis,* pp. 2320-2329. United Kingdom. ISBN: 978-0-7844-1360-9. [Status: **Presented**]
2. Salleh, N. H. M., Riahi, R., Yang, Z., Wang, J. (2014) A Proposed Fuzzy Bayesian Belief Network Model for Evaluating the Knowledge Management Capability of a Liner Shipping Operator. *Proc. of the 11th International Conference on Enterprise Systems, Accounting and Logistics,* pp. 12-24. Greece. ISBN: 978-960-287-146-1. [Status: **Presented**]
3. Salleh, N. H. M., Riahi, R., Yang, Z., Wang, J. (2014) A Proposed Fuzzy Bayesian Belief Network Approach for Assessing the Operational Reliability of a Liner Shipping Operator. *Proc. of the 2nd International Conference on Advances in Economics, Management and Social Study – EMS 2014,* pp. 11-15. Malaysia. ISBN: 978-1-63248-036-1. [Status: **Presented**]
4. Salleh, N. H. M., Riahi, R., Yang, Z., Wang, J. (2015) Business Environment-Based Risk (BEBR) Assessment Model for Container Liner Shipping: A Case of Malaysian Maritime Industry. [Status: **In preparation to be submitted to International Journal of Shipping and Transport Logistics**]
5. Salleh, N. H. M., Riahi, R., Yang, Z., Wang, J. (2015) A Model for Evaluating the Value of the Organisational Reliability and Capability of a Liner Shipping Operator: A Case of Malaysian Liner Shipping Operators. [Status: **In preparation to be submitted to Journal of Maritime Policy & Management**]
6. Salleh, N. H. M., Riahi, R., Yang, Z., Wang, J. (2015) Adopting a Fuzzy Rule-Base in the Fuzzy Bayesian Belief Network Model for Analysing and Predicting the Arrival Punctuality of a Liner Vessel. [Status: **In preparation to be submitted to Journal of Expert Systems with Applications**]
7. Salleh, N. H. M., Riahi, R., Yang, Z., Wang, J. (2015) Adopting a Fuzzy Rule-Base in the Fuzzy Bayesian Belief Network Model for Analysing and Predicting the Departure Punctuality of a Liner Vessel. [Status: **In preparation to be submitted to Journal of Expert Systems with Applications**]

CHAPTER TWO

Literature Review

Summary

In this chapter, the significant literature related to the current study is discussed. This chapter begins with an overview of the CLSI and the planning levels in the container liner shipping system. Then, SCRM and a critical review of the current research are deliberated. Finally, the methodological frameworks and methods that are used in the current research are discussed.

2.1 Introduction

Container liner shipping offers a number of benefits that can be listed as efficiency of the system and low environmental pollution impact (WSC, 2012). A single large containership can be operated by only about 13 crew members assisted by modern computerised systems. These computerised systems are highly cutting-edge, helping a shipmaster to navigate a vessel by offering precise routing, and loading and unloading of thousands of containers for every voyage. In a single year, an individual large vessel can carry over 200,000 containers around the world. Therefore, it is worth mentioning that the container liner shipping system provides greater efficiency than any other transportation network.

In the new era of globalisation, SCRM has become a central issue for the maritime transportation system. It is difficult to ignore that supply chains are increasingly exposed to many risks, and it is worth mentioning that the extreme risk to a business's sustainability lies along the wider supply chain rather than within the company itself (CLSCM, 2003). Despite the increasing awareness of managing supply chain risk among practitioners, the concepts of supply chain vulnerability and SCRM are still in their infancy. Although many organisations have already managed risk, they have often overlooked the critical exposures along their supply chains (Jüttner *et al.*, 2003). In the context of the maritime transportation system, it is worth mentioning that LSOs are still in the early stages of SCRM development in their strategic management. This immaturity in the development of SCRM has motivated the current study to develop integrated frameworks for assessing risk and reliability in the container supply chain.

2.2 The Overview of the CLSI

2.2.1 The Definition of Container Liner Shipping

In the maritime transportation system, there are several interpretations of the term ‘liner’. Branch (2007, page 51) defined liner shipping as an “activity of vessels that ply on a regular scheduled service between groups of ports”. IHS Global Insight (2009, page 4) interpreted a liner system as “the part of a maritime industry that includes all operations and related infrastructures involved in scheduled ocean-borne shipping”. In addition, WSC (2012) stated that liner shipping is “a service of transporting goods by means of high-capacity, ocean-going ships that transit regular routes on fixed schedules”. Also, Qi and Song (2012, page 864) claimed that liner shipping has a unique characteristic: “the ships are usually deployed on a closed route with weekly frequency following a published schedule of sailings with a fixed port rotation, and laden/empty containers are loaded on/off the ships at each port-of-call”. Other definitions can be found in Table 2.1. It is worth mentioning that the definition of liner shipping does not describe the size or speed of a liner vessel but its system, which sails based on scheduled services, regardless of whether slots are fully utilised or not (Branch, 2007).

Table 2.1: Definition of liner shipping

Authors	Definition of Liner Shipping
Ting and Tzeng (2003, page 765)	Provides regular services between specified ports according to timetables advertised in advance.
Stopford (2009, page 512)	A fleet of ships with a common ownership or management, which provide a fixed service at regular intervals, between named ports, offer transport of any goods in the catchment area served by those ports and ready for transit by their sailing dates.
Kjeldsen (2011, page ix)	Ships that operate on a published schedule that affects the demand for their services and where each cargo only constitutes a small part of the ship capacity.

Along with the established definition of liner shipping in the literature, the type of vessel that operates based on the liner shipping system has also been described. This type of system means that a particular liner vessel has to perform its operation based on fixed timetables and provide regular services between ports of call. These liner vessels are primarily in the form of containerships, roll-on/roll-off (Ro-Ro) vessels and vehicle carriers. The containership fleet that is exclusively deployed in liner shipping constituted 12.8% of the world fleet’s total deadweight tonnage in 2013 (UNCTAD, 2014). Containerships commonly transport manufactured goods such as electric and electronic goods, furniture, refrigerated goods, *etc.*, while vehicle carriers are exclusively designed to carry vehicles such as cars, trucks and buses. However, there are types of liner vessel that can transport both containers and vehicles. With the advanced technology of cranes and sophisticated cargo planning systems, a single vessel can be loaded with many different types of goods.

For the purpose of this study, the operation of container liner shipping is chosen as a focus of study. As a result, the services of Ro-Ro and vehicle carrier will be not considered in this study. However, the features and characteristics of Ro-Ro and car carrier still will be explained, as these vessels implement an identical function in the liner shipping system.

2.2.2 The Concept of Container and Containership in Liner Shipping

The aforementioned liner shipping system consists of three main types of vessel, which are containership, Ro-Ro and vehicle carrier. Every vessel is specially designed to carry particular cargos. Containership is designed exclusively for the carriage of containers while Ro-Ro is a multi-deck vessel in which the holds are accessed by ramps in the bow, stern or side; it is designed primarily to carry automobiles such as cars, trucks, semi-trailer trucks and trailers (Stopford, 2009). Vehicle carriers play a similar role to Ro-Ros that are designed to carry vehicles on deep-sea routes. Since the focus of the shipping system in this study is container liner shipping, the importance of containership(s) and container(s) will be highlighted in more detail, instead of Ro-Ro, vehicle carrier and other shipping systems.

A container is a receptacle designed to transport cargo of many types in continuous transportation. The container is often called a ‘box’ in the industry and can be measured in length (e.g. 20 feet, 40 feet and 45 feet). There are many types of container, which can be listed as dry storage, flat rack, open top, refrigerated, tunnel, open side storage, double doors, thermal or insulated, cargo storage roll, liquid or gas tanks, car carriers, half height, intermediate bulk shift, drum, special purpose and swap bodies. Each of these containers is designed based on cargo characteristics. Still, containers are usually both faster and cheaper to load and unload than general cargo.

2.2.3 Trade Routes of Container Liner Shipping

Globalisation has led to the evolution of a system of multimodal transport which provides fast and cheap access to almost every corner of the globe and consists of roads, railways, inland waterways, sea-borne and airfreight services (Stopford, 2009). This multimodal system can be classified into three zones: inter-regional shipping, short-sea shipping and inland transport. Inter-regional shipping covers international shipping; short-sea shipping involves coastal shipping operations by feeder ship and ferry; while the inland transport sector encompasses road and rail modes using lorry/truck and train as the main modes of transport. In order to cater for the concept of economies of scale, a large-size ship is built to serve inter-regional trades between continents or regions whereas a smaller ship is deployed to serve in short-sea shipping or coastal routes.

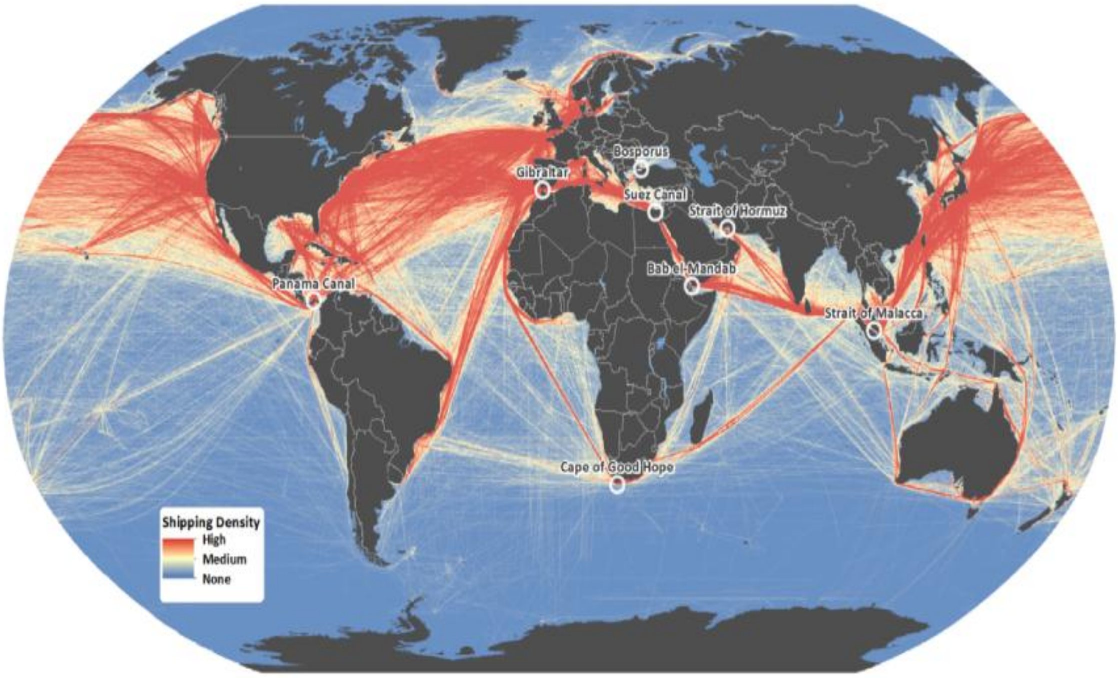

Figure 2.1: Maritime shipping routes and strategic passages
Source: The Geography of Transport System (ND)

Figure 2.1 shows maritime routes and passages for seaborne and coastal shipping. The red lines show a high density of shipping activity, while the yellow lines display medium density. There are six main containerised trade routes: Intraregional & South-South, North-South, Trans-Pacific, Far East-Europe, Secondary East-West and Transatlantic (UNCTAD, 2014). Three major routes connecting the manufacturing centres of the world and the major consumption markets are Trans-Pacific, Asia-Europe and Transatlantic (UNCTAD, 2014).

In 2013, global containerised trade grew by 4.6% and accounted for 160 million twenty-foot equivalent units (TEUs), up from 153 million TEUs in 2012 (UNCTAD, 2014). Together, in 2013, intraregional routes led by intra-Asian trade and South-South trade accounted for 39.8% of global containerised trade, followed by North-South trade (17%), the Trans-Pacific (13.6 %), Far East-Europe (13.1%), Secondary East-West (12.6%) and Transatlantic (3.9%).

2.2.4 Container Liner Shipping Structure and Connectivity

In 2014, 5,981 vessels were actively deployed on liner trades, representing 18,746,069 TEUs and 236,860,429 total deadweight tonnage including 5036 fully cellular vessels for 18,291,347 TEUs (Alphaliner, 2014). The largest LSO in terms of container carrying capacity (i.e. TEUs) in 2014 is Maersk Line (Denmark), followed by the MSC (Switzerland) and CMA CGM (France). In 2014, it was estimated that about 60% of the orderbook of new vessels was the "leased" form or so-called "charter owners", while the remaining 40% were directly ordered by the LSOs (UNCTAD, 2014).

UNCTADs Liner Shipping Connectivity Index (LSCI) has provided an indicator of each maritime nation's access to the global liner shipping network on a yearly basis. This LSCI is produced based on five elements that capture the deployment of containerships by LSOs to a country's port of call, which are: the number of ships; total container carrying capacity; the number of operators providing services with their own operated ships; the number of services provided; and the size (i.e. TEU) of the largest vessel deployed (UNCTAD, 2014). Based on UNCTAD (2014), the country with the highest LSCI is China, followed by Hong Kong, Singapore, South Korea and Malaysia. Morocco, Egypt and South Africa are the three best-connected countries on the African continent, reflecting their strategic location at the corners of the continent. Panama has become the country with the highest LSCI in Latin America, benefiting from its canal and location at the crossroads of the main East-West and North-South routes.

2.2.5 Container Liner Shipping Operations

The container supply chain has two main characters, which are nodes and links (Gurning, 2011). The nodes are physical entities where container movement is interrupted and/or containers are handled (e.g. ports, consolidation centres, shipper's premises and buyer's premises). The links between nodes are characterised by mode of transport (i.e. road, rail and waterway). These links can be represented by vessels, trucks, trains, *etc*. In this study, the operation scope of the container supply chain is limited to the port-to-port operations.

Container liner shipping operates between ports of call based on networked services (Christiansen *et al*., 2007). Figure 2.2 shows a simple container liner shipping network (CLSN) where a number of vessels (i.e. $VESSEL_1, VESSEL_2$ and $VESSEL_n$) sail around the network from $PORT_1$ to $PORT_n$ and turn back to $PORT_1$ to make a completed round trip. Strategically, the integrity of the CLSN depends on the vessel reliability, the reliability and capability of an agency that represents the LSO at each port of call, and the integration between inland carriers (i.e. trucks) and the external environment (i.e. country where the port, agency and inland carrier are located).

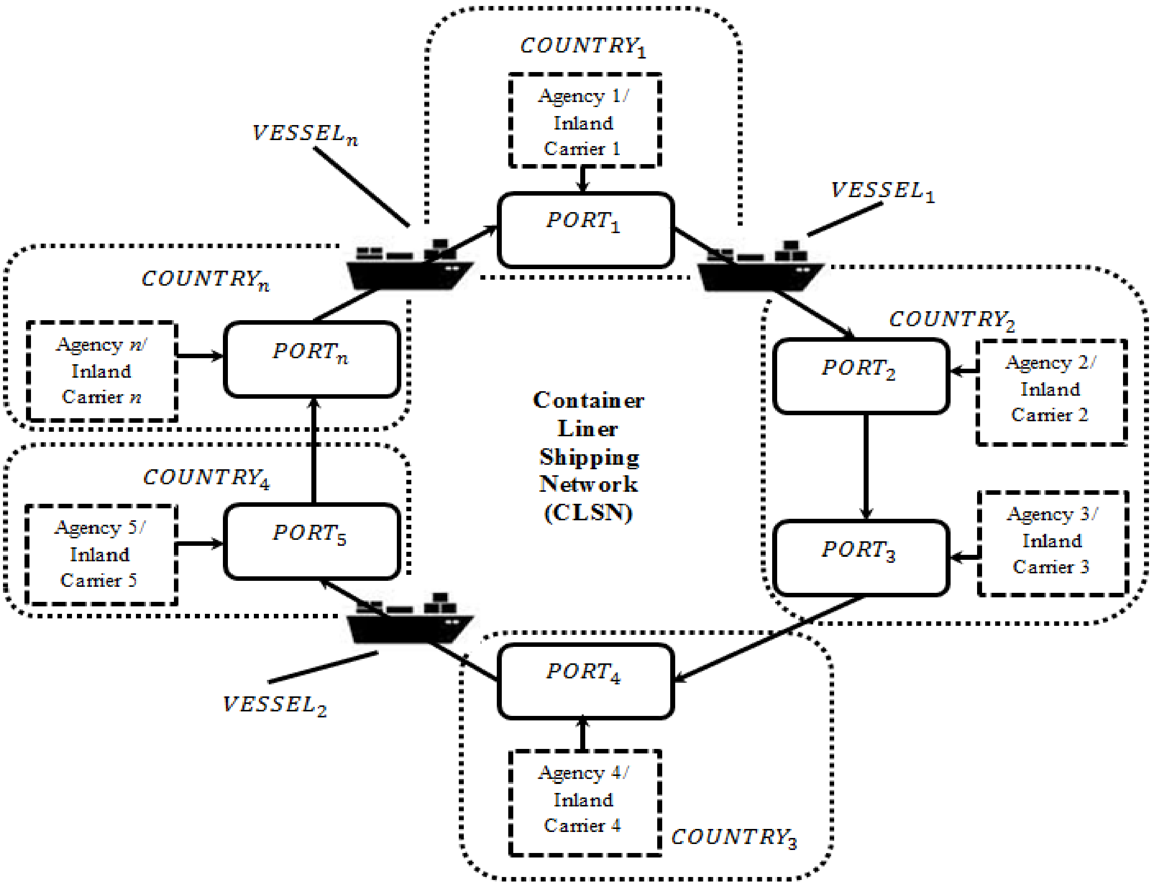

Figure 2.2: Container liner shipping network
Source: Self-study

2.3 Planning Levels and Terminology of Liner Shipping

In container liner shipping, there are three stages of planning levels, which can be listed as strategic, tactical and operational (Christiansen *et al.*, 2007). Each of these planning stages consists of various specific problems, and a hierarchical interrelation exists between stage levels. In addition, the terms of decisions in each stage are different, ranging from a few hours to 10 years.

2.3.1 Strategic Planning Level

Strategic planning is concerned with a broad spectrum of problems extending from setting up liner services to engaging in contracts with allies. These strategic decisions are long-term decisions that need to be implemented for five to 10 years. Moreover, strategic decisions set the framework for tactical planning and guidelines for operational planning.

Due to the length of the time horizon and the volatility of the CLSI, knowledge about the future is limited and associated with a high degree of uncertainty (Kjeldsen, 2011). There are a number of issues that need to be solved at this level, which can be listed as follows: (Christiansen *et al.*, 2007):

- *Service market selection*. Before a decision can be made, the LSO has to consider a number of factors such as market size, competition level, attainable market share, required market share, growth rate of the market, trade volumes in the market and forecasted profit and cost.
- *Networking and transportation design*. These issues are concerned with the container movements along the network, geographical characteristics, network connectivity and transhipment of intermodal services. In addition, the interchange points of container movements between the different trade routes also need to be determined.
- *Fleet size and mix decisions* (e.g. type, size and vessel numbers). These issues are concerned with the expansion of the fleet by buying or chartering vessels or, conversely, to charter out/sell owned vessel(s) to reduce the size of the fleet.
- *Port characteristics*. This issue is concerned with the selection of candidate calling ports by considering a number of factors such as port dues, pilotage, container handling performance, navigation safety and hinterland accessibility.
- *Ship characteristics and design*. In order to match the demand of an associated trade route, the LSO needs to deploy an optimal ship on the particular route. In addition, geophysical parameters also have to be considered, which mainly refers to draft restrictions in ports and entry channels which will determine the design of the ship.

2.3.2 Tactical Planning Level

Tactical planning is a level of planning that concentrates on medium-term decisions, which in liner shipping can be extended from two months up to one year. Due to the time horizon being shorter than for the strategic planning level, the information required for making tactical planning and decisions is reliable and available. The focus of this level in liner shipping is ship routing, ship scheduling and fleet deployment (Christiansen *et al*., 2007; Andersen, 2010). Therefore, most of the decision criteria are dedicated to planning for ship routing, scheduling and fleet deployment. This planning level can be divided into several criteria, which can be listed as follows (Christiansen *et al*., 2007):

- *Adjustments to fleet size and mix*. Although fleet size and mix is planned at the strategic planning level, these decisions also require tactical information. Frameworks applied for fleet size and mix decisions usually necessitate an evaluation of ship routing strategies. It is noteworthy to mention that there is a significant overlap between strategic and tactical/operational decisions.
- *Fleet deployment.* This problem is concerned with the assignment of vessels to established routes or lines. After the routes have been predefined, each one will be sailed by one or more vessels in a varied frequency during the planning horizon. Therefore, fleet deployment planning aims to utilise the different cruising speeds of the vessels in the fleet.
- *Ship routing and scheduling.* These issues are concerned with the sequencing of port calls to be made by the available ships and fixing the time of each port call for all ships involved.
- *Berth window scheduling* aims to achieve the time slot agreed with the terminal at which the ship will be able to berth.
- *Crane scheduling* refers to the determination of the appropriate crane capacity in order to achieve the desirable crane productivity.
- *Cargo management* consists of achieving an optimum container fleet size, storage yard efficiency and productivity of the terminal operators and allocation, and efficient distribution and movement of the empty containers.
- *Container stowage planning* aims to minimise the number of container shifting operations. However, container stowage is very complex, and no optimal solutions have been found, nor is there any agreement on the components of the objective functions.
- *Ship management* involves crew manning and scheduling, maintenance scheduling, positioning of spare parts and bunkering.

2.3.3 Operational Planning Level

Operational planning level is based on a short-term period that can be extended from a few hours to a few months (Kjeldsen, 2011). The information as a source of decision-making at this stage is reliable and easy to obtain due the shorter time horizon. Liner shipping consists of high uncertainty in its operation and often changes dynamically depending on different situations. As a result, short-term review at this stage is necessary. Operational planning usually depends on the decisions made at the strategic and tactical stages. It focuses on a particular cargo, country, ship and port. The operational problem mainly involves steaming speed selection, ship loading, environmental routing and disruption management.

LSOs can operate a vessel at optimum speed in order to reduce costs, especially during a recession. There are four different speeds in liner shipping operation, which are full steaming, slow steaming, extra slow steaming, and super slow steaming (Bonney and Leach, 2010). Full steaming speed ranges from 23 to 25 knots, slow steaming from 20 to 22 knots, extra slow steaming from 17 to 19 knots, and super slow steaming from 14 to 16 knots. These four types of speed represent a different amount of fuel consumption. Although a vessel is designed to operate at its maximum speed, a lower speed is significantly beneficial in terms of operational costs. As a result, LSOs need to set the vessel speed carefully, depending on the demand and fuel price.

Ship loading is an important operation in operational planning as this process can affect the vessel and container safety (Christiansen *et al.*, 2007). Containers must be loaded on a vessel in a safe manner in order to avoid any loss of cargo or to the vessel. When the vessel is partially loaded, vessel stability problems arise due to an imbalance of weight. As a result, container planners must plan properly during container distribution on a ship.

Since container liner shipping operates across the globe, their operation is exposed to a variety of environmental conditions such as currents, tides, waves and winds. LSOs should select the most environmentally friendly route which has the minimum negative effect on the vessel or takes advantage of the environmental conditions. Proper route selection ensures that the ship arrives at ports of call on-time and shortens the time taken. Another type of operation problem is disruption management; the purpose is to solve a problem when disruptions occur and get the ship back on schedule.

Disruptions in the container liner shipping operations can be listed in four levels: delay, deviation, stoppage and loss of platform service (Gurning, 2011). With the new era of unprecedented changes, the operations have become extremely complex and vulnerable to many risks. There are many elements that can cause disruptions in the operations such as bad weather conditions, and political, economic and social factors. These elements strategically influence the performance of container liner shipping.

2.4 Supply Chain Risk Management (SCRM)

Jüttner *et al*. (2003, page 201) defined SCRM as "the identification and management of risks for the supply chain, through a coordinated approach amongst supply chain members to reduce supply chain vulnerability as a whole". They also defined supply chain risk as the variation in the distribution of possible supply chain outcomes, their likelihood and their subjective values. The terms 'risk' and 'uncertainty' are repeatedly used interchangeably even though they are not the same. The distinction between risk and uncertainty is that risk can be measured while uncertainty cannot be measured, and the probabilities of the possible consequences are not known (Knight, 1921). However, this distinction has been queried, and many scholars have already started to develop models for measuring uncertainty.

The past decade has seen the rapid development and transmission of SCRM in many subjects such as general concept of supply chain and perspectives, stock price performances, multinational network, operational flexibility, manufacturing and shareholder wealth (Kogut and Kulatikata, 1994; Huchzermeier and Cohen, 1996; Hendricks and Singhal, 2003, 2005; Kleindorfer and Saad, 2005; Tang, 2006; Craighead *et al.*, 2007; Trkman and McCormack, 2009). The evolution of SCRM literature began in 1994 when the first two articles by Kogut and Kulatikata (1994) and Huchzermeier and Cohen (1996) discovered the field of risk in a supply chain context from the perspective of flexibility (Colicchia and Strozzi, 2012). Later, a considerable amount of literature related to SCRM was published in several main journals (e.g. International Journal of Production Economics, Journal of Operations Management, European Journal of Operational Research, Supply Chain Management: An International Journal, Production and Operations Management, Journal of the Operational Research Society and Management Science). It can be seen that the development of the theory of SCRM has been influenced by the evolution characterising the business environment (Colicchia and Strozzi, 2012).

2.4.1 Sources of Supply Chain Risk

Several studies have focused on clarifying the concept of SCRM and identifying an agenda for current research, such as CLSCM (2003), Jüttner *et al.* (2003), Ritchie and Brindley (2007), Trkman and McCormack (2009) and Colicchia and Strozzi (2012). CLSCM (2003) argued that, in order to improve supply chain resilience, the supply chain vulnerabilities can be instigated from several different levels, and they are inextricably linked. There are four interlocking levels of analysis, which can be listed as follows (CLSCM, 2003):

- *Level 1 - Process/value of a stream*. This level examines supply chain vulnerability from the prevailing engineering-based process perspective, seeing the supply chain as a linear 'pipeline' flowing through and between organisations in the network.

The emphasis is firmly on the efficient, value-based management of individual workflows and their accompanying information (i.e. usually by product, *etc*.).

- *Level 2 – Assets and infrastructure dependencies.* This level represents supply chains in terms of asset and infrastructure dependencies (e.g. factories, distribution centres, retail outlets, trucks, trains, vessels, planes, *etc*.).
- *Level 3 – Organisations and inter-organisational networks*. This level views supply chains as inter-organisational networks. The focus is on the organisation (e.g. reliability and capability performances) that owns or manages the assets and infrastructure in the supply chain networks.
- *Level 4 – The environment.* This level focuses on the wider macroeconomic and natural environment within which organisations do business, assets and infrastructure are positioned, supply chains pass and value streams flow. Factors for consideration are the political, economic, social and technological elements of the operating and trading environment, as well as natural phenomena – geological, meteorological and pathological.

Additionally, Jüttner *et al*. (2003) suggested that supply chain risk sources can be categorised into three groups, which can be listed as follows:

- *Environmental risk*. These sources comprise any uncertainties arising from the interaction between supply chain and environment. These may be the result of socio-political actions (e.g. fuel protests or terrorist attacks) or acts of God (e.g. extreme weather or earthquakes).
- *Organisational risk*. These sources lie within the boundaries of the supply chain parties and range from labour (e.g. strikes), production uncertainties (e.g. machine failure) to IT-system uncertainties.
- *Network-related risk.* These sources arise from interactions between organisations within the supply chain. Whatever damage is caused by suboptimal interaction between the organisations along the supply chain is attributable to network-related risk sources. In this regard, environmental and organisational risks are sources of the various links in the supply chain.

Later, Trkman and McCormack (2009) proposed a preliminary research concept regarding a new approach to the identification and prediction of supply risk, based on suppliers' characteristics and performances, and the environment of the industry in which they operate. They highlighted that the major challenges posed to supply chains are due to a turbulent environment. Therefore, they argued that the earlier research often neglects an important division of risks, namely the origin of risks that can either be within a chain or from the outside environment. In order to distinguish between the different kinds of risks, the sources of uncertainty need to be separated into two different constructs:

- *Endogenous uncertainty*. This source of uncertainty/risk is inside the supply chain and can lead to changing relationships between focal firm and suppliers.
- *Exogenous uncertainty*. This source of uncertainty/risk is from outside the supply chain.

2.4.2 Existing SCRM Frameworks

Managing supply chain risk is a complex process. There are several existing frameworks for directing SCRM, such as in Jüttner *et al*. (2003) and Ritchie and Brindley (2007). Jüttner *et al*. (2003) constructed four steps for managing supply chain risk, which can be listed as follows:

- Assessing the risk sources for the supply chain.
- Identifying the risk concept of the supply chain by defining the most relevant risk consequences.
- Tracking the risk drivers in the supply chain strategy.
- Mitigating risks in the supply chain.

On the other hand, Ritchie and Brindley (2007) proposed several phases of SCRM framework, which can be listed as follows:

- *Risk and performance: sources, profile and drivers.* This phase clarifies the factors from several sources (i.e. environment characteristics, industry characteristics, supply chain configuration, supply chain members and organisation's strategy), individually or in a combination, and determines the risk and performance profile for the organisation at that point in time and for that particular decision or set of decisions.
- *Risk and performance consequences*. This phase identifies, assesses, prioritises and evaluates the sources, and drivers that will yield an assessment of the risk and performance consequences for the organisation. This process will comprise some statements relating to the financial and non-financial performance outcomes together with a risk profile.

- *Risk management response*. This phase develops a response for possible risk consequences such as risk insurance, information sharing, relationship development, agreed performance standards, regular joint reviews, joint training and development programme, joint proactive assessment and planning exercise, development risk management awareness and skills, joint strategies and relationship marketing initiatives.
- *Risk and performance outcomes*. This phase is the *ex-ante* perspective of the risk management decision-makers, which is important in determining their assessment of the risk drivers and their responsiveness in terms of risk management solutions such as assurance on future employment for employees, security assurance on lending for lenders, return on share capital for shareholders and assurance on payment for suppliers.

2.4.3 Existing SCRM Studies in the Maritime Transportation System

In recent years, several attempts have been made to apply SCRM in the maritime transportation system with the focus on maritime network, container supply chain, multimodal supply chain, port and terminal operations (Barnes and Oloruntoba, 2005; Yang *et al*., 2005; Bichou, 2008; Yang *et al*., 2010; Gurning, 2011; Yang, 2011; Mokhtari *et al.*, 2012; Vilko and Hallikas, 2012; John *et al.*, 2014; Loh and Thai, 2014; Riahi *et al*., 2014). A summary of these studies is presented in Table 2.2.

Barnes and Oloruntoba (2005) explained that the complexity of interaction between ports, maritime operations and supply chain has created vulnerabilities and requires an extensive analysis. Bichou (2008) provided a conceptual explanation on modelling the maritime security assessment across the maritime network. Later, Loh and Thai (2014) proposed a model that can be used as a universal guide in assisting port management in managing port-related disruptions and seeking to reduce the occurrences of port-related supply chain disruption threats. Although these studies have been carried out to provide an assessment model, none of them has provided a mathematical approach in the assessment model.

A number of studies have provided a mathematical approach for assessing risk in the container supply chain. For example, Yang *et al*. (2005) provided a framework for assessing container supply chain-related risk by using a modified Formal Safety Assessment (FSA). This model emphasises the analysis of threats in the container supply chain with a high level of uncertainty from both safety and economic viewpoints. Yang *et al*. (2010) then developed a FER approach for carrying out the security estimation of a vulnerable port system against terrorism attacks. They also developed a Bayesian Network (BN) for identifying vulnerable assets in a port security protection scenario. Gurning (2011) used a Markovian approach in analysing maritime disruptions. Yang (2011) proposed a loss exposure matrix for identifying the security risk in Taiwan's maritime supply chain security. Latest, Riahi *et al*. (2014) employed an AHP and BN for evaluating a container's security score. Some other related papers are Mokhtari *et al*. (2012), Vilko and Hallikas (2012) and John *et al*. (2014).

2.5 Critical Reviews for the Current Research

Viewing from the strategic management approach, by integrating the concept of the CLSI, the planning levels of container liner shipping and the concept of SCRM, questions have been raised about risk and uncertainty arising from the external environments (i.e. country-limited scope) and how can these factors influence the ORC of an LSO. Another question concerns how uncertain environments can influence the punctuality of containerships.

By considering the three planning levels as discussed in Section 2.3, it is clear that no level has proposed risk and reliability management in the context of environment and organisation, or even in a general perspective. Therefore, it can be proposed in this study to consider the assessment of the BEBR and the evaluation of ORC at the strategic planning level. In addition, since disruption management (i.e. with the purpose to solve a problem when disruptions occur and get the vessel back on schedule) has been discussed at the operational level, what can be proposed at this level is a mathematical model as a decision support system for analysing and predicting the punctuality of containerships (i.e. arrival and departure) under uncertain environments.

Although extensive research has been carried out on SCRM in the field of container supply chain (i.e. Table 2.2.), far too little attention has been paid to the environmental risk in a country-limited scope. Riahi *et al*. (2014) found that the reliability value of a country is the most significant factor in assessing container security. They considered four sub-elements for evaluation of the reliability value of a country (i.e. geopolitical, socio-political, economic and natural disaster). However, these four elements have not been investigated in depth in previous research due to the generality of the assessment criteria. Therefore, there is a knowledge gap and a novel mathematical model for assessing the value of the BEBR in a country from the CLSI's perspective needs to be developed.

Table 2.2: Summary of the previous SCRM studies in the maritime supply chain

Article's Title	Author	Focus	Methodology	Suggestion/Contribution
Assurance of security in maritime supply chains: Conceptual issues of vulnerability and crisis management	Barnes, P. and Olorubtoba, R. (2005)	Maritime supply chain	- Theoretical Explanation	- There is a need to examine the goodness-of-fit of security initiatives against business efficiency and competitiveness and to consider the training needs for crisis management capabilities.
Reliable container line supply chains - A new risk assessment framework for improving safety performance	Yang, Z. L., Bonsall, S., Wall, A. and Wang, J. (2005)	Container supply chain	- Modified FSA	- This model emphasises the analysis of the threats in the container supply chain with a high level of uncertainty from both safety and economic viewpoints.
Security and risk-based models in shipping and ports: Review and critical analysis	Bichou K. (2008)	Maritime transportation network.	- Conceptual Explanation	- A conceptual piece that draws from the interplay between engineering and supply chain approaches to risk in the context of recent maritime security regulations.
Facilitating uncertainty treatment in the risk assessment of container supply chains	Yang, Z., Bonsall, S. and Wang, J. (2010)	Container supply chain	- FER - BN	- The outcomes of the models can provide decision-makers with a transparent tool to evaluate container supply chain safety and security policy options for a specific scenario in a cost-effective manner.
Maritime disruptions in the Australian-Indonesian wheat supply chain: An analysis of risk assessment and mitigation strategies	Gurning, R. O. S. (2011)	Australian-Indonesian wheat supply chain.	- Markovian Approach	- The results of this study indicate that maritime disruptions are an important issue for academic researchers as a theoretical discipline, and as a practical ground for examining such risk events in a complex supply chain network. - The balance of mitigation, adaptation, and intervention is important for any managers of a wheat supply chain network to understand.
Risk management of Taiwan's maritime supply chain security	Yang, Y-C. (2011)	Maritime supply chain in Taiwan.	- Loss Exposure Matrix	- The leading categories of Container Security Initiatives (CSI) risk factors are operational risk, physical risk and financial risk.

Decision support framework for risk management on sea ports and terminals using fuzzy set theory and evidential reasoning approach	Mokhtari, K., Ren, J., Roberts, C. and Wang, J. (2012)	Port and terminal operations	- FST - FER	- The proposed methodology and model in the form of decision support can be implemented at any specific port during the course of its risk management cycle, auditing and port-to-port risk evaluations.
Risk assessment in multimodal supply chains	Vilko, J. P. P and Hallikas, J. M. (2012)	Multimodal supply chains.	- Monte Carlo-based Simulation	- This paper illustrates the value of a holistic view towards actors in the supply chain attempting to assess the risks. - On the national or regional level it enhances understanding of such risks, their likelihood and consequences, which gives a good basis on which to prepare for and respond to supply chain actors in order to ensure the security of supply.
An integrated fuzzy risk assessment for seaport operations	John, A., Paraskevadakis, D., Bury, A., Yang. Z., Riahi, R. and Wang, J. (2014)	Seaport operations	- ER	- The proposed approach could provide managers and infrastructure analysts with a flexible tool to enhance the resilience of the system in a systematic manner.
Managing port-related supply chain disruptions: A conceptual paper	Loh, H. S. and Thai, V. V. (2014)	Port operation	- Conceptual Explanation	- The proposed model serves as a universal guide in assisting port management in managing port-related disruptions and seeks to reduce the occurrences of port-related supply chain disruption threats.
A proposed decision-making model for evaluating a container's security score	Riahi, R., Li, K., Robertson, I., Jenkinson, I., Bonsall, S. and Wang, J. (2014)	Container supply chain	- AHP - BN	- The proposed methodology can be used for targeting those containers that pose a high risk to the container supply chain.

It is worth mentioning that a mathematical model for assessing the BEBR for the CLSI up to now has not been developed and applied. As a result, firstly, this study will develop a mathematical model for assessing the value of the BEBR in a country from the CLSI's perspective. Secondly, this study will develop a mathematical framework for evaluating the ORC of an LSO. Finally, the arrival and departure punctualities of a liner vessel to/from a particular port of call will be analysed under uncertain environments. In particular, this thesis will investigate five main research aspects, as follows:

1. How can the BEBR in a country be categorised and assessed from the CLSI's perspective? What is a suitable mathematical method for assessing this BEBR?
2. How can the ORC of an LSO be categorised and evaluated? What is a suitable mathematical method for evaluating this ORC of an LSO?
3. How can the BEBR influence the ORC of an LSO from the CLSI's perspective?
4. How can the arrival punctuality of a liner vessel be analysed and predicted under dynamic and uncertain environments? What is a suitable mathematical method for analysing arrival punctuality of a liner vessel under dynamic and uncertain environments?
5. How can the departure punctuality of a liner vessel be analysed and predicted under dynamic and uncertain environments? What is a suitable mathematical method for analysing the departure punctuality of a liner vessel under uncertain environments?

2.5.1 Business Environment-Based Risk in the Container Liner Shipping Industry

The environmental risk comprises any uncertainties arising from the interaction between external environment and supply chain (CLSCM, 2003; Jüttner *et al.*, 2003). These uncertainties may be the result of socio-political actions (e.g. protests or terrorist attacks) or natural disasters (e.g. extreme weather or earthquakes). The environmental risk is likely to be beyond the direct control of supply chain managers. However, the vulnerability of the container supply chain can be assessed in advance, thus enabling informed decisions to be made regarding mitigation strategies (CLSCM, 2003).

There are several different classifications of risk and methodologies, which too often focus on the prediction of disruptive events instead of the root causes of the uncertainties (Trkman and McCormack, 2009). It is believed that disruptive events (e.g. accidents, delay, deviation, operation stoppage, *etc*.) can happen due to increases in the risk level of the root cause, which is driven by external environments. A disruptive event often receives attention from researchers and practitioners while potential risks arising from a turbulent external environment are ignored (Trkman and McCormack, 2009).

The impact of the environmental risk on LSOs along the supply chain stream can be direct or indirect. For example, natural disaster events (e.g. earthquakes, tsunamis, and wars) are catastrophic events that may cause a port's destruction and marine crew loss. As a result, natural disaster events will have a direct impact on the CLSI. On the other hand, social risks (e.g. demographic changes) in a country (i.e. where LSOs operate) that indirectly influence the labour quality and availability in the market may lead to insufficient workers or incompetent workers. Evidence has shown that the environmental effects on the CLSI can be catastrophic and some examples of these effects can be listed as follows:

- A multiple disaster earthquake and tsunami that struck Japan in March 2011 caused catastrophic damage to 15 ports in the northern part of Japan.
- Trade sanctions enacted against Iran in 2012 because of their nuclear programme led to dramatic effects on oil prices and wider consequences for shipping and trade. As a result, LSOs that are trading with Iran will not be insured by the insurance companies.
- Economic recession in 2008-2010 caused a massive loss to LSOs due to unutilised ships and slots.
- Domestic conflict and regime change in Libya in 2011 led to a dramatic plummet in Libyan export trades.

An unhealthy business environment will adversely affect liner shipping performance in the context of operational reliability and financial aspects. In the CLSI, there are many players who are intractably linked with each other such as port operator, liner carrier, agency and inland carrier. As these players operate in an environment which directly and indirectly influences their business performance, they are susceptible and vulnerable to many risk events from environmental risk, which finally impacts their business profitability. Hendricks and Singhal (2005) claimed that there is evidence of negative effects of disruptions associated with increases in financial leverage (i.e. risk that one's investment will depreciate because of disruptions or stock market dynamics causing one to lose money). As a result, selecting the best environment for business is becoming a vital decision among LSOs for overall business performance and safety.

Several risk rating agencies such as Political Risk Services (PRS) Group, Euromoney Country Risks, Eurasia Group, The Legion Group, etc. use different techniques to assess environment risk in the context of country risk. These techniques combine a range of qualitative and quantitative information regarding alternative measures of economic, financial and political risks into associated composite risk ratings (Hoti and McAleer, 2004). However, some of the factors that are considered in the country risk assessment are not related to the CLSI and some of the critical factors for CLSI are not being assessed. In this regard, there is a need for a specific assessment of environmental risk in the CLSI.

In this study, environmental risk is called BEBR, which can be defined as a wider scope of external risks (i.e. political risks, economic risks, social risks and natural hazards) that directly or indirectly influence the CLSI and its overall business performances. A further review on BEBR can be found in Chapter 3.

2.5.2 Organisational Reliability and Capability of a Liner Shipping Operator

Reliability and capability management for organisations have been widely discussed in many disciplines including energy supply, aviation and transportation, military and space, fire and disasters, healthcare, and education (Berman, 1961; Carroll *et al*., 2002; Bellamy *et al*., 2005; Larson *et al.*, 2007; Lee, 2008; Schulman, 2008; Miller and Horsley, 2009; Riley, 2009; O'Neil, 2011). These studies have been primarily discussed under the concept of high-reliability organisations that cover management of hazards, theory of high-reliability organisation, resilience management, and safety culture. According to Forrester Research (2010), high-reliability organisations can be defined as "organisations that can manage and sustain almost error-free performance despite operating in hazardous conditions where the consequences of errors could be catastrophic". Plenty of studies have discussed the theory and characteristics of high-reliability organisations, but only a few of them have published details of how organisations can develop into high-reliability organisations. In addition, most of these studies pay more attention to the manufacturing industry, land transportations and militaries rather than the CLSI (i.e. with a focus on security, safety, physical reliability, manufacturing capability and supply chain capability).

Literature exploring reliability and capability at an organisational level from a viewpoint of the CLSI is still scarce. Since no available study has directly dealt with this issue, this research makes an effort towards providing an evaluation model for ORC of an LSO. In this study, ORC of an LSO can be defined as the performance of the internal reliability and capability factors within a liner shipping organisation. Based on an extensive literature review, five key reliability and capability factors, namely operational reliability, financial capability, knowledge management capability, compliance with regulations and service quality capability, are proposed in the evaluation model (Parasuraman *et al.*, 1988, 1991; Durvasula *et al.*, 1999; Frost *et al*., 2001; Addicott *et al.*, 2006; Trucco *et al*., 2008; Celik *et al*., 2010; Gaonkar *et al*., 2011; Bang *et al.*, 2012; PWC, 2012; Liang *et al*., 2012; Drewry Shipping Consultants, 2013). A further review on the ORC of an LSO can be found in Chapter 4.

2.5.3 Vessel Punctuality under Uncertain Environments

Since container liner shipping operates on a schedule basis, LSOs have to allocate a transit time for vessels on a particular route involving duration of sailing and port stay. Usually, LSOs generate schedules based on demand for containers. Forecasting a future demand for containers is necessary before creating a ship's schedule by considering macroeconomics (e.g. Gross Domestic Product (GDP), consumer confidence, price index and other related information). In addition, to maintain schedule reliability, certain considerations must be made by LSOs including berth availability in the various ports, transit time requirements, frequency of service between main hubs and the level of buffer time (Kjeldsen, 2011).

Despite this careful planning in scheduling, normal operations in liner shipping are often disrupted due to uncertainties and unforeseen events. An unforeseen event refers to an event that rarely happens but has a high adverse impact on the operation (e.g. pirate attack, terrorism, *etc.*). On the other hand, uncertainty relates to an event that is difficult to predict and forecast (Gurning, 2011). Port congestion, bad weather at sea, machinery breakdown, fire, grounding, collision and tidal windows are examples of uncertainty in a liner shipping operation (Kjeldsen, 2011). The consequences of these events could adversely affect schedule reliability and punctuality in the liner shipping operation.

In recent years, many scholars have paid more attention to the schedule reliability of road networks, railways and airlines, rather than container liner shipping operations. There is little discussion about the analysis of schedule reliability in liner shipping services in literature. In the context of liner shipping operations, only a few studies on schedule reliability, such as Notteboom (2006), Vernimmen *et al.* (2007), Wu *et al*. (2009), Gaonkar *et al.* (2011), Chung and Chiang (2011), and Ducruet and Notteboom (2012), are available in the literature. Notteboom (2006) discussed causes of schedule unreliability from the perspective of a shipping line. Later, Vernimmen *et al*. (2007) analysed the impact of schedule unreliability on shippers and consignees. Vernimmen *et al*.'s study also provides the factors causing liner shipping unreliability that can be used in this study. Nevertheless, the studies by Notteboom (2006) and Vernimmen *et al.* (2007) do not provide a mathematical model for analysing and predicting arrival and departure punctuality.

Several attempts have been made to analyse schedule reliability by using a mathematical model, such as Chung and Chiang (2011) and Gaonkar *et al*. (2011). Gaonkar *et al*. (2011) assessed the timeliness of operational reliability in a maritime transportation system by only considering congestion at ports and sea. Nevertheless, these elements are not deeply investigated as their study generally evaluates the criteria without observing the sub-criteria of each element. As a result, the collected data might not be accurate due to the generality of the criteria. On the other hand, Chung and Chiang (2011) developed a model for evaluating the schedule reliability in liner shipping. However, they only assigned a weight for each criterion without assessing the real condition of each element in their model.

It is worth mentioning that most of the available literature is focused on the arrival perspective while schedule reliability is believed to be ultimately dependent on both arrival and departure punctuality. So far, no mathematical model has been developed for analysing the arrival and departure punctuality of liner vessels under uncertain environments; thus, making these attempts is essential for the current research.

2.6 Research Methodological Framework

The aim of this section is to describe how the research was directed in order to achieve the objectives. Based on the extensive literature review and by considering the knowledge gap as discussed in this chapter, the direction of the research is established. This direction is to develop integrated frameworks and models for identifying, assessing and analysing the BEBR, the ORC and punctuality of a liner vessel in the CLSI. However, the process of the research is complex and wrought with complications. Therefore, a systematic approach is to conduct the research in different chapters based on the objective.

Figure 2.3 illustrates an explicit framework for the research. The thesis began with the introduction to the research in Chapter 1 by outlining the background and objectives which have been developed based on the extensive literature review. In this chapter (Chapter 2), an overview of the CLSI, the planning levels in the container liner operations, SCRM and critical review of the current research are elucidated. In Chapter 3, a combination of different decision-making methods such as AHP, FST and ER is employed for the assessment of the BEBR. In Chapter 4, an FBBN method is applied to evaluate the value of

ORC of an LSO. In Chapter 5, an FBBN method incorporated with an FRB is adopted for analysing and predicting the arrival punctuality of a liner vessel to a port of call under uncertain environments. In Chapter 6, the same technique used in Chapter 5 is used (i.e. FBBN and FRB methods) for analysing and predicting the departure punctuality of a liner vessel from a port of call under uncertain environments. The links between the chapters are presented in Figure 2.3.

In this research there are four main methods: AHP, Fuzzy Logic (FL) (i.e. FST and FRB), ER and a BBN, which are employed in different chapters. The backgrounds of these methods are elaborated as follows:

2.6.1 Analytic Hierarchy Process (AHP)

The AHP approach is a theory of measurement through pair-wise comparisons and relies on the judgements of experts to derive priority scales (Saaty, 2008). In the AHP approach, comparisons are made using a set of scales of absolute judgements that represents the relative importance of one element to another element in a given attribute. The fundamental scale has been shown to be one that captures individual preferences with respect to quantitative and qualitative attributes as well as, or better than, other scales (Saaty, 1980; 1994). In addition, the AHP is a well-structured approach for organising and analysing complex decisions (i.e. multiple attributes or multilevel criteria). It has been developed based on precise mathematical structures of consistent matrices and their associated right-eigenvector's ability to generate weights (Merkin, 1979; Saaty, 1980; 1994). Furthermore, if the judgements are inconsistent due to different perceptions and beliefs with regard to criteria or alternatives, the AHP approach is capable of measuring inconsistencies and improving judgements (Saaty, 2008).

The main objective of the AHP approach is to provide judgements on the relative importance of given attributes. The AHP approach also ensures that the judgements are quantified to the extent that permits their quantitative interpretation with respect to given attributes (Pillay and Wang, 2003; Riahi *et al.*, 2012a). There are several advantages of using the AHP approach, which can be listed as follows (Pam, 2010):

- It is capable of analysing both qualitative and quantitative criteria.
- It is capable of taking a large quantity of criteria into consideration.
- It is capable of facilitating the construction of a flexible hierarchy to address decision-making problems.

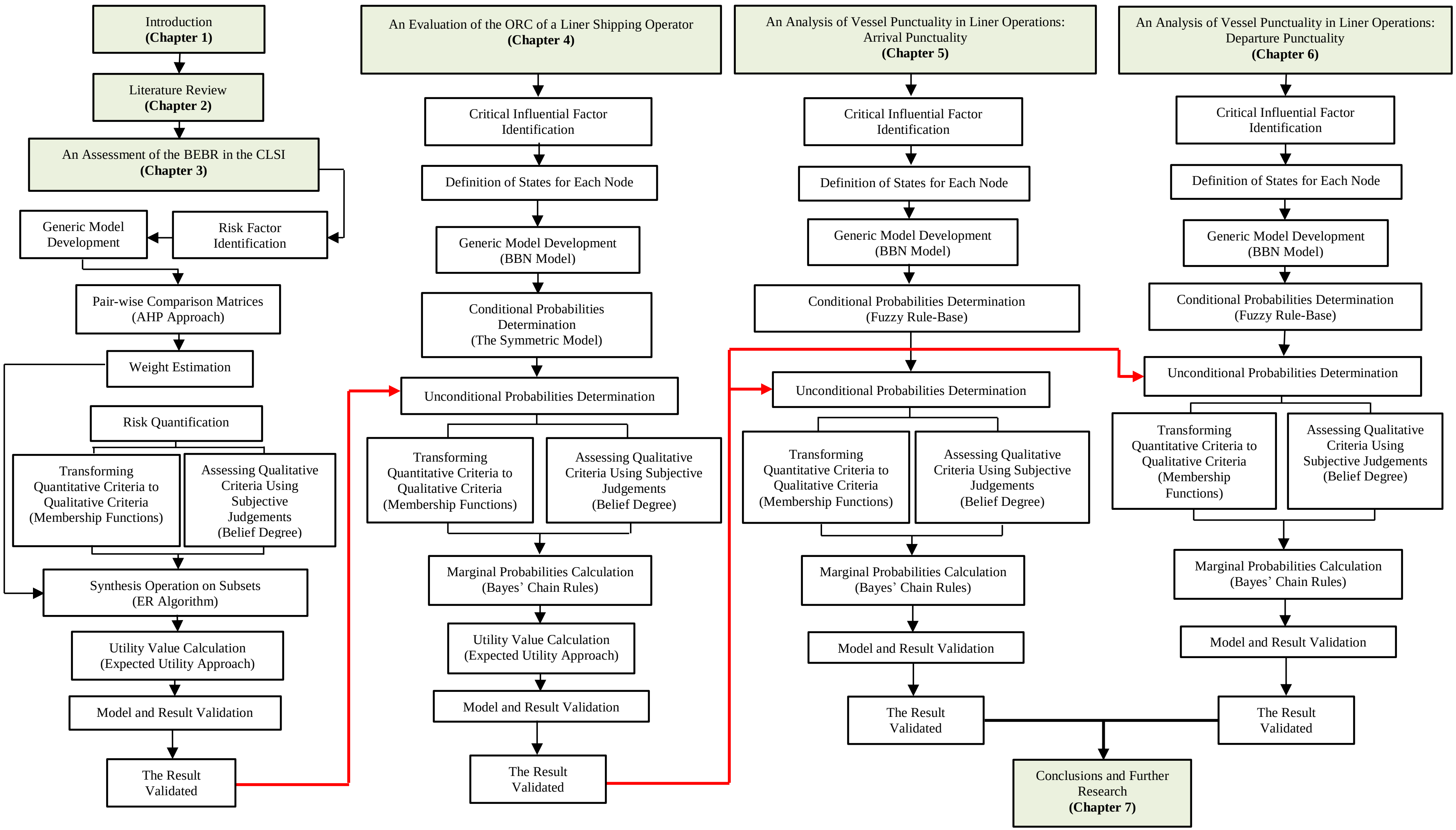

Figure 2.3: Research methodological frameworks

The application of the AHP approach has been widely used in many disciplines including maritime studies. Several studies have applied the AHP approach in maritime and supply chain studies, which can be listed as follows:

- Wu *et al*. (2006) reinforced inbound SCRM by suggesting an integrated methodology to classify, manage and assess inbound supply risks. They applied the AHP to rank risk factors for suppliers in the supply chain.
- Chung and Chiang (2011) combined the AHP and fuzzy theory to evaluate critical factors in determining schedule reliability in liner shipping.
- Mokhtari *et al.* (2012) used the AHP to find relative weights for the operational risks factors in seaports and terminals.
- Riahi *et al.* (2012a; 2012b) developed an AHP model to calculate the relative importance of seafarers' reliability criteria.

2.6.2 Fuzzy Logic (FL)

Fuzzy sets were initiated by Lukasiewicz in the 1920s as he studied the mathematical calculation of fuzzy terms such as hot, tall and old (Tah and Carr, 2000). These fuzzy sets expanded on the traditional fuzzy developed by Aristotelian logic in the two-valued judgement such as true or false. Lukasiewicz developed the fuzzy sets system, which is able to denote a range of truth values covering all real numbers from 0 to 1, which formed the basis of the inexact reasoning technique named possibility theory (Tah and Carr, 2000).

In 1965, Zadeh extended the work on possibility theory into mathematical logic, which is called FL. FL is primarily concerned with dealing with uncertainty and imprecise information from human judgement (Zadeh, 1965, 1968). FL is an extension of Boolean Logic, and it accounts for imprecise information (Riahi, 2010). In general, FL is a multivalued logic that allows vague information, knowledge and concepts to be interpreted in a numerical manner. In addition, FL is capable of modelling the imprecise modes of reasoning that play a significant role in enhancing the human ability to make rational decisions in an environment of imprecision and uncertainty (Zadeh, 1988).

The difference between the traditional set theory and FST lies in the degree of membership that elements may possess in a set (Tah and Carr, 2000). In traditional set theory, the membership values are defined as 1 or 0, which states that the element is either a member of a set or not. In contrast, in FST, a membership value can be defined as any real value from 0 to 1. For instance, the traditional set theory is unable to answer the question 'Mike is taller than most of his friends. How tall is Mike?' In contrast, FL shows the ability to deal with this uncertainty. Firstly, FL describes the meaning of a lexically imprecise proposition as being represented as an elastic constraint on a variable; and secondly, the answer to a query is deduced through a propagation of elastic constraints (Zadeh, 1988). With FL, it allows use of fuzzy quantifiers; for instance, answers to the question 'How tall is Mike?' can be illustrated by "extremely tall", "very tall", "tall", "slightly tall", and "more or less tall" and so on. Thus, the application of FST in risk evaluation can be defined in vague linguistic terms such as "very low risk", "low risk", "medium risk", "high risk", "very high risk" and so on.

FL has two techniques, which can be listed as FST and FRB. Both of these techniques are used based on the particular situation, as is elaborated as follows:

2.6.2.1 Fuzzy Set Theory (FST)

Zadeh (1965, 1968) proposed the notion of fuzzy sets to model vague judgement and imprecise reasoning in the form of FL. A fuzzy set $\tilde{F}$ is a subset characterised by the set of pairs "$\tilde{F} = \left\{\left(x, \mu\tilde{F}(x)\right), x \epsilon X\right\}$", where $\mu\tilde{F}(x)$ is a degree of membership with possible values ranging over the real interval [0, 1].

A membership function (MF) value of 1 means full representation of the set under consideration (Riahi, 2010). If MF value = 0, it means the value does not belong to the set under consideration. If MF value is between the two limits [0, 1], it indicates the degree of membership to the set under consideration. A fuzzy set $\tilde{F}$ is normalised if there exists one $x,$ such that $\mu\tilde{F}(x) = 1.$ A fuzzy set whose MF only takes on the value of zero or one is called crisp (Riahi, 2010).

One of the primary operations in FST is the Triangular Fuzzy Number (TFN). TFNs are often used in the application of FST because of their computational simplicity, and efficiency in representing and processing information in a fuzzy environment (Ertugrul and Karakasoglu, 2009). The TFN can be defined as three real numbers such as (a_1, a_2, a_3) where a_1 is a smallest possible value, a_2 is a medium possible value and a_3 is a largest possible value that describes a fuzzy event. To illustrate the TFN function, let $\tilde{A}$ = (a_1, a_2, a_3) and $\tilde{B}$ = (b_1, b_2, b_3) be two TFNs, as shown in Figure 2.4. The operational laws of the TFN can be represented as follows (Wang and Chang, 2007):

$$\tilde{A} + \tilde{B} = (a_1, a_2, a_3) + (b_1, b_2, b_3) = (a_1 + b_1, a_2 + b_2, a_3 + b_3)$$

$$\tilde{A} \times \tilde{B} = (a_1, a_2, a_3) \times (b_1, b_2, b_3) = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3)$$

$$\tilde{A} - \tilde{B} = (a_1, a_2, a_3) - (b_1, b_2, b_3) = (a_1 - b_3, a_2 - b_2, a_3 - b_1)$$

$$\tilde{A} \div \tilde{B} = (a_1, a_2, a_3) \div (b_1, b_2, b_3) = \left(\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1}\right)$$

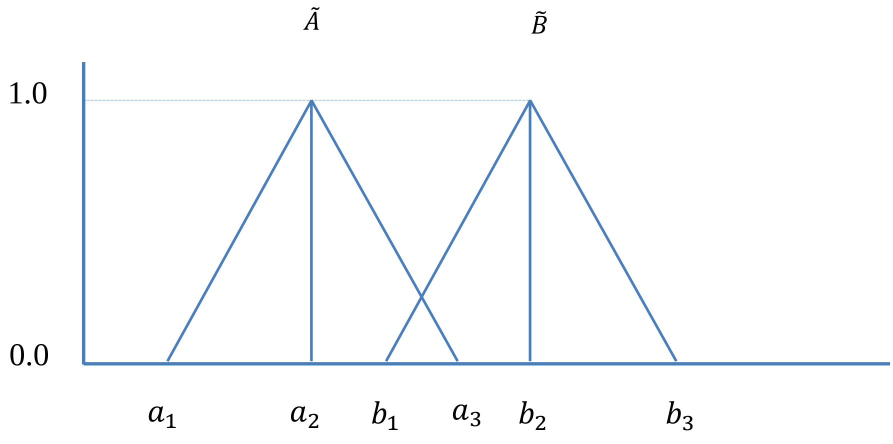

Figure 2.4: A Triangular Fuzzy Number (TFN)

2.6.2.2 Fuzzy Rule-Base (FRB)

The FRB theory is created from human knowledge in the form of fuzzy IF-THEN rules (Sii *et al.*, 2001). The FRB theory is often called IF-THEN rules since they are simply adapted by fuzzy conditional statements. In addition, the FRB theory is also easily formulated in linguistic terms compared to numerical terms. The important contribution of FRB theory is that it is offering simple procedures and intuitively transforming a knowledge base into a non-linear mapping (Sii *et al.*, 2001). With the FRB theory, it allows information to be categorised as a continuous membership function, which is cause and consequence parts (Sii *et al.*, 2001; Riahi, 2010). A simple IF-THEN rule 'if X_1 is A then, Y is B', 'X_1 is A' is called *antecedent* or *premise*, while 'Y is B' is called the *consequent* or *conclusion* (Abraham, 2005; Yang *et al.*, 2009). For example, IF the frequency of tsunami (X_1) is frequent and its severity (X_2) is catastrophic and the impact cost is very high (X_3) THEN the risk level of tsunami (Y) is very high.

The features of the FRB theory in representing knowledge can be characterised as: (1) rules are incremental where new rules can be added with relative ease; (2) rules tend to be modified where old rules can be altered relatively independent from the others; (3) rules are modular where each rule defines a small and relatively independent piece of knowledge;

and (4) rules support system transparency where it facilitates the system to be able to explain its reasoning (Tucker, 1998).

The FRB theory has been widely used in many areas such as system safety, maritime security assessment, maritime finance, *etc*. (Liu *et al*., 2005; Yang *et al*., 2008; Yang *et al*., 2009). This FRB theory has become a popular method especially in risk assessment and decision-making processes as a result of several advantages, which are: (1) each rule can be presented as a unit of knowledge, (2) all the knowledge is expressed in the same format (i.e. uniformity), and (3) the rules have a natural format to express knowledge in a domain (Rahman, 2012).

2.6.2.3 Application of Fuzzy Logic in the Maritime Industry

In recent years, there has been an increasing interest in FL application in fields ranging from social science to engineering. FL is also widely applied in the maritime and offshore industry, ranging from solving decision-making problems to risk assessment issues, which can be listed as follows:

- Sii *et al.* (2001) used FRB to carry out risk analysis of qualitative safety modelling for marine systems.
- Yang *et al.* (2005) combined fuzzy sets and ER approaches to deal with subjective methods for risk analysis in container supply chains.
- Liu *et al.* (2005) applied FRB and ER approaches in analysing the safety of a marine and offshore engineering system.
- Chung and Chiang (2011) analysed and investigated the key influential factors of schedule reliability by using the Fuzzy Analytic Hierarchy Process (FAHP).
- Riahi *et al.* (2012a) carried out a seafarer's reliability assessment incorporating subjective judgements. They used fuzzy sets for the mapping process by transforming a lower-level criterion to an upper-level criterion in the seafarer's reliability model.
- Mokhtari *et al.* (2012) used FST to describe and evaluate the associated risk factors within the port and terminal operations and management.
- Rahman (2012) combined a fuzzy link-based technique, AHP and ER in the decision-making process of selecting the most beneficial shipping business strategy for super slow steaming.

2.6.3 Evidential Reasoning (ER)

The ER approach was initially generated by Dempster in 1967 and further developed and refined by Shafer in 1976; it is referred to as the Dempster-Shafer theory of evidence or D-S theory (Riahi, 2010; Rahman, 2012). Based on the D-S theory, in order to deal with the hybrid multiple criteria decision analysis (MCDA) problems with uncertainties, the ER approach was developed in the 1990s. The ER algorithm was first developed by Yang and Singh (1994), later modified by Yang (2001) and further improved by Yang and Xu (2002). The ER approach has been developed using the concepts from several disciplines, including decision sciences (in particular utility theory), artificial intelligence, statistical analysis, FST and computer technology (Xu and Yang, 2005). The ER approach uses an evidence-based reasoning process to get a conclusion that differs from traditional MCDA methods. Consequently, the ER approach is widely used as a decision-making tool in many different disciplines.

The development of the ER approach has experienced five major stages, which can be listed as follows (Xu and Yang, 2005):

- *First stage:* Introduction of a belief structure into a decision matrix. This introduction provides a novel way to model MCDA problems, in particular quantitative and qualitative criteria with uncertainties. In the ER approach, an MCDA problem is described using a belief decision matrix as compared to a single value of a decision matrix in traditional MCDA methods.
- *Second stage:* Introduction of the D-S theory into the ER approach. As a result, the two-dimensional information contained in the belief decision matrix could be aggregated to produce rational and consistent assessment results.
- *Third stage:* Development of the rule and utility-based information transformation techniques to transform various types of evaluation information to a unified framework. As a result, all criteria of both a qualitative and quantitative nature can be assessed in a consistent and compatible manner in the ER framework.
- *Fourth stage:* Enhancement of the approximate reasoning process of the original ER approach. Significant modifications have been made to the D-S theory since it was first introduced into the ER approach to deal with MCDA problems. In the ER approach, a new reasoning process satisfies the common sense synthesis rules or axioms.
- *Fifth stage:* The implementation of the ER approach by developing a Windows-based software package, the intelligent decision system (IDS). As the ER approach

uses a belief decision matrix with two-dimensional values, the calculation could be more complicated than some traditional methods. With the implementation of the IDS software package, the calculation process can be eased.

The aforementioned ER approach is capable of producing consistent and reliable results for MCDA problems. In addition, it is also capable of dealing with the following features (Xu and Yang, 2005):

- A mixture of quantitative and qualitative information.
- A mixture of deterministic and random information.
- Incomplete (missing) information.
- Vague (fuzzy) information.
- Large numbers (hundreds) of criteria in a hierarchy and alternatives.

Because of the capabilities of the ER approach listed above, it has been widely used in several disciplines such as supplier selection, service quality, reliability assessment, business strategy, maritime studies, engineering, *etc.* In the area of maritime studies, the ER approach has also been addressed in the literature as follows:

- Yang *et al.* (2005) combined fuzzy sets and the ER approach to deal with the subjective method for risk analysis in container supply chains.
- Liu *et al.* (2005) applied the ER approach in analysing the safety of a marine and offshore engineering system.
- Nwaoha *et al.* (2011) investigated the safety/risk level of a liquefied natural gas (LNG) carrier system through the application of an FER method to uncertainty treatment of its failure modes.
- Mokhtari *et al.* (2012) used FST and ER to describe and evaluate the associated risk factors within the port and terminal operations and management.

2.6.4 Bayesian Belief Network (BBN)

A BBN method was first developed by Bayes in 1761; later, Bayes' Theorem was published in 1763 (Bernando and Smith, 1994). Emerging from Bayes' Theorem, a BBN was developed which was later called different terms such as "Bayesian Networks (BNs)", "Belief Networks", "Causal Probabilistic Networks", "Causal Nets", "Graphical Probability Networks" and "Probabilistic Cause-Effect" approaches (Neapolitan, 1990). A BBN modelling is an artificial intelligence tool aimed at providing a decision support framework for problems involving uncertainty, complexity and probabilistic reasoning (Nadkarni and Shenoy, 2001). In addition, a BBN demonstrates the fundamental concept of probabilistic graphical models or probabilistic networks. When BBNs were first applied (during the period 1988-1995), they tended to focus on classical problems, primarily in fault diagnosis and medicine (Fenton and Neil, 2007). Then, the MUNIN BBN (i.e. a BBN application system) was produced and aimed to provide a decision support system for the intended use of medical professionals. Since then, the BBN has become an increasingly popular paradigm for reasoning under uncertainty.

A BBN model is a Directed Acyclic Graph (DAG) consisting of nodes, representing variables with a finite set of states, and arcs, representing the probabilistic causal dependence among the variables (Trucco *et al.*, 2008; Riahi *et al.*, 2012b). As shown in Figure 2.5, *Nodes* (i.e. usually drawn as a circle) represent random variables (i.e. chances) such as events that take values from the given domains, which may in principle be "discrete" or "range" (Wang and Trbojevic, 2007). There are four types of nodes, which are parent, child, root and leaf nodes. As shown in Figure 2.5, nodes with arcs directed into them are called "child" nodes (e.g. X_b), nodes from which the arcs depart are called "parent" nodes (e.g. X_a), nodes without arc directed into them are called "root" nodes (i.e. X_a, X_1) and nodes without children are called "leaf" nodes (i.e. X_b, X_4). *Arcs* are used to represent the direct probabilistic dependence relations among the nodes. The DAG represents the structure of causal dependence between nodes and gives the qualitative part of causal reasoning in a BBN (i.e. unconditional probabilities); thus, the relations between variables and the corresponding states give the quantitative part, consisting of a Conditional Probabilistic Table (CPT). As a result, a BBN structure is constrained to be acyclic.

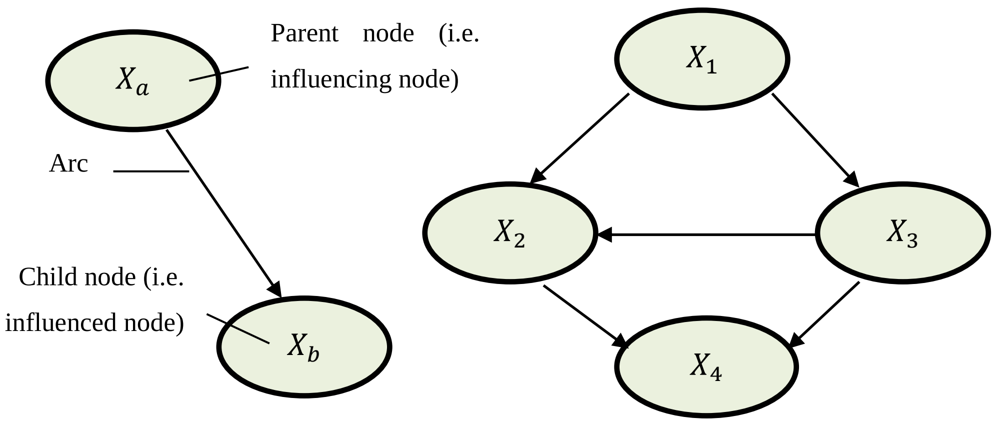

Figure 2.5: Samples of BBNs

The main characteristic of the BBN is to deal with the probability of nodes. Probability can be defined as a way of expressing knowledge of belief that an event will occur or has occurred (Rahman, 2012). The probability distribution is called unconditional probability if a node has no parents, while if a node has a parent it is called conditional probability (Wang and Trbojevic, 2007). Based on Figure 2.5, an example of conditional probability is $P(X_b|X_a)$ and unconditional probability is $P(X_a)$.

A BBN method is expected to produce a valuable result about the reliability assessment under uncertainty (Ullman and Spiegel, 2006). The advantages of the BBN method can be listed as follows (Rahman, 2012):

- The output of the model is easily interpreted.
- The model can be improved continuously with the new data addition.
- It is capable of providing an intuitive visual representation with a sound mathematical calculation.
- It is capable of conducting an assessment incorporating both qualitative and quantitative data, allowing easy understanding of the causality relationship of the parameters.

The application of the BBN method has been widely used in many disciplines including maritime studies. Several studies have applied the BBN method in maritime and supply chain studies, which can be listed as follows:

- Friis-Hansen (2000) introduced the use of BNs and influence diagrams to the maritime industry. He focused on applications for decision support, mainly regarding maintenance planning and risk-related issues.
- Trucco *et al.* (2008) applied BBN to model a Maritime Transport System (MTS), by focusing on a collision in open sea hazard.
- Jones *et al.* (2010) applied BN modelling to a maintenance and inspection department. The primary aim of their study is to establish and model the various parameters responsible for the failure rate of a system by using Bayesian network modelling, and to apply BN to a delay-time analysis study.
- Riahi *et al.* (2012b) developed and extended Fuzzy Bayesian Networks (FBNs) and a “symmetric method” by exploiting a conceptual and sound methodology for the assessment of seafarers’ reliability.

2.7 Conclusion

The vulnerability of container liner shipping has necessitated the need for LSOs to assess the BEBR, the ORC and the punctuality of their vessels by using appropriate mathematical models. Within this chapter, the significant literature and the critical review of the current research are discussed. Also, the problem analysis and research gap have been highlighted. Several mathematical methods to be employed to answer the research objectives are elaborated. These methods and their algorithms will be further explained in each technical chapter (Chapters 3, 4, 5 and 6). The main novelties of this research are expected to be 1) the development of four mathematical models in each technical chapter, and 2) the application of the BEBR assessment, ORC evaluation and vessel punctuality analysis models in the real case studies.

CHAPTER THREE

Business Environment-Based Risk Assessment in the Container Liner Shipping Industry by Using a Fuzzy Evidential Reasoning Methodology

Summary

Container liner shipping is a dynamic industry. In an era of unprecedented global changes, the CLSI faces a variety of internal and external risks. As a result, an appropriate mathematical model and a decision support framework for assessing the BEBR for the CLSI are proposed in this chapter. For assessing the value of the BEBR, a combination of different decision-making techniques such as AHP, FST and ER (i.e. called FER), is employed. Based on the proposed methodology, LSOs will be able to assess the risk value of a country or a port prior to investment and strategic decisions. In addition, with the help of the proposed methodology, LSOs will be able to regularly assess the overall level of existing BEBR in a host country. The BEBR assessment model is demonstrated with the case study of the CLSI in Malaysia.

3.1 Introduction

The CLSI is an industry consisting of a fleet of vessels with a common ownership or management that provides a fixed service at regular intervals between ports of call and offers transport of containerised goods in the catchment area served by those ports of call (Stopford, 2009). One of the significant concerns in the container liner shipping operations is to ensure that the stability and reliability of services during operations are maintained. With the era of unprecedented global changes and uncertainties, the CLSI faces a variety of risks that not only can be seen internally but also result from uncertain environments (i.e. externally). As a result, it is important for the involved parties (i.e. from managers to stakeholders) to strategically manage supply chain risks in container liner shipping operations based on the external environments.

In this chapter, the BEBR assessment methodology is developed by using a combination of different methods such as AHP, FST, and ER (i.e. FER). The aforementioned term BEBR is defined as a wider scope of external risks (i.e. political risks, economic risks, social risks, and natural hazards) that directly or indirectly influence the CLSI and its business performances. Based on the proposed methodology, LSOs will be able to assess the risk value of a country or a port prior to investment and strategic decisions. In addition, with the help of the proposed methodology, LSOs will be able to assess the overall level of existing BEBR in a host country regularly.

The remainder of this chapter is organised as follows. The literature review is explained in Section 3.2. Section 3.3 presents the methodology for assessing the BEBR. The test case is conducted in Section 3.4. The results and discussion are explained in Section 3.5, and finally, the conclusion is given in Section 3.6.

3.2 Literature Review

The global operation of container liner shipping in different countries has necessitated the need for LSOs to assess and understand the riskiness of the business environment in a country under consideration. CLSCM (2003) defined environmental risk as the external risks (i.e. consisting of political risk, economic risk, social risk, technology risk, and natural hazards) that affect an organisation's performance, operations, assets, infrastructure, supply chains, and the value of stream flows. Trkman and McCormack (2009) elucidated that exogenous uncertainty is a source of risk from outside of the supply chain. This exogenous uncertainty can be due to discrete risks (e.g. terrorist attacks, contagious diseases, and workers' strikes) or continuous risks (e.g. inflation rate, consumer index changes). Riahi *et al*. (2014) considered four sub-elements for evaluation of the reliability value of a country (i.e. geopolitical, socio-political, economic, and natural disaster). These four elements have not been investigated in depth in previous research due to the generality of the assessment criteria. Based on the literature review (i.e. Chapter 2), it is clear that a mathematical model for assessing the BEBR for the CLSI up to now has not been developed and applied. As a result, the aim of this chapter is to develop a mathematical model for assessing the value of the BEBR in a country from a liner shipping perspective.

In this study, the value of the BEBR in a country is evaluated by aggregating the values of political risks, economic risks, social risks and natural hazards. Although these risk criteria have originated from different sources, it is necessary to synthesise them into a single value to obtain the value of the BEBR in a country. As a result, the proposed model for assessment of the BEBR in a country from a liner shipping perspective is capable of synthesising these four risk criteria. Moreover, the decision-makers are provided with a single assessment model that is capable of dealing with multi-complex elements.

Since the political risks, economic risks, social risks and natural hazards have originated from multiple disciplines, quantifying the BEBR is a challenging task. When such risks are considered from a wider viewpoint, the procedures for data collection, measurement and quantification will be exceptionally complicated. These problems not only resulted from the extension of the searching scope but also originated from the incompleteness of data.

For assessing the BEBR four main criteria (i.e. political risks, economic risks, social risks and natural hazards) are investigated and need to be synthesised. This classification follows the recommendation and adaptation of various studies in the literature and further consulted with the domain experts in the CLSI.

3.2.1 Political Risks

Political risks can be defined as any change in political aspects that may alter the probability of achieving business objectives (DiPianza and Bremmer, 2006). Political risks faced by organisations are categorised as strategic, financial and personnel. The aforementioned risks can cause financial losses or disruptions to an LSO due to non-market factors (e.g. policy, restrictions, *etc*.), and events related to political instability (e.g. terrorism and civil war) (Kennedy, 1991). For instance, governmental actions and stability in a host or parent country are significant factors that lead to increasing risk in the business environment (Nigh, 1986; Tsai and Su, 2005). There are a number of studies relating to political risk and its application to investment and international business. For example, Noordin *et al*. (2006) studied the political risk assessment strategies on Malaysian-based multinational corporations; they found that the perceptions of firms about political elements varied with the location of their investment. In another study, Khattab (2011) investigated a Jordanian multinational enterprise and argued that the role of risk managers in country risk assessment is still not maximised.

In the context of the maritime industry, several studies of political risk assessment have been implemented such as CLSCM (2003), Hoti and McAleer (2004), UNCTAD (2011), and Riahi *et al*. (2014). In this chapter, political risks are classified into two categories: macro and micro political risks. The classification of political risk into macro and micro political risks is well known in literature and it may stimulate additional conceptualisations, and provide a clear structure, purposive orientation and theoretical efforts regarding political risks (Friedmann and Kim, 1988; Tsai and Su, 2005).

3.2.1.1 Macro Political Risks

Macro political risks result from the political changes that affect all industries (Tsai and Su, 2005). The impact of a country's macro political risks can intrude into all businesses in that country. For the purpose of this study, based on the literature, macro political risks are categorised as government instability, domestic conflict, foreign conflict, restriction in foreign enterprise policy, corruption and lawlessness (Clark *et al*. 2004; Awosuke and

Gempesaw, 2005; Jones *et al*., 2005; Tsai and Su, 2005; Magee and Massoud, 2011; UNCTAD, 2011).

i. Government Instability

Government instability can be defined generally as the degree of tendency for a change in the governance of a country, which may include policy changes, insurrection, *etc*. The government instability in a country has a profound effect on the level of demand and supply of maritime services at ports and also shipping operations (He, 2009). The effect of government instability can be listed as follows (Awokuse and Gempesaw, 2005):

- In the case of the *exporting country*, government instability can directly affect the level of exports. In addition, domestic production may be negatively affected by the increasing level of political and economic uncertainty.
- In the case of the *importing country*, government instability can indirectly affect the level of imports demanded via the impact of political uncertainty on economic growth such as domestic prices, income, interest rates, unemployment, and exchange rates.

Factors such as government unity, legislative strength and public support are the main indicators that signify the stability of a country (Macridis and Burg, 1991; Miller, 1993; Chen *et al*., 1997; Hankla, 2006; Chigora and Guzura, 2011; PRS Group, 2012).

ii. Domestic Conflict

The assessment of domestic conflict in a country is considerably vital for determining domestic political stability. There is strong evidence to support the view that domestic conflict can damage international trade performance and reduce shipping safety levels. Stewart *et al.* (2001) argued that conflict in a country leads to an increase in the costs and risks associated with trading due to domestic insecurity and disruption of trade routes. Magee and Massoud (2011) claimed that domestic conflict and instability decrease the international trade share of a country's economy. Since the CLSI is a tool of international trade, domestic conflict could also affect its performance. Domestic conflicts are categorised as civil war, political violence and civil disorder (Schurink, 1990; Steward *et al*., 2001; Blomberg and Hess, 2002; Murdoch and Sandler, 2002; Sambanis, 2004; Black, 2007; Waters, 2007; Bodea and Elbadawi, 2008; Martin *et al*., 2008).

iii. Foreign Conflict

Foreign conflict can be defined as foreign action, ranging from non-violent external pressure (trade restriction, diplomatic pressure, territorial disputes, *etc*.) to violent external pressure (cross-border conflict and war). Nitsch and Schumacher (2003) measured the impact of foreign conflict on international trade and found that increases in violence have a negative effect on international trade. The effect can be direct destruction of ports and ships, or the need for additional security, which raises the cost of transactions and should thereby lower the volume of international trade. Foreign conflict can severely affect liner shipping operations in many ways such as possibility of war, cross-border conflict and trade sanctions (Anderton and Carter, 2001; Glick and Taylor, 2005; Marinov, 2005; ICS, 2012).

A possibility of war can be defined as the possibility of prolonged conflict that is organised, armed and carried on between nations. Anderton and Carter (2001) used an interrupted-series model to evaluate the impact of war on trade and found that there is reasonably strong evidence that war between major powers is associated with a decline in trade relative to the pre and post-war periods. Figure 3.1 illustrates the impact of World War II on trade between the UK and Japan from 1931 to 1945.

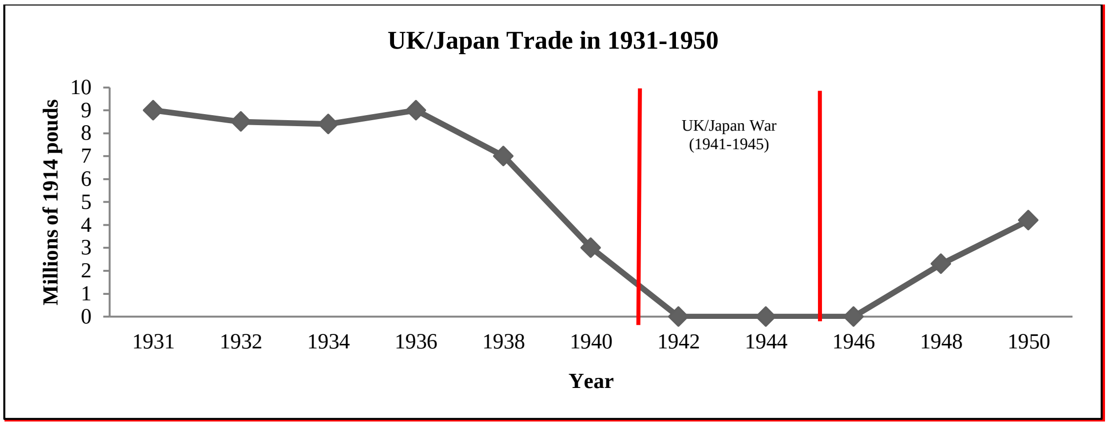

Figure 3.1: Impact of World War II on trade between the UK and Japan from 1931 to 1950
Source: Adapted from Anderton and Carter (2001)

Cross-border conflict can be defined as a tension occurring between neighbouring countries which can cause a violent change in society. With the financial turmoil condition, some countries prefer to have a short-distance trade with their neighbours, called regional trade. Three regions, Eastern Europe, Latin America and East Asia, have had vastly different experiences with regional trade and enjoyed varied levels of success; increased their trade with neighbours and work under a broader free trade system. However, if these countries experienced a conflict between their neighbours, a harmonious free trade system would be difficult to implement.

Trade sanction is the type of foreign pressure used to destabilise the targeted government. The trade sanction stress is on liquidating stock to pressurise a government, industry or company towards a change in policy, government or regime. Marinov (2005) expressed that sanctions are more effective for pressuring the targeted government to change its policies. The impact of trade sanctions on the CLSI may be direct or indirect. An example of direct impact is the sanctions enacted against Iran in 2012 which led to the operational halting of trade between UK/US and Iranian ports. Indirectly, the consequences go far beyond the UK and US (ICS, 2012). This is because most marine insurance and reinsurance is based in London; therefore, non-US and non-UK ship operators will not be insured if they trade with Iran.

iv. Restriction in Foreign Enterprise Policy

A restriction in foreign enterprise policy on trade has a profound influence on the CLSI. In some countries (e.g. Cuba and India), local operators enjoy government protection policies while foreign operators have to face discriminatory rules imposed by the host country. This is to ensure the survival of local companies in the market. However, these government policies and private anti-competitive practices are the reasons for high transport costs in those countries (Fink *et al.*, 2002). As a result, a foreign enterprise policy imposed by a host government can lead to a negative impact on the CLSI.

In some cases, the foreign enterprise policy varies depending on domestic culture and form of government (Abdin, 2009). For example, the policy in a democratic country would be different from that in an autocratic country. The policy in a politically stable country will also be different from that of an unstable country. Thus, to deal with anticompetitive business practices in the CLSI, the international conference called the General Agreement on Tariffs and Trade (GATT) was formed in 1947 with a further modification in 1994 (WTO, 2012). According to its preamble, the purpose of the GATT is the substantial reduction of tariffs and other trade barriers and the elimination of preferences, on a reciprocal and mutually advantageous basis (GATT, 1994).

v. Corruption

Corruption can be defined as an insidious plague that has a wide range of corrosive effects on societies as it undermines democracy and the rule of law, leads to violations of human rights, distorts markets, erodes the quality of life and allows organised crime, terrorism and other threats to human security to flourish (UNODC, 2004). A common form of corruption in business is financial corruption, which is demand for special payment and bribes. Clark *et al.* (2004) argued that corruption is a core risk in reducing port efficiency. Yang (2008) found evidence that corruption is persistent and difficult to reduce. Similarly, Maachi and Sequeira (2009) expressed the view that corruption reduces the investment returns in transportation services, which has recently happened in many developing countries.

vi. Lawlessness

The important elements of the supply chain in liner shipping are the security of containers, ports, equipment and ships. A country with a weak legal system and people who are highly ignorant of the law may suffer from a high crime rate from actions such as theft, homicide, political violence, corruption, *etc*. Consequently, the liner shipping operation may be exposed to criminal activities, resulting in financial losses. Generally, law and order play a significant role in the maritime industry to control the criminal activities which can affect supply chain security, including piracy, cargo theft, corruption in port and customs, sabotage, *etc*. Law is the strength and impartiality of the legal system while order is the capability of citizens to comply with the law (PRS Group, 2012). These law and order systems include courts, legislature, legal statutes and codes, executive agencies and independent non-governmental organisations (NGOs), which improve security levels, supported by internal security institutions such as police, justice system, military and other security bodies in the host country (Jones *et al*., 2005).

3.2.1.2 Micro Political Risks

Micro political risks refer to the risks resulting from the political changes that affect only a certain business activity or enterprises (Tsai and Su, 2005). Micro political risk can also result from any government actions or processes that directly influence the CLSI performance and development. For the purpose of this study, based on the literature, the criteria such as customs-related risk, exchange control rules and excessive bureaucracy in trade are micro political risks that directly affect the LSOs' performances (Haughton and Desmeules, 2001; José *et al.*, 2003; Sawhney and Sumukadas, 2005; Wei and Zhang, 2007; Gurning, 2011; Ng *et al.*, 2013).

i. Customs-Related Risk

Customs procedures and clearance processes are still very severe hindrances in many countries (Sawhney & Sumukadas, 2005). For example, customs-related risk events in Indonesia and Australia from 2007-2009 occurred once a month and once every three months, respectively (Gurning, 2011). Furthermore, José *et al.* (2003) claimed that customs clearance is a factor predominantly known as an additional trade disturbance. There is a potential disruption in the CLSI due to slow customs services and information support system unreliability that connects customs, ports and shipping operators (Haughton and Desmeules, 2001). As a result, cargo delay and cargo rerouting may occur due to slow tracking including inspection of cargo handled by customs agencies at ports (Gurning, 2011).

ii. Exchange Control Rules

In many countries, in order to protect the local economy, the government has enforced specific exchange control rules as a political tool to protect its national interests. This type of government policy is commonly used in most countries, especially in developing countries and transition countries. Wei and Zhang (2007) argued that there is economically and statistically significant evidence of the negative effects of exchange control rules on trade. Although the Free Trade Agreement (FTA) has been established in response to the globalisation trend and economic liberalisation, some countries still impose exchange control rules such as controls on payments for imports and exports (i.e. documentation and financing requirement), capital and foreign exchange transactions (i.e. derivatives, credit operations, real estates, ban on currency derivative trading and control on bank accounts) (Wei and Zhang, 2007).

iii. Excessive Bureaucracy in Trade

Bureaucracy in trade in this study refers to onerous bureaucratic procedures and port institution deficiencies that are not related to customs operations but that have a direct impact on the CLSI. The irregularities and uncertainties of the bureaucratic system have a profoundly negative impact on port operations, and lead to slow cargo movement in ports, higher demands for inventory storage, and demands for extended free time for cargo movements. Ng *et al.* (2013) argued that the institutional deficiencies affected roles in Brazilian ports in several ways including the relationship between sea and dry ports, influencing LSOs' strategies and decisions, and also influencing other companies using these facilities. As a result, it is worth mentioning that institutional deficiencies and excessive bureaucracy can undermine the transportation roles in the maritime industry.

3.2.2 Economic Risks

Economic risks of a country refer to the national economic situations that affect the outcomes of financial transactions and international trade served by the CLSI. A fall in economic development will adversely affect the performance of the CLSI. The CLSI noticeably acts as an artery in making a contribution to the global economy. As a result, the CLSI performances and economic development are directly proportional and they have always been inextricably linked. In this study, economic risks are classified into two categories (i.e. macroeconomic and microeconomic risks) (Bouchet *et al*., 2003).

3.2.2.1 Macroeconomic Risks

Macroeconomic risks refer to the variability in the economic environment such as output, prices, interest rates, foreign exchange rates and terms of trade (Bouchet *et al.*, 2003). A further point is that macroeconomic risks do not negatively impact all industries but are only concerned with certain industries or even merely a few companies. In the context of maritime transportation, macroeconomic risks highly influence trade performance as it is very sensitive to industrial production and economic stability, as has been proven by the 2008 financial crisis (Rodrigue *et al*., 2011). Several attempts have been made to consider macroeconomic risk factors in determining expected stock returns in the shipping industry (Kavussanos and Marcoulis, 2000a; Kavussanos and Marcoulis, 2000b; Grammenos and Arkoulis, 2002; Drobetz *et al.*, 2010). Grammenos and Arkoulis (2002) used a set of macroeconomic factors as drivers of international shipping stock returns, while Drobetz *et al.* (2010) used shipping stocks together with a set of country or other industry indices to estimate the macroeconomic risk profiles and the corresponding factor risk premiums. Based on their research, they found that, instead of market factors, the macroeconomic risks should be taken into consideration before making a decision to invest in the shipping industry. In this chapter, GDP per employed person, current account to GDP, exchange rate fluctuation, inflation rate, and industrial production are the significant indicators that signify the macroeconomic performance of a particular country (Alizadeh and Nomikos, 2009; Stopford, 2009; Riahi *et al*., 2014).

i. GDP per Employed Person

GDP, GDP per capita, and GDP per employed person are commonly used to compare the economic performance of different countries. Gross domestic product (GDP) is the value of all market and some non-market goods and services produced within a country. GDP per capita may therefore be viewed as a rough indicator of a nation's prosperity, while GDP per employed person and GDP per hour worked can provide a general picture of a country's productivity (US Department of Labour, 2009). Countries with the lowest employment population ratios, such as Belgium, Hungary, and Italy, have relatively larger gaps between GDP per capita and per employed person (US Department of Labour, 2009). Riahi (2010) measured the reliability of a country from an economic point of view by using GDP per employed person as a general indicator of productivity. In order to evaluate a country's productivity, using the number of persons employed as a measure of labour input ignores differences in the number of hours worked and the skill levels of different people. In addition, to measure and compare GDP per employed person in different countries, it must be converted into a common unit value. Purchasing power parities (PPPs) are currency conversion rates that allow GDPs to be expressed in a common unit value (US Department of Labour, 2009).

ii. Current Account to GDP

The current account to GDP provides an indication of the level of international competitiveness of a country (Trading Economics, 2012). The current account to GDP of a country goes hand in hand with the CLSI. A country recording a surplus on current account describes its economy as heavily reliant on export revenues. In contrast, countries recording a current account deficit have strong imports, low saving rates and high personal consumption rates as a percentage of disposable incomes (Trading Economics, 2012). A country with a strong current account surplus can be assumed as a country with low risk while one with a high current account deficit presents a high risk (Trading Economics, 2012).

To measure and compare the current account to GDP of a country, the estimated balance on the current account of the balance of payments for a given year (i.e. converted into US dollars at the average exchange rate for a year) is expressed as a percentage of the estimated GDP of that country (i.e. converted into US dollars at the average of exchange for the period covered) (PRS Group, 2012).

iii. Exchange Rate Fluctuation

Liner shipping is an integral part of maritime transportation and has always been regarded as one of the most volatile industries, where LSOs are exposed to ample financial and business risks. One of these risks originates from exchange rate fluctuations, which can affect the cash flows of shipping investment and operations; for instance, having a profound impact on the profitability of LSOs as well as their business viability (Alizadeh and Nomikos, 2009). The impact of the fluctuation in exchange rate can be financially devastating to LSOs. Therefore, having a good understanding of risk and its dynamics is important in the setting up and implementation of effective risk-management techniques, efficient portfolio construction and asset allocation, derivatives' pricing and trading, as well as value-at-risk estimation and risk monitoring (Alizadeh and Nomikos, 2009).

iv. Inflation Rate

Inflation presumably has an influence on returns in the shipping industry (Drobetz *et al.,* 2010). The World Economic Forum (2012) has highlighted unmanageable inflation or deflation as a significant global economic risk in the coming 10 years. Failure to redress an extreme rise in the value of money relative to prices and wages in a country may reduce the purchasing power of money, as the value of money will be lost due to inflation. For this reason, reductions in purchasing power may reduce the demand for export and import purposes. In addition, if the inflation rate in a country is higher than that of another country, export volumes will be less attractive as compared to the latter.

v. Industrial Production

Industrial production is a measurement of real output and is expressed as a percentage of real output of the industrial sector including manufacturing, mining and utilities. Stopford (2009) argued that industrial production is a main parameter that influences the demand for the container liner shipping and is used to assess the economic health of a country. A 1% increase in industrial production leads to a 2.2% increase in monthly returns in the container sector (Drobetz *et al.*, 2010). As liner shipping mostly carries industrial products (i.e. furniture, machinery parts, electric and electronic goods) in a form of containers, the industrial production figures may signal the demand for liner shipping services. In the context of shipping stock returns, Drobetz *et al.* (2010) identified those changes in industrial production as long-run systematic risk factors that drive expected stock returns in the shipping industry.

3.2.2.2 Microeconomic Risks

Microeconomic risks can be categorised as risks associated with resources that are required by a firm to run its business and risks associated with outputs and marketing uncertainties (Bouchet *et al.*, 2003). Microeconomic risks may arise at the industry or organisation level. Business firms often face microeconomic risks in a host country when they want to implement regular operations that are the same as in their parent country. They need to include all risks specific to the host country that will affect their business transactions and management of local operations (i.e. production, marketing, finance, supply and logistics, human resources, technology and organisational structure) (Bouchet *et al.*, 2003). Kavussanos and Marcoulis (1997) found that there is a link between shipping industry stock returns and microeconomic factors. In the CLSI, freight rate fluctuation, bunker price fluctuation and labour cost are the significant indicators that signify the microeconomic performance of a particular country and they will impact the operational cost of LSOs (Alizadeh and Nomikos, 2009; Rodrigue *et al*., 2011).

i. Labour Cost

With the growth of globalisation and international trade, multinational companies including LSOs allocate their operations to more effective locations which have an economical advantage for labour cost. Labour cost is mainly external to the LSO and LSOs are unable to have direct control of the labour cost determination. In this context, changes in labour income level may affect the magnitude of LSOs' cash flows. Alizadeh and Nomikos (2009) argued that the labour income will eventually increase the LSO expenditure. As the CLSI requires an enormous supply of labour in its operation (e.g. onboard ship, ports, *etc*.), labour cost is a crucial factor for business profitability.

ii. Freight Rate Fluctuation

Kavussanos and Marcoulis (1997) pointed out that freight rates are the most important source of income for the shipping industry and they are determined by the interaction of demand and supply in shipping services. The maritime transportation services generate a projected annual income of USD 500 billion from freight rates (i.e. representing 5% of the total world economy) (UNCTAD, 2012). Freight rate fluctuation refers to the variability in the earnings of an LSO due to changes in freight rates (Alizadeh and Nomikos, 2009). A freight rate fluctuation is considerably significant to LSOs as the freight market volatility can directly impact on company profitability. For example, in 2011, container shipping lines lost over USD6 billion due to freight rate fluctuation (Damas, 2012; UNCTAD, 2013). In addition, 14 major container shipping lines have been rated as ‘in the distress zone’ because they are unable to survive in the market due to the freight rates competition (Damas, 2012). Consequently, it is worth mentioning that extreme freight rate fluctuation will result in bankruptcy.

iii. Bunker Price Fluctuation

One of the major costs in shipping operations is fuel cost. As fuel is the main energy source for moving ships, volatility in bunker prices is an important factor in the expenditure of the CLSI (Rodrigue *et al.,* 2011). Alizadeh and Nomikos (2009) argued that the most important source of risk on the costs side of the shipping operation is fluctuations in bunker prices. From the middle of 2008, many LSOs suffered with regard to their vessels’ operation due to the global economic recession as well as the sharp increase in bunker prices (Rahman *et al.,* 2012). These events led to a dramatic fall in trade demand on all major routes and ultimately caused a surplus of containership services. Consequently, sharp and unanticipated changes in bunker prices may have a major impact on the operational costs of LSOs and can lead to reduced marginal profits or even losses. As a result, it is of the utmost importance for LSOs to assess their risk exposure to bunker price fluctuation in order to secure their operating profit (Alizadeh and Nomikos, 2009).

3.2.3 Social Risks

Liner shipping operates across the globe and connects many countries. As a result, the CLSI is potentially exposed to a high risk level as it has to deal with social risks in different countries. Social risks can be defined as challenges instigated by stakeholders to companies’ business practices. Social risks can impact on a broad range of issues related to human welfare such as working conditions, health, and quality of work (Bekefi *et al*., 2006). Numerous studies have attempted to evaluate social risks in the maritime industry. For example, Celik *et al*. (2009) investigated the degree of control, labour quality, and safety standards as the elements of social risks for the evaluation of preferable flagging choice for LSOs. Extending from this study, Kandakoglu *et al*. (2009) evaluated ship registry choice by considering the reputation of the ship-owners, NGOs’ pressure and environmental concerns as the external assessment criteria. Based on the literature review, labour quality and availability in the market, working cultures, reputational risk and religious/ethnic tensions are four crucial factors in the CLSI (Bekefi *et al.,* 2006; Lu and Tsai, 2010; Zhang, 2011; Riahi *et al*., 2012a).

3.2.3.1 Labour Quality and Availability in the Market

Employees in container liner shipping consist of seafarers, management workers, managers, port stevedores, *etc*. The quality of these employees is a primary concern of the LSOs. Low-quality employees undoubtedly can contribute to lower productivity, accidents and errors and incompetence in operations. Statistically, 80% of maritime accidents are instigated by human error (Riahi, 2010). Liberman and Boehe (2011) argued that, in countries where managers perceive that the labour quality is lower (e.g. lack of competence, motivation and probity), the managerial willingness to hand over power to subordinates decreases. Thus, unwillingness to delegate work will reduce efficiency in the management system, which finally results in lower productivity.

The availability of quality labour in the market also plays a significant role for recruitment purposes, instead of labour quality itself. In a country where there is high availability of skilled labour, the human resources department can choose the preferred labour from the market. In contrast, a country with low availability of skilled workers may lead to employment of incompetent labour.

3.2.3.2 Working Cultures

As liner shipping operates in many countries where there are different cultures, the working safety culture of local people is a major concern for LSOs. Previous studies have claimed that safety cultures are interrelated with safety-related outcomes such as human loss, injuries, accidents and infrastructure damage (Glendon and Litherland, 2001; Mearns and Yule, 2008; Lu and Tsai, 2010). The cultural values from a country's environment can influence the organisational culture, positively or negatively. The employees brought into the organisation are saturated with the values, belief and attitudes that come from the national culture, which can influence the organisation's internal cultures. Lu and Tsai (2010) claimed that national culture affects the way people understand the importance of safety during work. Extended from Lu and Tsai's (2010) research, Lu *et al.* (2012) highlighted the importance of national culture in explaining the human errors. They found that national culture is of one of the important factors influencing human errors in ship operations.

3.2.3.3 Reputational Risk

Globalisation and liberalisation encourage LSOs to operate globally in many different countries and establish branches in host countries. However, they are inevitably subject to reputational risk. The consequences of this risk may include reputation damage, heightened regulatory pressure, legal action and boycotts (Bekefi *et al.*, 2006). Reputation image can account for over 60% of a company's market value, so LSOs need to maintain their reputation among stakeholders (Bekefi and Epstein, 2006). When a reputation is damaged due to negative publicity and costly litigation, this can lead to financial losses and loss of customers as well as exit of employees. Although negative perception of an LSO can be accurate or inaccurate, both can lead to challenges against the company. In respect of modern company strategies to manage reputational risk, corporate social responsibility is becoming a vital way to increase the relationship between stakeholders.

3.2.3.4 Religious/Ethnic Tensions

LSOs may operate in a country that has a high degree of fractionalisation of its societies; leading to them facing a high risk of religious/ethnic tensions. Ethnic tension is derived from the unwillingness and intolerance of ethnic groups towards other ethnic groups sharing national wealth, political power, social interest, *etc.* Religious tension can be linked to the domination of society or governance by a single religious group in several ways, such as to replace civil law by religious law, to exclude other religions from the political process and/or social process, to dominate government, to suppress religious freedom, to express religious identity, or to separate from the country as a whole (PRS Group, 2012). In addition, a country with a high risk of religious/ethnic tensions is associated with bad policy and poor security environments (Easterly and Levine, 1997; Alesina *et al*., 1999; Bodea and Elbadawi, 2008).

3.2.4 Natural Hazards

The CLSI offers an advantage in terms of the environmental transport problem by reducing pollution, traffic congestion and accidents; natural hazards, however, threaten the smooth operation of the liner shipping operation. Haddow and Bullock (2003) defined natural hazards or natural disasters as those hazards that exist in the natural environment and pose a threat to human populations and communities. The impact of natural disaster on the CLSI can be devastating. It can cause various types of destruction as well as loss of human life, such as port destruction, damage to port and ship or to a port's or ship's equipment, and loss of maritime personnel. Maritime disruption events resulting from natural hazards can cause delay of ship and port operations, deviation of ship, destruction of ports, operation stoppage or even loss of service platform (Gurning, 2011). In maritime transportation, these phenomena have been critically discussed at the operational planning level, where the disruption management department considers natural hazards as the major events that can lead to operation disruptions. In an annual review of maritime transport, UNCTAD (2011) highlighted the multiple risks including natural hazards which undermined the prospect of a sustained recovery and a stable development of the maritime industry. For the purpose of this study, based on the literature, the classification of natural hazards can be summarised into five categories: geophysical, meteorological, hydrological, climatological and biological disasters (Turner and Pedgeon, 1997; WHO, 2003; EM-DAT, 2009).

3.2.4.1 Geophysical Disaster

EM-DAT (2009) has defined geophysical disasters as seismic events related to the motion of the earth's tectonic plates. The notable geophysical events are earthquakes, tsunamis, volcanoes and mass movement. Geophysical disasters have the largest portion of overall economic impact including infrastructure damage and social disruption as well as loss of human life (Okuyama and Sahin, 2009). In 2011, 36 geophysical disasters were registered, representing a share of 10.8% of total disaster occurrence (Guha-Sapir *et al.*, 2012). In the CLSI, earthquake, tsunami and ash from volcanic eruptions are three geophysical disasters that cause a devastating impact on port infrastructures, facilities and vessel safety (Chang, 2000; EM-DAT, 2009; Gurning, 2011).

i. Earthquake

Earthquake can be defined as shaking and displacement of the ground due to seismic waves resulting from the sudden release of stored energy in the Earth's crust (CRED, 2009; Guha-Sapir *et al*., 2012). Data from several sources have identified the impact of earthquake occurrences on operational performance of ports, where downtime annual losses are detrimental (Chang, 2000; Wisner *et al*., 2004; Pachakis and Kiremidjian, 2005). In addition, earthquakes are major contributors to the loss of supply chain platforms including ports, berth, warehouses, utilities, inland roads and bridges (Carpignano *et al*., 2009). Gurning (2011) investigated earthquake as one of the events that caused maritime disruption in the wheat supply chain between Indonesia and Australia and found that:

- One day after an earthquake destroyed a particular port, 50% to 60% of the port facilities were damaged and dry bulk ships that were going to call at the port had to reroute to other ports.
- On the 7th day, the port could not provide its main services as 70% of its facilities were unavailable.

- After finding back-up supports, providing temporary facilities and new operational procedures, the port managed to recover, with 30% of the port facilities ready for operation on the 50th to 62nd days.
- It took a further month (until the 90th day) for the port facilities to be fully restored.

Earthquakes are predominantly considered by researchers to be major contributors to port damage and operation stoppage; however, earthquakes with a low magnitude of scale rarely cause port operations to shut down for a long time. As an example, the Port of Oakland California suffered only short-term damage (only damage to three main berths, tilted container crane, one ship being rerouted) after being hit by the Loma Prieta earthquake in 1989 (Gurning, 2011).

ii. Tsunami

Since the majority of ports and shipping activities are located at coastal areas, they are vulnerable to tsunamis. According to EM-DAT (2009), tsunamis can be defined as having waves characterised by a very long wavelength and their amplitude is much smaller offshore. Tsunamis can be triggered either by earthquakes, volcanic eruptions, mass movements, meteorite impact or underwater explosions (EM-DAT, 2009). Based on historical events, the impact of a tsunami on a port can be destructive, as the huge waves advance the tidal area, which can cross over many kilometres from the coast. Overall, principal damages to ports and vessels caused by tsunamis can be summarised as damages resulting from parting of vessels from their moorings, out-of-control movements of manoeuvring or unmoored vessels transported by tsunami-induced currents, vessels are lifted out of the water onto piers, and tsunami-induced sediment scour and deposition (PIANC, 2009). The impact of tsunamis on ports and the shipping industry can be listed as follows (PIANC, 2009):

- Susaki Port, Japan. The port suffered damage by tsunamis repeatedly in 1946 (the Nankai Earthquake Tsunami) and 1960 (Chilean Tsunami).
- Kamaishi Port. The port suffered a number of tsunami disasters in the same way as Susaki Port. The 1896 Meiji Sanriku Earthquake Tsunami, 1933 Showa Sanriku Earthquake Tsunami and 1960 Chilean Tsunami caused serious disasters in Kamaishi. 411 vessels were reported as seriously damaged due to these three tsunami events.

- The US has experienced over 80 significant tsunamis in its 230-year history, resulting in over 370 deaths and over US $180 million in damage to ports, property and vessels.
- Sumatra Island ports. A tsunami induced heavy damage to ports and coastal facilities along the west and north coasts of Sumatra Island in 2004.

iii. Ash from Volcanic Eruption

The composition of magma eruptions can be explosive and effusive and result in variations of rock fall, ash fall, lava streams, pyroclastic flows and emission of gas (EM-DAT, 2009). Several effects of volcanic eruptions on maritime transportation can be listed as follows (NOAA, 2011):

- Volcanic ash can clog air intake filters in a matter of minutes, crippling airflow to vital machinery. Ash particles are very abrasive and if they get into an engine's moving parts, they can cause severe damage quickly.
- Water is the main component in volcanic eruptions; it is what makes them so explosive. Through chemical reactions, toxic gases that are released in eruptions can bond or adsorb to ash fall particles. As the particles land on skin, metal, or other exposed shipboard equipment, they can begin to corrode.
- Heavy amounts of volcanic ash reduce visibility to less than ½ mile, which is a hazard to navigation. This, combined with the above two other main impacts, makes sailing in the vicinity of volcanic ash very dangerous for mariners.

3.2.4.2 Meteorological Disasters

EM-DAT (2009) defined meteorological disasters as events caused by short-lived or small- to meso-scale atmospheric process and main meteorological disasters are storms and tornadoes. In 2011, 84 meteorological disasters were reported across the world, which represented 25.3% of the total disaster occurrence and caused economic damages accounting for US $50.87 billion (Guha-Sapir *et al*., 2012). Due to the severity of these meteorological disasters, maritime operations were recorded as experiencing disruption from slowdown to the loss of platform service for all types of ports. Gurning (2011) investigated the impact of meteorological disasters termed severe weather conditions, and highlighted hurricanes and cyclones as major factors of disruption in maritime-related operations. For this study, two types of meteorological disaster will be investigated: storms and tornadoes (NOAA, 2007; EM-DAT, 2009; Gurning, 2011).

i. Severe Storms

EM-DAT (2009) defined severe storms or thunderstorms as the result of convection and condensation in the lower atmosphere and the accompanying formation of a cumulonimbus cloud. Storms are collections of windstorms such as tropical storms, hurricanes, cyclones, and typhoons. The threat of storms to maritime operations is very familiar to mariners. It is noteworthy to mention that the severe storms that occurred in Australia between the years 2004-2006 caused closure of ports, grounding of vessels, and an increase in the numbers of ships queuing (Australian Transport Safety Bureau, 2007). A further point is that the indirect effects of severe storms were an increase in demurrage cost, decrease in port productivity, deviation of vessels from port of call, *etc*. Increased wind speed triggered by severe storms has a potential impact on maritime operations such as increased vulnerability of port structures and wave agitation in the port basin. The impact of severe storms can also reduce working hours of port equipment and capacity of port services (Gurning, 2011).

ii. Tornadoes

A tornado is defined by EM-DAT (2009) as a rotating column of air (vortex) that emerges out of the base of a cumulonimbus cloud and has contact with the Earth's surface. A further characteristic of tornadoes is that they can generate wind speeds above 400 km/h and are considered the most destructive weather phenomenon. A tornado is also called a twister or waterspout when over open water. NOAA (2007) points out that, although tornadoes and tropical cyclones are quite weak and only last for a short time, they still pose a dangerous threat to ship and port operations.

3.2.4.3 Hydrological Disasters

EM-DAT (2009) has defined hydrological disasters as events caused by deviations in the normal water cycle and/or overflow of bodies of water caused by wind set-up. In 2011, 173 hydrological disasters were registered; they took the largest share in natural disaster occurrence (52.1%), and caused 139.8 million victims and US $70.72 billion in economic damages (Guha-Sapir *et al.*, 2012). Sea surges and coastal floods may pose a significant threat to maritime services such as: increase overtopping to decks and jetties; reduce regularity of the port operations; possibility of the closure of ferry terminals; increase port damages; reduce a vessel's speed; detour of shipping route; frequent shipping delays; unavailability of ferry service; road structure damages; bridges flooded and travel time delay (Goodwin, 2003; Nicholls *et al*., 2007; Gurning, 2011).

3.2.4.4 Climatological Disasters

EM-DAT (2009) defined climatological disasters as events caused by long-lived/meso- to macro-scale processes such as extreme temperature, extreme winter condition, haze, and climate change. In 2011, climatological disasters shared 11.7% of total disaster occurrence globally, and the second-largest share of total disaster victims (64.6 million or 26.4% of total disaster victims), as was also the case for the period 2001-2010 (Guha-Sapir *et al.*, 2012). A rise in climatological disasters can reduce trade (i.e. destroy human and physical capitals, transportation, energy and communications), increase the cost of trade (i.e. require a longer route, increase insurance premiums, increase cost of distribution) and reduce economic activity (Oh and Reuveny, 2010). As a result of the discouraged trade activity and increase of trade cost, the demand level for maritime transportation, especially the CLSI, will also be reduced.

Events such as extreme temperature, drought, climate change, extreme winter conditions and haze are crucial climatological disaster factors that affect the performance of liner shipping operations (Palecki *et al*., 2001; Andrey and Mills, 2003; Peterson *et al*., 2006; Rowland *et al.,* 2007; National Research Council, 2008; PIANC, 2008). In the context of operational reliability and safety, these climatological disasters are profound, reducing transportation reliability by reducing visibility, causing occasional damage to vehicle sheet metal, causing human fatigue, reducing traffic speed, increasing accident risk and travel time delays, *etc*. (Goodwin, 2003; Silander and Järvinen, 2004; Peterson *et al*., 2006; Rowland *et al*., 2007; National Research Council, 2008; Rauhala *et al*., 2009).

i. Extreme Temperature

Extreme temperature can occur in two waves, which are cold and heat, and its impact on transportation is considerably hazardous. Several attempts have been made to measure the impact of extreme temperature on transport operations (National Research Council, 2008; Peterson *et al*., 2006; Andrey and Mills, 2003; Rowland *et al.*, 2007). However, researchers have not treated maritime transportation in much detail, with only a few previous studies having investigated the impact of extreme temperature on waterway shipping operations. For example, PIANC (2008) claimed that key parameters influencing navigation on inland waterways are precipitation and air temperature, as these parameters determine the water supply and the water temperature in the navigable river sections. As a result, water temperature changes may cause the presence of ice, which affects navigability and port infrastructure. Based on the literature, extreme cold and heat can cause possible problems in the liner shipping operation such as: presence of ice in the liner route can lead to suspension of navigation and possible damage of infrastructure; increased crash rate in port area; port workers and seafarers becoming fatigued due to extreme heat; limited working time of port workers and seafarers; heat exhaustion; and power outages (Palecki *et al*., 2001; Rowland *et al*., 2007; National Research Council, 2008; PIANC, 2008).

ii. Drought

Drought poses an indirect impact on the maritime industry as well as affecting production volume, especially of agricultural products. For example, the impact of drought on inland waterway traffic in Finland can be listed as follows (Silander and Järvinen, 2004):

- A decrease of water depth by one centimetre due to drought will decrease cargo by 10 tonnes.
- If water depth of a river is less than 1.8 metres, navigation will need tugboat guidance; otherwise the vessel's journey will be interrupted.
- Exposure of passenger boats to grounding risk and difficulties in operation.

iii. Climate Change

PIANC (2008) discussed the impact of climate change in respect of waterborne transport, ports and waterways, mentioning that these unavoidable changes need to be adapted to by moderating and realising opportunities associated with climate change. Change of climate will have negative impacts on navigation and port operations as well as on related infrastructures. There are four main drivers of climate change that have a potential impact on ports, offshore structures and vessels, which can be listed as follows (PIANC, 2008):

- Increased and changed wind speed can cause degradation and change dredging requirements at ports.
- Higher wave level increases the vulnerability of port and offshore structures.
- Changes in sea level range cause corrosion of wharves and jetties.
- Changes in frequency, duration and intensity of storms cause problems in vessels' manoeuvrability and reduce work regularity of the port.

iv. Extreme Winter Conditions

Extreme winter conditions can be in the form of heavy snowfall, ice and freezing rainfall. Most of the impact studies of extreme weather conditions have only focussed on roads and railways (Knapp *et al*., 2000; Eisenberg and Warner, 2004). However, adapted from road and railway studies, the direct effect of extreme winter conditions on liner shipping operations can be negative. For example, black ice created on roads in port areas can cause accidents to port vehicles such as trailers and other vehicles; boat traffic on the river Danube has been disrupted between January and March of every year (i.e. it still happens) due to thick ice cover; the occurrence of ice may damage navigation signs, leading to reduced safety of navigation; and reduced visibility due to heavy snowfall may lead to speed reductions which might lead to delays (Symons and Perry, 1997; Pinto *et al*., 2007; PIANC, 2008).

v. Haze

Visibility is a very important element in ensuring safe navigation at sea. Haze and fog threaten the smooth navigation of liner vessels by reducing visibility of the ship. Peterson *et al.* (2006) argue that, in the USA, a vessel's visibility reduced to less than 800 metres leads to the suspension of two-way maritime navigation. Moreover, visibility limited to less than 400 metres causes all vessel movements to be stopped. Although the severity of haze and fog leading to accidents is not as great as other severe disasters such as storms, a vessel with limited visibility has to slow down, causing delays and finally financial losses.

3.2.4.5 Biological Disasters

Biological disasters as defined by OCHA (2012) are processes of organic origin or those conveyed by biological vectors, including exposure to pathogenic microorganisms, toxins and bioactive substances. The threat of biological disaster associated with the CLSI is indirect. For example, the deviation of liner vessels may happen in respect of a ship's command decisions to avoid a particular port which is infected or contaminated by biological disasters. For example, as a ship's master tries to protect his crew from any diseases (e.g. influenza, H1N1) he may not enter an infected port. In addition, the possibility of a ship being an agent of disease is high since a ship calls at every port on its designated route. Based on the literature, insect infestations and epidemic and pandemic diseases are two major factors discussed under biological disaster (EM-DAT, 2009; WHO, 2009).

i. Insect Infestation

Insect infestation is a pervasive influx and development of insects or parasites affecting humans, animals, crops and material (EM-DAT, 2009). According to the UK P&I Club

(2006), insects and mites of plant products such as swarms and mealy bugs may be found within cargo spaces and can be defined as:

- Introduced infestation (carried onboard from land).
- Cross-infestation (moves across from one product parcel to another).
- Residual infestation (remaining onboard from a prior infested cargo to attack subsequent cargoes).

It is worth mentioning that the spreading of insects through a vessel causes damage to seafarers' health, the industry and to ship-owners. In addition, the ship's maintenance cost will be increased as the pest-control budget rises in order to eliminate insect infestation onboard. For this reason, a proactive assessment of insect infestation at a particular port of call or country is essential.

ii. Epidemic and Pandemic Diseases

An epidemic disease is particular to certain areas such as a city, region or country, while a pandemic goes much further than national borders. The term pandemic has been separated to include diseases such as smallpox and tuberculosis and, most recently, HIV/AIDS and H1N1. There are some diseases which receive high attention and have the possibility to impact the maritime industry such as H1NI, HIV/AIDS, Malaria, Ebola, Dengue, Cholera, and H5N1. In 2009, Mitsui O.S.K. Lines (MOL) commenced a fleet-wide safety campaign by concentrating on the exchange of opinions between onshore and seagoing personnel regarding MOL's approaches to safe operation and measures to prevent the spread of the new influenza epidemic (TANKEROperator, 2009).

The following table summarises the BEBR classifications discussed in the preceding sections.

Table 3.1: The BEBR classifications

Main Criteria	Sub-criteria	Sub-sub-criteria
Political Risks	Macro Political Risks	Government Instability (Sub-sub-sub-criteria: Government Unity, Legislative Strength and Popular Support), Domestic Conflict (Sub-sub-sub-criteria: Civil war, Political Violence and Civil Disorder, Foreign Conflict (Sub-sub-sub-criteria: Possibility of War, Cross-Border Conflict and Trade Sanction), Restriction in Foreign Enterprise Policy, Corruption and Lawlessness

	Micro Political Risks	Customs-Related Risk, Exchange Control Rules and Excessive Bureaucracy in Trade
Economic Risks	Macroeconomic Risks	GDP per Employed Person, Current Account to GDP, Exchange Rate Fluctuation, Inflation Rate and Industrial Production
	Microeconomic Risks	Labour Cost, Freight Rate Fluctuation and Bunker Price Fluctuation
Social Risks	Labour Quality and Availability in the Market	Labour Quality and Labour Availability
	Working Culture	
	Reputational Risks	
	Religious/Ethnic Tensions	
Natural Hazards	Geophysical Disasters	Earthquakes, Tsunamis and Ash from Volcanic Eruption
	Meteorological Disasters	Severe Storms and Tornadoes
	Hydrological Disasters	Sea Surges and Floods
	Climatological Disasters	Extreme Temperatures, Climate Change and Haze
	Biological Disasters	Insect Infestations and Epidemic/Pandemic Diseases

3.3 Methodology Development

In this chapter, in order to assess the BEBR from a liner shipping perspective, a generic model is constructed and a combination of different decision-making methods such as AHP, FST, and ER is used. An AHP is employed to quantify the importance of attributes and is adapted into a deterministic weight vector (i.e. in the context of impact level) (Saaty, 1980). An FST is used by exploiting a membership function for assessing the BEBR factors (Zadeh, 1965). Furthermore, an ER algorithm is used to synthesise the belief degrees of linguistic variables of BEBR criteria (Yang and Xu, 2002). The backgrounds of AHP, FST and ER were elaborated in Sub-sections 2.6.1, 2.6.2 and 2.6.3 respectively. To develop the calculation process of the BEBR model, a flow chart of proposed methodology in sequential order is illustrated in Figure 3.2.

Step 1: The BEBR factors were critically identified using several techniques including literature review, discussion with experts and brainstorming technique.

Step 2: Generic BEBR factors are displayed in a hierarchical structure. Assessment grades will be assigned to all the criteria in the hierarchical structure in the form of either qualitative or quantitative method.

Step 3: A weight is assigned to each criterion by using an AHP approach. To present the degree of dominancy of one element to another element in a given attribute, each risk factor will be prioritised.

Step 4: Each quantitative criterion is transformed to a qualitative criterion by using membership functions of continuous fuzzy sets.

Step 5: The qualitative criterion is assessed using linguistic variables. Belief degrees are used as an assessment grade for each qualitative criterion.

Step 6: The ER algorithm is used to synthesise the criteria. A process of synthesis can be accomplished through manual calculation or through use of mathematical software. In this study, the Intelligent Decision System (IDS) software package is used.

Step 7: The utility value of the model is evaluated.

Step 8: The sensitivity of the model is analysed and the result is validated.

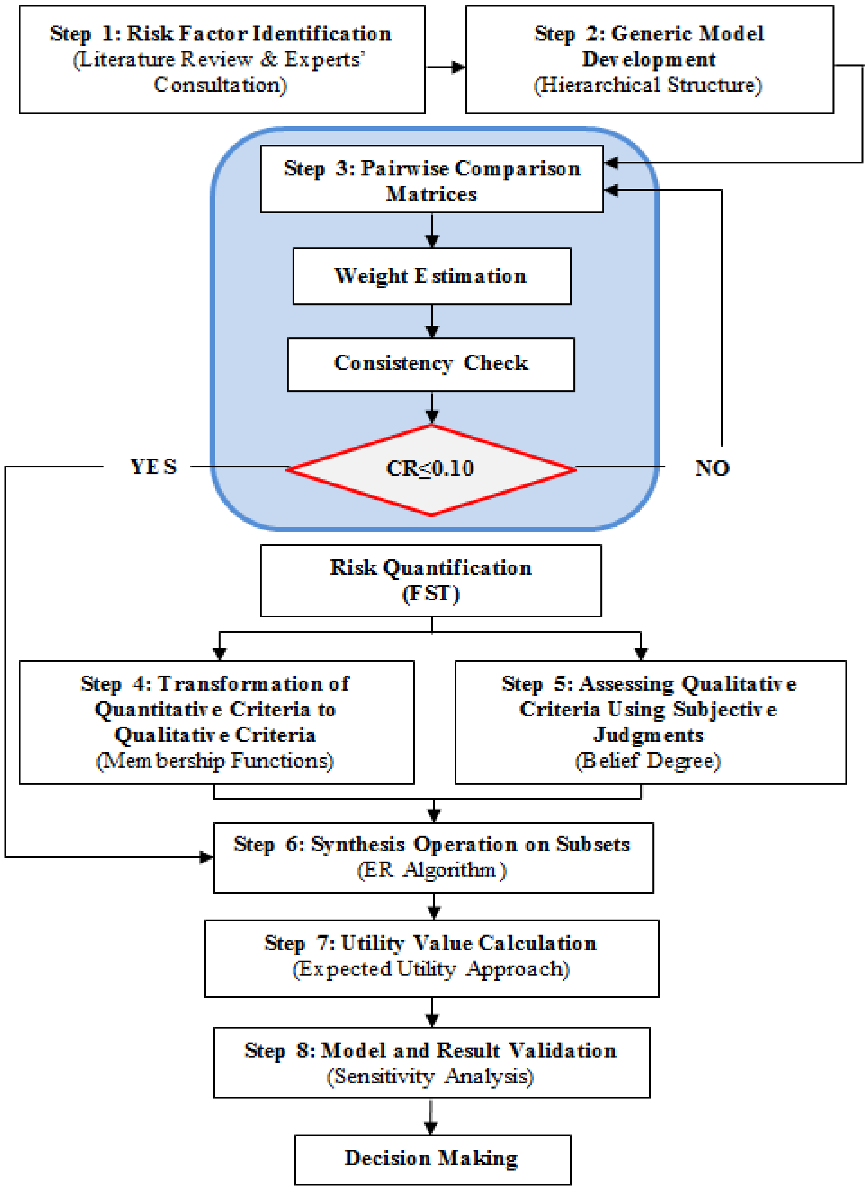

Figure 3.2: The flowchart of the generic BEBR assessment model

3.3.1 Risk Factor Identification (*Step 1*)

The first step in any risk management is risk factor identification (UNCTAD, 2006). The risk factor identification step forms visualisation of the potential risk factors and builds the foundations for the ensuing risk assessment and management process (Blome and Schoenherr, 2011). The process requires an overall understanding of the CLSI and the specific political, economic, social and natural factors which affect the LSO's business. There are several techniques to implement the risk factor identification process including literature, physical inspection, check-lists, safety audit, hazard identification (HAZID), hazard and operability study (HAZOP), expert discussion and brainstorming (Mokhtari *et al*., 2012).

The process of identifying the BEBR factors in the CLSI involves the listing of risk factors, and then classifying them into appropriate criteria in the categorisation system. With the focus on the BEBR, every significant external risk factor in the CLSI is carefully reviewed. A literature review was used as the main technique for the risk factor identification process in this study. The major BEBR factors and their backgrounds were discussed in Section 3.2.

3.3.2 Development of a Generic Model for the BEBR (*Step 2*)

The kernel of developing a generic model is that it can be modified or adjusted to be used for a particular firm or industry. The identified risk factors as listed in Table 3.1 are used for developing a generic model in a hierarchical structure form (i.e. Figure 3.3).

As shown in Figure 3.3, BEBR (i.e. Goal) is determined by four main criteria (i.e. political risks, economic risks, social risks and natural hazards). Sub-criteria of political risks consist of macro and micro political risks. Macro political risks indicate government instability (i.e. government unity, legislative strength and popular support), domestic conflict (i.e. civil war, political violence and civil disorder), foreign conflict (i.e. possibility of war, cross-border conflict and trade sanction), restriction in foreign enterprise policy, corruption and lawlessness. Micro political risks include customs-related risk, exchange control rules and excessive bureaucracy in trade. Sub-criteria of economic risks are divided into macroeconomic and microeconomic risks. The indicators for macroeconomic risks are the GDP per employed person, current account to GDP, exchange rate fluctuation, inflation rate and industrial production. The indicators for microeconomic risks are labour cost, freight rate fluctuation, and bunker price fluctuation. The sub-criteria of social risks consist of labour quality and availability in the market, working cultures, reputational risks, and religious/ethnic tensions. The sub-criteria of natural hazards consist of geophysical, meteorological, hydrological, climatological and biological disasters. Earthquakes, tsunamis, and ash from volcanic eruptions are classified as geophysical disasters; severe storms and tornadoes are classified as meteorological disasters; sea surges and coastal floods are categorised as hydrological disasters; extreme temperature, climate change and haze are classified as climatological disasters; and insect infestation and epidemic/pandemic diseases are categorised as biological disasters.

3.3.3 Establishing Weight Assignment for Each Criterion (*Step 3*)

A weight can be assigned to each criterion using established methods such as simple rating methods or more elaborate methods based on pair-wise comparisons (i.e. AHP). To compare the criteria or alternatives in a nature of pair-wise comparison mode, a fundamental scale of absolute numbers is used. Table 3.2 shows an example of the ratio scale of pair-wise comparison which consists of linguistic meaning and numerical assessment. In this table, the comparison scale is described as “1 i.e. equally important”, “3 i.e. weakly important”, “5 i.e. strongly important”, “7 i.e. very strongly important”, “9 i.e. extremely important” and “2, 4, 6 and 8 are intermediate values of important”. Each expert should understand the ratio scale of the pair-wise comparison before the assessment has been taken in order to avoid misjudgement.

Table 3.2: Comparison scale

Numerical Assessment (Scale)	Linguistic Meaning
1	Equally Important (EQ)
3	Weakly Important (WE)
5	Strongly Important (ST)
7	Very Strongly Important (VS)
9	Extremely Important (EX)
2, 4, 6, 8	Intermediate values between the two adjacent judgements (Inta, Intb, Intc, Intd)

To construct the pair wise-comparison matrix, firstly, set up n criteria in the row and column of an $n \times n$ matrix. Secondly, experts can perform the pair-wise comparison for all the criteria by applying the ratio scale as shown in Table 3.2. To quantify judgements on pairs of attributes, A_i and A_j are presented by an $n \times n$ matrix *D*. The entries a_{ij} are defined by entry rules as follows:

- Rule 1: If a_{ij} = α, then a_{ji} = 1/α, α ≠ 0.
- Rule 2: If A_i is judged to be of equal relative importance as A_j, then $a_{ij} = a_{ji} = 1$

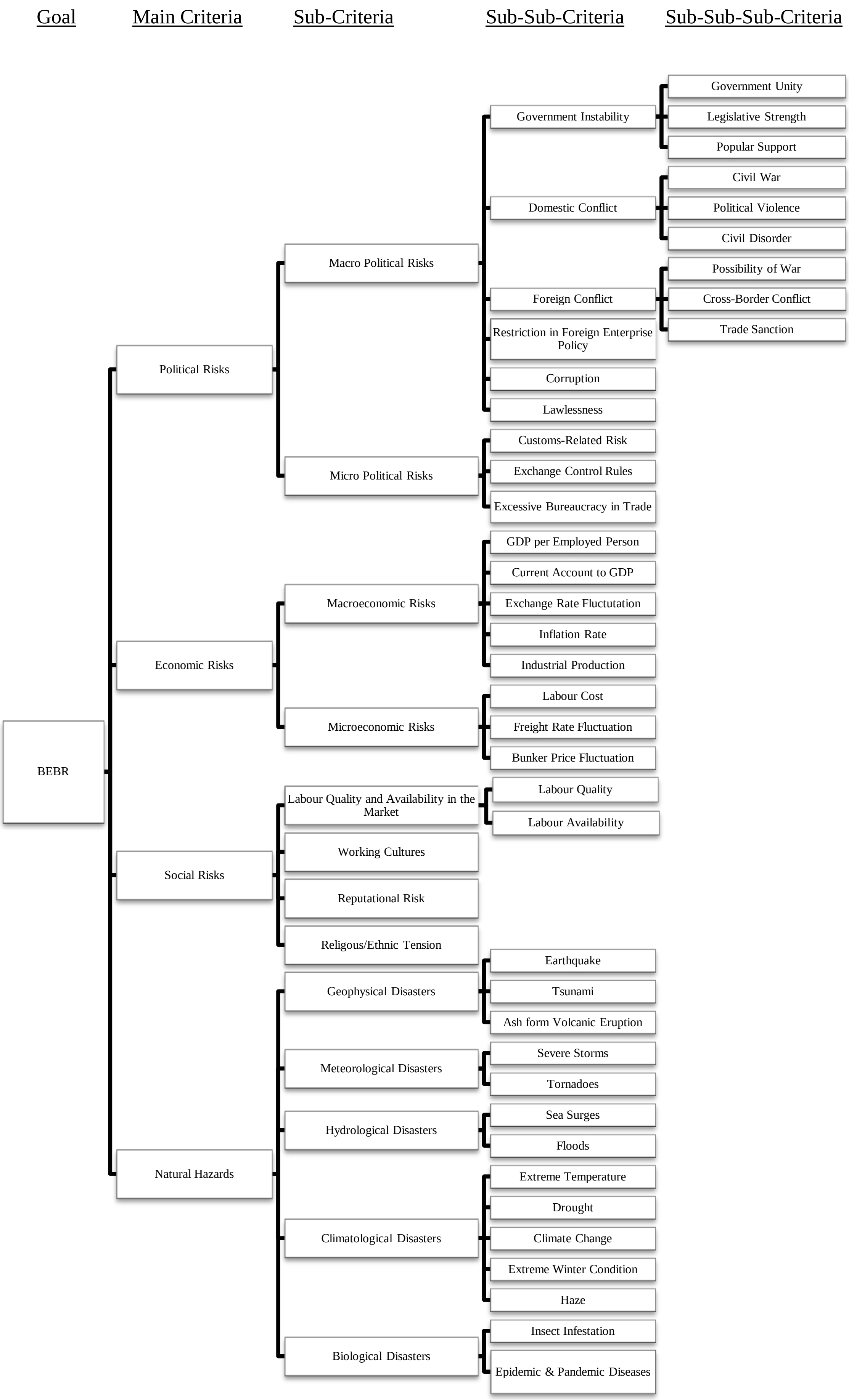

Figure 3.3: The generic BEBR model

According to above rules the matrix *D* is shown as follows:

$$D = a_{ij} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \cdot & \cdot & \cdots & \cdot \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \tag{3.1}$$

where *i*, *j* = 1, 2, …, *n* and each a_{ij} is the relative importance of attribute A_i to attribute A_j.

The quantified judgement of comparison on pair (A_i, A_j) is noted as a_{ij} in the matrix *D*; a further step is to allocate the weight vector for each criterion or alternative, as it indicates the prioritisation of the criteria or alternatives (Riahi *et al*., 2012a). A weight value w_k can be calculated as follows:

$$w_k = \frac{1}{n} \sum_{j=1}^{n} \left(\frac{a_{kj}}{\sum_{i=1}^{n} a_{ij}} \right) \; (k = 1, 2, 3, \ldots, n) \tag{3.2}$$

where a_{ij} stands for the entry of row *i* and column *j* in a comparison matrix of order *n*.

The judgements may be inconsistent due to different perceptions and belief with regard to criteria or alternatives. By using a Consistency Ratio (CR), inconsistency of the pair-wise comparisons can be measured; moreover, experts can obtain better consistency and improve the judgements by using CR computations (Saaty, 2008). If CR value is 0.10 or less, the consistency of the pair-wise comparison is considered reasonable, and the AHP can continue with the computations of weight vectors (Andersen *et al*., 2008; Riahi *et al*., 2012a). In contrast, a CR with a greater value than 0.10 indicates an inconsistency in the pair-wise judgements (Saaty, 1980). Thus, decision-makers should review the pair-wise judgements before proceeding. To check the consistency of the judgements, a Consistency Ratio (CR) is computed by using Equations 3.3-3.5 (Andersen *et al.*, 2008):

$$CR = \frac{CI}{RI} \tag{3.3}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3.4}$$

$$\lambda_{max} = \frac{\sum_{j=1}^{n} \left[\frac{\sum_{k=1}^{n} w_k \, a_{jk}}{w_j} \right]}{n} \tag{3.5}$$

where CI is the inconsistency index, RI is the average random index (Table 3.3), *n* is the number of items being compared, and λ_{max} is the maximum weight value of the *n* × *n* comparison matrix D.

Table 3.3: Value of average random index versus matrix order

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

3.3.4 Transferring Quantitative Criteria to Qualitative Criteria (*Step 4*)

Risk estimation and analysis can be done by using quantitative data. A quantitative analysis uses numerical values rather than the descriptive scales that are used in analysing the qualitative and semi-quantitative methods (Malaysian Department of Occupational Safety and Health, 2008). Numerical values can be obtained from historical evidence, scientific research, statistics, established reports, *etc*. In this study, quantitative data can be obtained from annual reports such as the International Country Risk Guide (ICRG) database, Trading Economics, World Bank database, Federal Reserve database, Corruption Perception Index (CPI) and Total Economy Database.

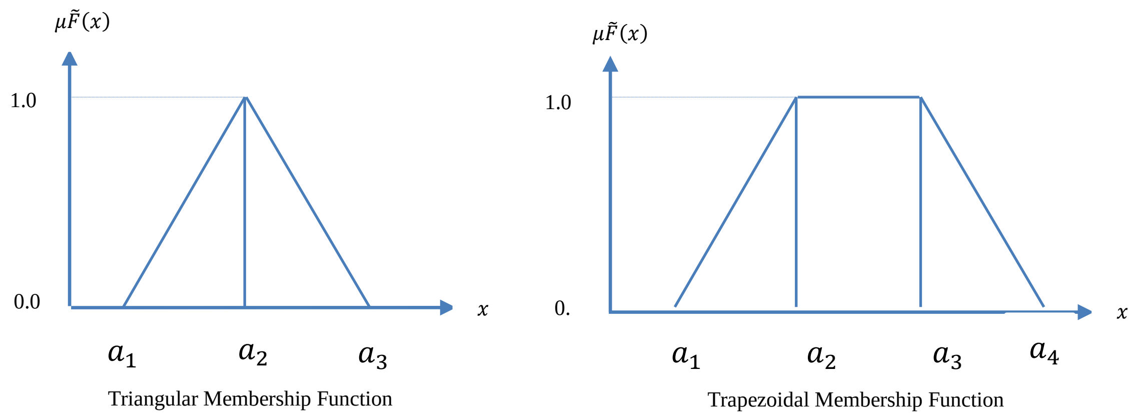

Figure 3.4: Triangular and trapezoidal membership functions

As the fuzzy logic assessment is used in this study, a quantitative criterion needs to be transformed to a qualitative criterion. This transformation can be done by using the membership function of a fuzzy continuous set. There are two types of membership function that are most commonly used, which are triangular and trapezoidal membership functions (Figure 3.4), due to their simple formula and computational efficiency (Riahi *et al.*, 2012a). In general, the degree of membership is often indicated on the vertical axis and with possible values ranging over the real interval [0, 1]. A fuzzy shape defines the relationship between the domain and the membership value of a set (Riahi *et al.*, 2012a).

The triangular membership functions can be calculated by using Equation 3.6:

$$\mu\tilde{F}(x) = \begin{cases} 0, & if\ x \leq a_1 \\ \frac{x-a_1}{a_2-a_1}, & if x \in\ ]a_1, a_2[\\ 1, & if x = a_2 \\ \frac{a_3-x}{a_3-a_2}, & if x \in\ ]a_2, a_3[\\ 0, & if\ x \geq a_3 \end{cases} \quad (3.6)$$

In this case a_2 is a modal value where $\mu\tilde{F}(x) = 1$; lower and upper bounds are presented by a_1 and a_3 and as shown in Figure 3.4.

The trapezoidal membership function can be calculated by using Equation 3.7:

$$\mu\tilde{F}(x) = \begin{cases} 0, & if\ x \leq a_1 \\ \frac{x-a_1}{a_2-a_1}, & if x \in\ ]a_1, a_2[\\ 1, & if x \in\ [a_2 a_3] \\ \frac{a_4-x}{a_4-a_3}, & if x \in\ ]a_3, a_4[\\ 0, & if\ x \geq a_4 \end{cases} \quad (3.7)$$

In this case a_2 and a_3 are modal values where $\mu\tilde{F}(x) = 1$; lower and upper bounds are presented by a_1 and a_4, as shown in Figure 3.4.

3.3.5 Measuring the Qualitative Criterion Belief Degree Concept (*Step 5*)

Due to the complex nature of the CLSI, LSOs face various critical issues in making better decisions for their business sustainability. Owing to a lack of data in the literature, imprecise information about past events, and high uncertainty about future events, a qualitative method can be employed in analysing some of the BEBR factors. There are various methods of qualitative data collection and one of them is through domain expert judgements.

A qualitative criterion can be presented by linguistic variables (i.e. linguistic terms and their corresponding belief degrees). Miller (1956) expressed the number of remarkable coincidences between the channel capacity of a number of human cognitive and perceptual tasks. Based on Miller's study, the effective channel capacity is between five and nine equally weighted errorless choices. In this chapter, all BEBR factors are presented by five linguistic terms, which are "very low", "low", "medium", "high", and "very high".

To illustrate the above linguistic terms, let $\tilde{B}_1, \tilde{B}_2$ and $\tilde{B}_3$ be three different experts who assess $\tilde{B}$ (bunker price fluctuation) as follows:

$\tilde{B}_1 = \{(0, very\ low), (0, low), (0, medium), (0.6, high), (0.4, very\ high)\}$

$\tilde{B}_2 = \{(0, very\ low), (0, low), (0.2, medium), (0.5, high), (0.3, very\ high)\}$

$\tilde{B}_3 = \{(0, very\ low), (, low), (0.5, medium), (0.5, high), (0, very\ high)\}$

These three assessments can be aggregated by using an ER algorithm (Sub-section 3.3.6).

3.3.6 Construction of ER calculation (*Step 6*)

The kernel of the ER approach is an ER algorithm developed on the basis of a multi-attribute evaluation framework and the evidence combination of the D-S theory (Yang and Xu, 2002). By using the ER algorithm, aggregation of multi-attributes in a hierarchical structure can be implemented. In a hierarchical structure, an upper level is assessed through associated lower level attributes. For example, *political risks, economic risks, social risks* and *natural hazards* are the subsets of the BEBR. If all these subsets are assessed to be exactly low risk, then the BEBR should also be low risk.

The top goal of a decision problem is usually unable to be assessed directly due to its generality; it needs to be disintegrated into a detailed concept; for example, to assess the BEBR for the CLSI, it can be broken down into *political risks*, *economic risks*, *social risks* and *natural hazards*. If the detailed concept is still too abstract to be assessed directly, it can be broken down until it meets the specific concepts. For example, social risks (R_3) can be measured by labour quality and availability (e_1), working cultures (e_2), reputational risk (e_3) and religious/ethnic tensions (e_5), which can be directly assessed and therefore referred to as basic attributes. The ER algorithm can be demonstrated as follows (Yang and Xu, 2002):

Suppose there is a simple two-level hierarchy of attributes with a general attribute at the top level and a number of basic attributes (subsets) at the bottom level. Suppose there are L basic attributes R_i $(i = 1, 2, 3, \dots, L)$ associated with a general attribute R. A set of L basic attributes is stated as follows:

$$R = \{R_1, \cdots, R_i, \cdots, R_L\} \qquad (3.8)$$

Given weight ω_i $(i = 1, 2, \cdots, L)$ of the basic attributes, where ω_i is the relative weight of the i^{th} basic attributes (e_i) with $0 \leq \omega_i \leq 1$. These weight values can be estimated using the AHP approach. Suppose N distinctive assessment grades are defined that collectively provide a complete set of standards for assessing attributes, as presented as $H =$

$\{H_1, H_2, \cdots H_n \cdots H_N\}$ (Yang and Xu, 2002; Mokhtari *et al.*, 2012). Consequently, five assessment grades for risk factors are defined as follows:

$$H = \{very\ low\ (H_1), Low\ (H_2), Medium\ (H_3), High\ (H_4), Very\ High\ (H_5)\}$$

Nevertheless, the assessment of attributes is denoted by belief degrees. A given assessment of attributes can be mathematically calculated using Equation 3.9 (Yang and Xu, 2002):

$$S(R_i) = \{(H_n, \beta_{n,i}), n = 1, 2, \dots, N\}, i = 1, 2, \dots, L \quad (3.9)$$

where H_n is the n^{th} assessment grade, and $\beta_{n,i}$ denotes a degree of belief satisfying $\beta_{n,i} \geq 0$ and $\sum_{n=1}^{N} \beta_{n,i} \leq 1$. An assessment $S(R_i)$ is called complete if $\sum_{n=1}^{N} \beta_{n,i} = 1$ and incomplete if $\sum_{n=1}^{N} \beta_{n,i} < 1$. To demonstrate it, let "R" represent the set of five risk expressions and be aggregated by two subsets, R_1 and R_2, as follows:

$$\tilde{R} = \{(\beta^1, very\ low), (\beta^2, low), (\beta^3, medium), (\beta^4, high), (\beta^5, very\ high)\}$$

$$\tilde{R}_1 = \{(\beta_1^1, very\ low), (\beta_1^2, low), (\beta_1^3, medium), (\beta_1^4, high), (\beta_1^5, very\ high)\}$$

$$\tilde{R}_2 = \{(\beta_2^1, very\ low), (\beta_2^2, low), (\beta_2^3, medium), (\beta_2^4, high), (\beta_2^5, very\ high)\}$$

where "very low", "low", "average", "high" and "very high" (risk expressions) are associated with their corresponding degree of belief. Given that M_1^m and M_2^m $(m = 1, 2, 3, 4, 5)$ are individual degrees to which the subsets R_1 and R_2 support the hypothesis that the risk assessment is confirmed to the five risk expressions, then M_1^m and M_2^m are obtained as (Riahi *et al*., 2012a):

$$M_1^m = \omega_1 \beta_1^m \quad (m = 1, 2, 3, 4, 5)$$

$$M_2^m = \omega_2 \beta_2^m \quad (m = 1, 2, 3, 4, 5) \quad (3.10)$$

Suppose that H_1 and H_2 are individual remaining belief values unassigned for M_1^m and M_2^m $(m = 1, 2, 3, 4, 5)$, then, H_1 and H_2 are calculated as follows (Riahi *et al*., 2012a):

$$H_1 = \overline{H}_1 + \widetilde{H}_1$$

$$H_2 = \overline{H}_2 + \widetilde{H}_2 \quad (3.11)$$

where $\overline{H}_n$ $(n = 1\ or\ 2)$ represents the degree to which the other assessor can play a role in the assessment, and $\widetilde{H}_n$ $(n = 1\ or\ 2)$ is caused by the possible incompleteness in the subsets R_1 and R_2. $\overline{H}_n$ $(n = 1\ or\ 2)$ and $\widetilde{H}_n$ $(n = 1\ or\ 2)$ are further calculated as follows (Yang and Xu, 2002; Riahi *et al*., 2012a):

$$\bar{H}_1 = 1 - \omega_1 = \omega_2$$
$$\bar{H}_2 = 1 - \omega_2 = \omega_1$$
$$\tilde{H}_1 = \omega_1\left(1 - \sum_{m=1}^{5} \beta_1^m\right) \tag{3.12}$$
$$\tilde{H}_2 = \omega_2(1 - \textstyle\sum_{m=1}^{5} \beta_2^m)$$

Suppose that $\beta^{m'}$ (m=1, 2, 3, 4 or 5) represents the non-normalised degree to which the risk assessment is confirmed to each of the five risk expressions as a result of the synthesis of the judgements produced by assessors 1 and 2. Suppose that $\bar{H}'_U$ represents the non-normalised remaining belief unassigned after the commitment of belief to the five risk expressions because of the synthesis of the judgements produced by assessors 1 and 2. The ER algorithm is represented by Equation 3.13 (Yang and Xu, 2002; Riahi *et al*., 2012a):

$$\beta^{m'} = K(M_1^m M_2^m + M_1^m H_2 + M_2^m H_1)$$
$$\bar{H}'_U = K(\bar{H}_1 \bar{H}_2)$$
$$\tilde{H}'_U = K\left(\tilde{H}_1 \tilde{H}_2 + \tilde{H}_1 \bar{H}_2 + \tilde{H}_2 \bar{H}_1\right) \tag{3.13}$$
$$K = \left(1 - \sum_{T=1}^{5} \sum_{\substack{R=1 \\ R \neq 1}}^{5} M_1^T M_2^R\right)^{-1}$$

Finally, the combined degrees of belief are generated by assigning $\bar{H}'_U$ back to the five risk expressions using the normalisation process as follows (Yang and Xu, 2002; Riahi *et al*., 2012a):

$$\beta^m = \frac{\beta^{m'}}{1 - \bar{H}'_U} \ (m = 1, 2, 3, 4, 5)$$
$$H_U = \frac{\tilde{H}'_U}{1 - \bar{H}'_U} \tag{3.14}$$

where H_U is the unassigned degree of belief to any individual assessment after all the L subsets have been assessed. It represents the extent of incompleteness in the overall assessment.

As mentioned in Sub-section 2.6.3, the ER approach uses a belief decision matrix with two-dimensional values; the calculation involved in the aggregation processes could be more complicated than some traditional methods. With the help of the IDS software package, a process of aggregation in the hierarchical structure can be implemented.

Consequently, the IDS software package will be employed in the case study to synthesise the BEBR criteria.

3.3.7 Utility Value Calculation (***Step 7***)

The result of the BEBR assessment is presented by the five linguistic terms (i.e. very low risk, low risk, medium risk, high risk and very high risk). From this result, which is associated with a fuzzy set, a single value which is useful to professional decision-makers for ranking the alternatives and for comparison purposes can be evaluated. Consequently, a utility value approach concept developed by Yang (2001) is used in this study to obtain a single crisp number for a goal that can be calculated by using Equations 3.15 and 3.16.

$$u(H_n) = \frac{V_n - V_{min}}{V_{max} - V_{min}} \tag{3.15}$$

$$U_v = \sum_{n=1}^{N} \beta_n u(H_n) \tag{3.16}$$

where $u(H_n)$ denotes the utility value of each linguistic term (i.e. H_n) and can be estimated using Equation 3.15. V_n is the ranking value of the linguistic term that has been considered (H_n); V_{max} is the ranking value of the highest-risk linguistic term H_N; and V_{min} is the ranking value of the lowest-risk linguistic term (H_1). In Equation 3.16, the utility of the concerned criterion (i.e. goal) is denoted by U_v, and β_n stands for the belief degree associated with the n^{th} linguistic term of the concerned criterion.

3.3.8 Model and Result Validation (***Step 8***)

There are several techniques to validate a knowledge-based system: by field test, subsystem validation and sensitivity analysis (Mokhtari *et al.*, 2012). Nevertheless, sensitivity analysis (SA) is the most preferred method when dealing with the uncertainty consideration. SA can be defined as the process of analysing how sensitive the result of a belief update (i.e. change in input belief degrees) is to variations of the parameters' value in the model. Technically, SA is a very useful technique for analysing how sensitive the conclusions (i.e. model output) are. In addition, SA can be used to calculate the impact of parameter changes on the model output. As a result, the robustness of the FER model in this case will be tested through sensitivity analysis.

In this study, SA is employed to scrutinise the sensitivity of the BEBR model to an individual criterion or risk factor. In order to ensure the methodology is consistent, the SA must at least meet the following axioms (Riahi *et al.*, 2012a):

Axiom 1: A slight increase in the degree of belief associated with the highest linguistic term of a lowest-level criterion will certainly result in a relative increment in preference degree of the model output.

Axiom 2: A slight increase in the degree of belief associated with the highest linguistic term of a lowest-level criterion by l and m will simultaneously result in the decrease of the degree of belief associated with its lowest linguistic term by l and m ($1 > m > l$), and the utility values of the model are evaluated as U_l and U_m respectively; then U_l should be greater than U_m.

Axiom 3: If N and K ($K < N$) criteria from all the lowest-level criteria are selected and the degrees of belief associated with their highest linguistic terms are increased by the same amount (i.e. simultaneously the degree of beliefs associated with their lowest linguistic terms are decreased by the same amount) and the utility values of the model output are evaluated as U_K and U_N respectively, then U_N should be greater than U_K.

The use of SA is only for testing the logicality of the delivery of the analysis result as it is used to calculate the impact of parameter changes on the model output. As a result, SA is called 'partial validation' due to its locality analysis. To ensure that the BEBR assessment model can be used in the CLSI, the result of the model needs to be validated by using external statistics for comparison. Consequently, the result of the BEBR model will be compared and cross-validated with benchmarks.

3.4 Test Case

3.4.1 Data Information

In this test case, the Malaysian CLSI is selected as a case study. For the assessment of the BEBR, a decision-maker has to deal with both qualitative and quantitative data. For quantitative data collection, established databases will be used such as the ICRG, Federal Reserve, Trading Economics, CPI and World Bank. On the other hand, to deal with qualitative data, five domain experts in the CLSI are approached to perform the pair-wise comparison for the BEBR factors. To evaluate the qualitative risk factors, three domain experts working in the CLSI are approached to assign the appropriate grade for every risk factor under fuzzy environments.

The selection of domain experts for subjective judgements was based on their experiences and qualifications. In this study, the domain experts have at least 15 years' experience in the CLSI. The methods of evaluation are conducted through telephone interviews between the researcher and the domain experts, who are guided with an evaluation form which was given to them in advance.

3.4.2 Identification of the BEBR Criteria and Development of a Model for BEBR (*Steps 1 and 2*)

As mentioned in Sub-section 3.3.1, risk factor identification is concerned with the comprehensive and structured recognition, determination and collection of potential external risks to the CLSI. Through the extensive literature review, the 42 assessment criteria (Table 3.1) that adversely affect the business environment of LSOs are identified. In this test case, these criteria are further revised to avoid the unnecessary extension of the model's size. Only those criteria that are significant to the CLSI in Malaysia are considered, and insignificant criteria were omitted from the model. As shown in Table 3.4, 34 assessment criteria are selected.

Table 3.4: Summary of revised factors for assessing the BEBR

Main Criteria	Sub-criteria	Sub-sub-criteria
Political Risks	Macro Political Risks	Government Instability, Domestic Conflict, Foreign Conflict, Restriction in Foreign Enterprise Policy, Corruption, Lawlessness
	Micro Political Risks	Customs-Related Risk, Exchange Control Rules, Excessive Bureaucracy in Trade
Economic Risks	Macroeconomic Risks	GDP per Employed Person, Current Account to GDP, Exchange Rate Fluctuation, Inflation Rate, Industrial Production
	Microeconomic Risks	Labour Cost, Freight Rate Fluctuation, Bunker Price Fluctuation
Social Risks	Labour Quality and Availability	Labour Quality, Labour Availability
	Working Culture	
	Reputational Risks	
	Religious/Ethnic Tensions	
Natural Hazards	Geophysical Disasters	Earthquakes, Tsunamis, Ash from Volcanic Eruption
	Meteorological Disasters	Severe Storms, Tornadoes
	Hydrological Disasters	Sea Surges, Floods
	Climatological Disasters	Extreme Temperatures, Climate Change, Haze
	Biological Disasters	Insect Infestations, Epidemic/Pandemic Diseases

The kernel of developing a generic model is that it can be modified or adjusted to be used for a particular firm or industry. In this test case, based on the revision that has been made, the insignificant risk factors for Malaysia are withdrawn from the model. Consequently, the BEBR factors, as shown in Table 3.4, are used for developing a specific model in a hierarchical structure (i.e. Figure. 3.5).

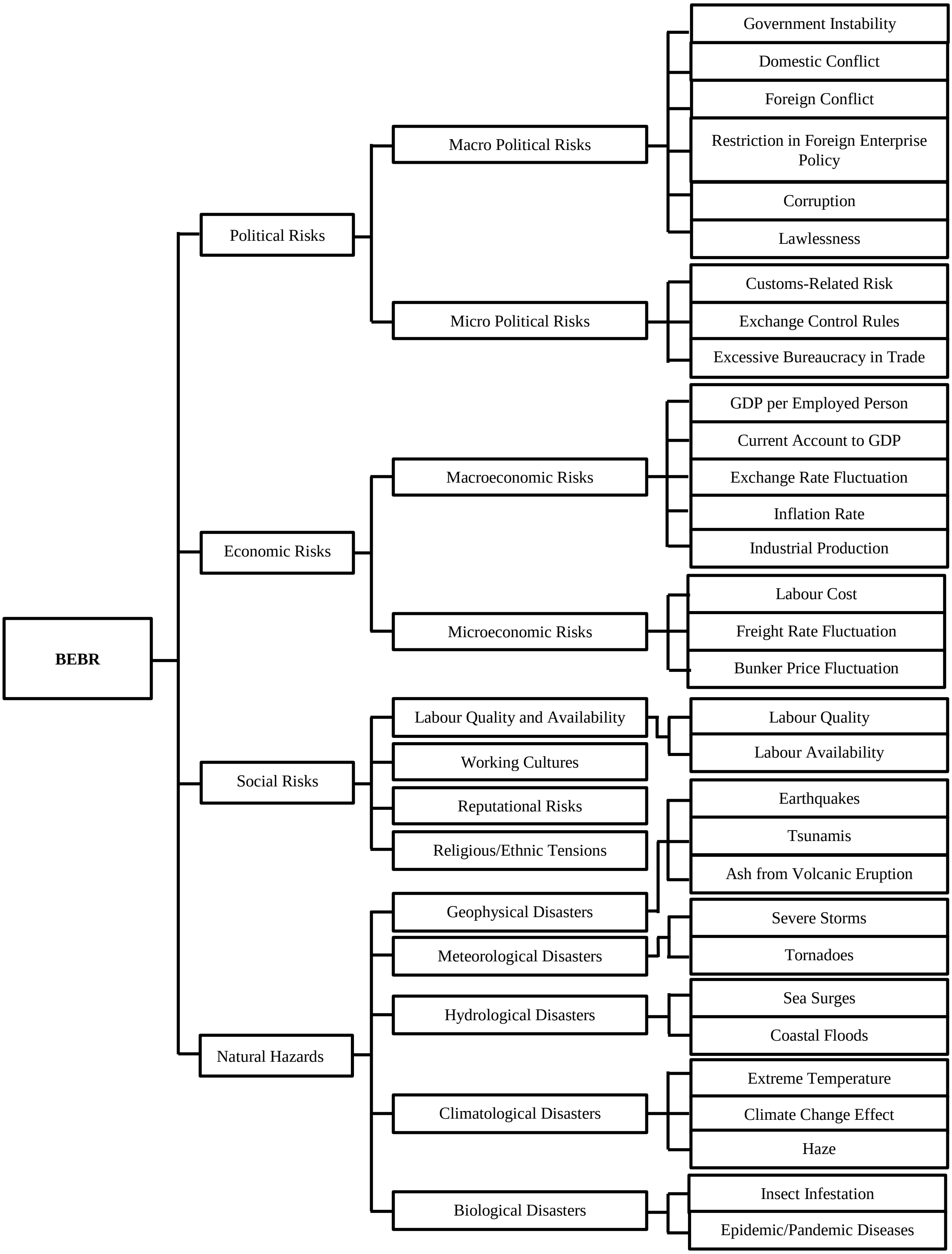

Figure 3.5: The specific BEBR model

Based on Miller (1956), as shown in Table 3.5, five assessment grades were assigned to all qualitative criteria.

Table 3.5: Assessment grades for the BEBR criteria

Assessment Grades						
Goal	BEBR	Very Low	Low	Medium	High	Very High
Main Criteria	Political Risks	Very Low	Low	Medium	High	Very High
	Economic Risks	Very Low	Low	Medium	High	Very High
	Social Risks	Very Low	Low	Medium	High	Very High
	Natural Hazards	Very Low	Low	Medium	High	Very High
Sub-criteria	Macro Political Risks	Very Low	Low	Medium	High	Very High
	Micro Political Risks	Very Low	Low	Medium	High	Very High
	Macroeconomic Risks	Very Low	Low	Medium	High	Very High
	Microeconomic Risks	Very Low	Low	Medium	High	Very High
	Labour Quality and Availability	Very Low	Low	Medium	High	Very High
	Working Cultures	Very Low	Low	Medium	High	Very High
	Reputational Risks	Very Low	Low	Medium	High	Very High
	Religious/Ethnic Tension	Quantitative (Based on the ICRG database)				
	Geophysical Disasters	Very Low	Low	Medium	High	Very High
	Meteorological Disasters	Very Low	Low	Medium	High	Very High
	Hydrological Disasters	Very Low	Low	Medium	High	Very High
	Climatological Disasters	Very Low	Low	Medium	High	Very High
	Biological Disasters	Very Low	Low	Medium	High	Very High
Sub-sub-criteria	Government Instability	Quantitative (Based on the ICRG database)				
	Domestic Conflict	Quantitative (Based on the ICRG database)				
	Foreign Conflict	Quantitative (Based on the ICRG database)				
	Restriction in Foreign Enterprise Policy	Very Low	Low	Medium	High	Very High
	Corruption	Quantitative (Based on the CPI database)				
	Lawlessness	Quantitative (Based on the ICRG database)				
	Customs-Related Risk	Very Low	Low	Medium	High	Very High
	Exchange Control Rules	Very Low	Low	Medium	High	Very High
	Excessive Bureaucracy in Trade	Very Low	Low	Medium	High	Very High
	GDP per Employed Person	Quantitative (Based on the Total Economy Database™)				
	Current Account to GDP	Quantitative (Based on the ICRG database)				
	Exchange Rate Fluctuation	Quantitative (Based on the ICRG database)				
	Inflation Rate	Quantitative (Based on the ICRG database)				
	Industrial Production	Quantitative (Based on the Trading Economics database)				
	Labour Cost	Very Low	Low	Medium	High	Very High
	Freight Rate Fluctuation	Very Low	Low	Medium	High	Very High
	Bunker Price Fluctuation	Very Low	Low	Medium	High	Very High
	Labour Quality	Very Low	Low	Medium	High	Very High
	Labour Availability	Very Low	Low	Medium	High	Very High
	Earthquake	Very Low	Low	Medium	High	Very High
	Tsunami	Very Low	Low	Medium	High	Very High
	Ash from Volcanic Eruption	Very Low	Low	Medium	High	Very High
	Severe Storms	Very Low	Low	Medium	High	Very High
	Tornadoes	Very Low	Low	Medium	High	Very High
	Sea Surges	Very Low	Low	Medium	High	Very High
	Coastal Floods	Very Low	Low	Medium	High	Very High
	Extreme Temperature	Very Low	Low	Medium	High	Very High
	Climate Change	Very Low	Low	Medium	High	Very High
	Haze	Very Low	Low	Medium	High	Very High
	Insect Infestation	Very Low	Low	Medium	High	Very High
	Epidemic/Pandemic Disease	Very Low	Low	Medium	High	Very High

3.4.3 Establishing Weight Assignment for Each Criterion (*Step 3*)

The AHP method is used to assign a weight to each criterion using pair-wise comparisons. Five selected experts, each with more than 15 years' experience in the CLSI, were approached (Mokhtari *et al*., 2012). The following five domain experts are listed as follows:

1. A planning manager for an international liner shipping company in Malaysia who has worked in the CLSI for about 15 years.
2. A senior manager for an international liner shipping company in Malaysia who has worked in the CLSI for about 15 years.
3. A senior manager for an international liner shipping company in Malaysia who has worked in the CLSI for about 15 years (i.e. from a different company).
4. A senior lecturer who has been involved in the maritime industry for more than 20 years.
5. A senior lecturer who has been involved in Malaysian maritime policy for more than 15 years.

Due to difficulties in assigning weights for experts and to avoid prejudgment, they are assigned with equal weight (Riahi *et al*., 2012a; Mokhtari *et al*., 2012). For the four main criteria, a 4×4 pair-wise comparison matrix needs to be developed for obtaining the weight for each criterion. For example, $D(P_R E_R S_R N_H)$ is a matrix for comparing the relative priority of the political risks, economic risks, social risks and natural hazards. To obtain the aggregated comparison matrices, geometric mean is used in this study to aggregate judgements of individuals within a group. As an example, for evaluating the priority of the criterion "P_R" to the criterion "S_R", expert one (e_1) ticked number 1, expert two (e_2) ticked number 2, expert three (e_3) ticked number 1, expert four (e_4) ticked number 5 and expert five (e_5) ticked number 3. The geometric mean of the importance of the criterion "P_R" to the "S_R" can be calculated as follows (Aull-Hyde *et al*., 2006):

$$Geometric\ Mean_{ij} = \left[e_{ij}^{1} \cdot e_{ij}^{2} \cdot e_{ij}^{3} \cdots e_{ij}^{k}\right]^{\frac{1}{k}} \tag{3.17}$$

where "k" is the number of participant and e_{ij}^{k} stand for the k^{th} expert opinion for relative importance of the i^{th} criterion to the j^{th} criterion. As a result, the GM of the importance of the criterion "P_R" to the "S_R" is: $(1 \times 2 \times 1 \times 5 \times 3)^{\frac{1}{5}}$ =1.97. The same calculation technique is applied to all pair-wise comparisons for the aggregation processes. Based on Equations 3.1-3.5, the a_{ij} values can be evaluated as follows:

The matrix D for the main criteria is obtained as follows:

$$D(P_R E_R S_R N_H) = \begin{bmatrix} 1 & 0.80 & 1.97 & 1.11 \\ 1.25 & 1 & 1.82 & 1.40 \\ 0.51 & 0.55 & 1 & 0.44 \\ 0.90 & 0.71 & 2.27 & 1 \end{bmatrix}$$

Weight calculation for each main criterion is demonstrated as follows:

$$w_{PR} = \frac{1}{4}\left(\frac{1}{1+1.25+0.51+0.90}\right) + \left(\frac{0.80}{0.80+1+0.55+0.71}\right) + \left(\frac{1.97}{1.97+1.82+1+2.27}\right) + \left(\frac{1.11}{1.11+1.40+0.44+1}\right) = 0.2737$$

$$w_{ER} = \frac{1}{4}\left(\frac{1.25}{1+1.25+0.51+0.90}\right) + \left(\frac{1}{0.80+1+0.55+0.71}\right) + \left(\frac{1.82}{1.97+1.82+1+2.27}\right) + \left(\frac{1.40}{1.11+1.40+0.44+1}\right) = 0.3201$$

$$w_{SR} = \frac{1}{4}\left(\frac{0.51}{1+1.25+0.51+0.90}\right) + \left(\frac{0.55}{0.80+1+0.55+0.71}\right) + \left(\frac{1}{1.97+1.82+1+2.27}\right) + \left(\frac{0.44}{1.11+1.40+0.44+1}\right) = 0.1430$$

$$w_{NH} = \frac{1}{4}\left(\frac{0.90}{1+1.25+0.51+0.90}\right) + \left(\frac{0.71}{0.80+1+0.55+0.71}\right) + \left(\frac{2.27}{1.97+1.82+1+2.27}\right) + \left(\frac{1}{1.11+1.40+0.44+1}\right) = 0.2632$$

As a result, w_{PR}, w_{ER}, w_{SR} and w_{NH} are evaluated as 0.2737, 0.3201, 0.1430 and 0.2632. A further step is to calculate and check the consistency ratio of the pair-wise comparison. Firstly, λ_{max} is calculated as to lead to the consistency index (*CI*) and consistency ratio (*CR*).

$$P_R = (1 \times 0.2737) + (0.80 \times 0.3201) + (1.97 \times 0.1430) + (1.11 \times 0.2632) = 1.1037$$
$$E_R = (1.25 \times 0.2737) + (1 \times 0.3201) + (1.82 \times 0.1430) + (1.40 \times 0.2632) = 1.2910$$
$$S_R = (0.51 \times 0.2737) + (0.55 \times 0.3201) + (1 \times 0.1430) + (0.44 \times 0.2632) = 0.5745$$
$$N_H = (0.90 \times 0.2737) + (0.71 \times 0.3201) + (2.27 \times 0.1430) + (1 \times 0.2632) = 1.0614$$

$$\lambda_{max} = \frac{\left(\frac{1.1037}{0.2737}\right) + \left(\frac{1.2910}{0.3201}\right) + \left(\frac{0.5745}{0.1430}\right) + \left(\frac{1.0614}{0.2632}\right)}{4} = 4.029$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{4.029 - 4}{4 - 1} = 0.0097$$

Based on Table 3.3, the random index (*RI*) for the four criteria is 0.9000. As a result, the *CR* is calculated as follows:

$$CR = \frac{CI}{RI} = \frac{0.0097}{0.90} = 0.0108$$

The *CR* value for the main criteria is 0.0108. Saaty (1980) stated that a *CR* ≤ 0.1 indicates that the judgements are acceptable. As a result, the consistency of the pair-wise comparison for the main criteria is acceptable. The same calculation technique is applied to rank the sub-criteria and sub-sub-criteria in the given attributes. The weight values and consistency ratio values for the sub- and sub-sub-criteria are shown in Table 3.6.

3.4.4 Transferring Quantitative Criteria to Qualitative Criteria (*Step 4*)

In order to perform an assessment under a fuzzy environment, quantitative criteria need to be transformed to qualitative criteria. Based on the available information, the quantitative criteria can be modelled as follows:

3.4.4.1 Government Instability

Based on the ICRG methodology, risk ratings for government stability of Malaysia can be interpreted as a risk value for government instability (PRS Group, 2012). To construct the membership functions of government instability, Triangular Fuzzy Numbers (TFN) are used. The vertical axis represents the degree of a membership and the horizontal axis shows the quantitative numbers (i.e. rating numbers).

If there is any quantitative number (e.g. h_i) plotted in the range of $h_{n+1,i}$ (with a grade H_{n+1}) and $h_{n,i}$ (with a grade H_n), the belief degrees can be evaluated as follows (Riahi *et al.*, 2012a):

$$\text{If } h_{n,i} < h_i < h_{n+1,i} \text{ then } \beta_{n,i} = \frac{h_{n+1,i} - h_i}{h_{n+1,i} - h_{n,i}}, \beta_{n+1,i} = 1 - \beta_{n,i} \qquad (3.18)$$

where $\beta_{n,i}$ is the belief degree of the particular quantitative number with the grade H_n and $\beta_{n+1,i}$ is the belief degree of the particular quantitative number with the grade H_{n+1}.

Table 3.6: Result of weight values and consistency ratios for all main, sub- and sub-sub-criteria in the BEBR model

Goal	Main Criteria	Weights	Sub-criteria	Weights	Sub-sub-criteria	Weights
BEBR	Political Risks	0.2737	Macro Political Risks	0.5000	Government Instability	0.2109
					Domestic Conflict	0.1781
					Foreign Conflict	0.2055
					Restriction in Foreign Enterprise Policy	0.1442
					Corruption	0.1373
					Lawlessness	0.1240
					***CR*=**	0.0253
			Micro Political Risks	0.5000	Customs-Related Risk	0.2757
			***CR*=**	0.0000	Exchange Control Rules	0.4411
					Excessive Bureaucracy in Trade	0.2832
					***CR*=**	0.0237
	Economic Risks	0.3201	Macroeconomic Risks	0.6260	GDP per Employed Person	0.2584
					Current Account to GDP	0.2342
					Exchange Rate Fluctuation	0.1819
					Inflation Rate	0.1480
					Industrial Production	0.1775
					***CR*=**	0.0102
			Microeconomic Risks	0.3740	Labour Cost	0.2667
			***CR*=**	0.0000	Freight Rate Fluctuation	0.3099
					Bunker Price Fluctuation	0.4234
					***CR*=**	0.0018
	Social Risks	0.1430	Labour Quality and Availability in the Market	0.3862	Labour Quality	0.6538
					Labour Availability	0.3462
			Working Cultures	0.2022	***CR*=**	0.0000
			Reputational Risk	0.2097		
			Religion and Ethnic Tension	0.2019		
			***CR*=**	0.0178		

Natural Hazards		0.2632	Geophysical Disasters		0.3336	Earthquake		0.4438
	CR **=**	0.0108				Tsunami		0.4438
						Ash from Volcanic Eruption		0.1124
							***CR*=**	0.0000
			Meteorological Disasters		0.1985	Severe Storms		0.6137
						Tornadoes		0.3863
							***CR*=**	0.0000
			Hydrological Disasters		0.1286	Sea Surges		0.5000
						Coastal Flood		0.5000
							***CR*=**	0.0000
			Climatological Disasters		0.1990	Extreme Temperatures		0.3684
						Climate Change		0.3858
						Haze		0.2458
							***CR*=**	0.0018
			Biological Disasters		0.1403	Insect Infestation		0.3462
				***CR*=**	0.0095	Epidemic/Pandemic Diseases		0.6538
							***CR*=**	0.0000

Based on the ICRG methodology, a score point for Malaysia is 6.5 out of 12, where a score of 12 points (i.e. highest point) equates to very low risk and a score of 0 (i.e. lowest point) to very high risk (PRS Group, 2012). In order to avoid prejudgement, scores are uniformly distributed in the form of triangular membership functions. By using Equation 3.18 and Figure 3.6, the belief degrees are calculated as follows.

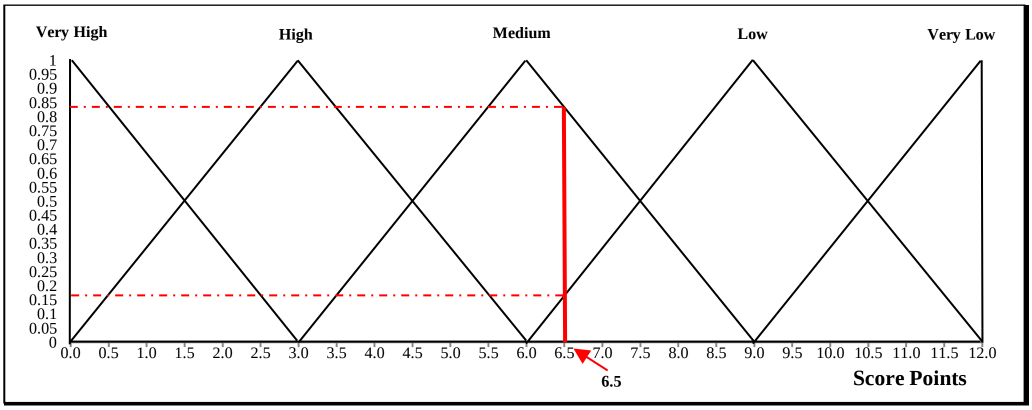

Figure 3.6: Membership functions for government instability

1. H_n is Medium Risk
2. H_{n+1} is Low Risk
3. h_i = 6.5, $h_{n,i}$ = 6 and $h_{n+1,i}$ = 9.
4. $\beta_{n,i}$ = (9-6.5) / (9-6) = 0.83 with Medium Risk and $\beta_{n+1,i}$ = 1-0.83 = 0.17 with Low Risk.

Based on Figure 3.6, the set for government instability in Malaysia is evaluated as:

GI = {(Very Low, 0), (Low, 0.17), (Medium, 0.83), (High, 0), (Very High, 0)}

3.4.4.2 Domestic Conflict

Based on the ICRG methodology, a score point of internal conflict can be used to evaluate domestic conflict in this study (PRS Group, 2012). A score point for Malaysia is 10 out of 12, where a score of 12 points (i.e. highest point) equates to very low risk and a score of 0 (i.e. lowest point) to very high risk. Scores are uniformly distributed in the form of triangular membership functions. By using Equation 3.18 and Figure 3.7, the belief degrees are calculated as follows.

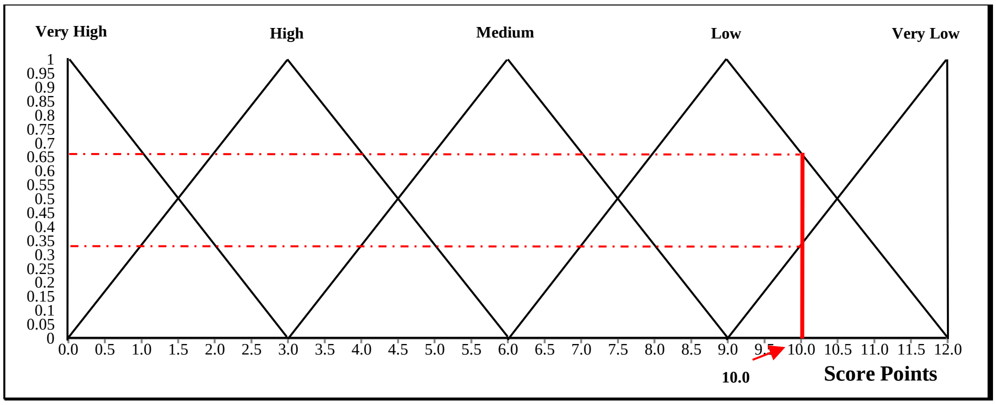

Figure 3.7: Membership functions for domestic conflict

Based on Figure 3.7, the set for domestic conflict in Malaysia is evaluated as:

DI = {(Very Low, 0.33), (Low, 0.67), (Medium, 0), (High, 0), (Very High, 0)}

3.4.4.3 Foreign Conflict

Based on the ICRG methodology, a score point of external conflict can be used to evaluate foreign conflict in this study (PRS Group, 2012). A score point for Malaysia is 10.5 out of 12, where a score of 12 points (i.e. highest point) equates to very low risk and a score of 0 (i.e. lowest point) to very high risk. Scores are uniformly distributed in the form of triangular membership functions. By using Equation 3.18 and Figure 3.8, the belief degrees are calculated as follows.

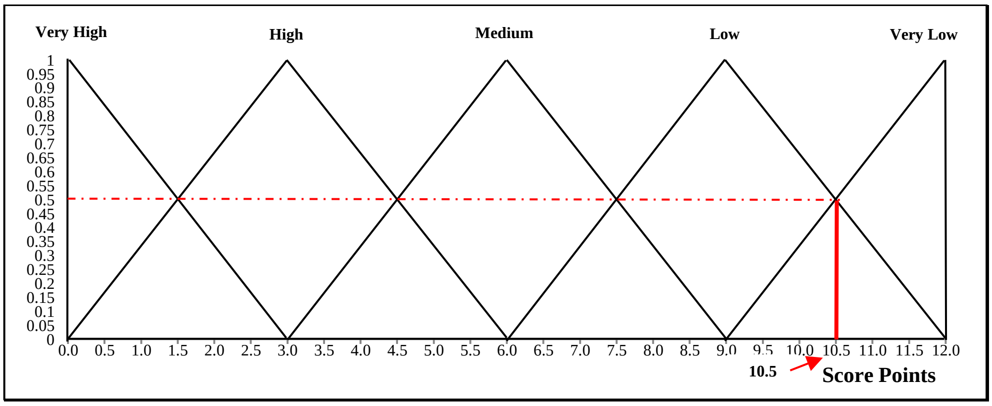

Figure 3.8: Membership functions for foreign conflict

Based on Figure 3.8, the set for foreign conflict in Malaysia is evaluated as:

FC = {(Very Low, 0.5), (Low, 0.5), (Medium, 0), (High, 0), (Very High, 0)}

3.4.4.4 Corruption

Based on the CPI (2012) score, the corruption risk of concerned countries can be modelled. The CPI (2012) scores are based on how corrupt a country's public sector is perceived to be. The index is produced by a combination of surveys and assessment of corruption, collected by a variety of reputable institutions. A trapezoidal fuzzy number is used to reflect the measurement scale produced by the CPI (2012). Based on the CPI statistics and further consultation with domain experts in the CLSI, a score between 0 and 20 can be assessed as very high, between 30 and 40 as high, between 50 and 60 as medium, between 70 and 80 as low, and between 90 and 100 as very low. Based on the CPI database, a score point for Malaysia is assessed as 49 out of 100. By using Equation 3.18 and Figure 3.9, the belief degrees are calculated as follows.

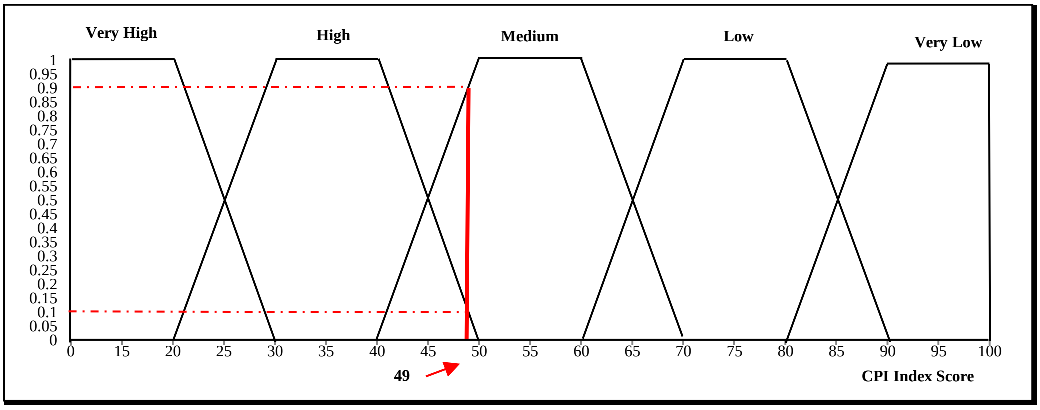

Figure 3.9: Membership functions for corruption risk

Based on Figure 3.9, the set for corruption risk in Malaysia is evaluated as:

$$CR = \{(\text{Very Low}, 0), (\text{Low}, 0), (\text{Medium}, 0.9), (\text{High}, 0.1), (\text{Very High}, 0)\}$$

3.4.4.5 Lawlessness

Based on the ICRG methodology, a score point of law and order can be used (PRS Group, 2012). A score point for Malaysia is 3 out of 6, where a score of 6 points (i.e. highest point) equates to very low risk and a score of 0 (i.e. lowest point) to very high risk. A rule has been stated based on a uniform distribution in the form of triangular membership functions. By using Equation 3.18 and Figure 3.10, the belief degrees are calculated as follows.

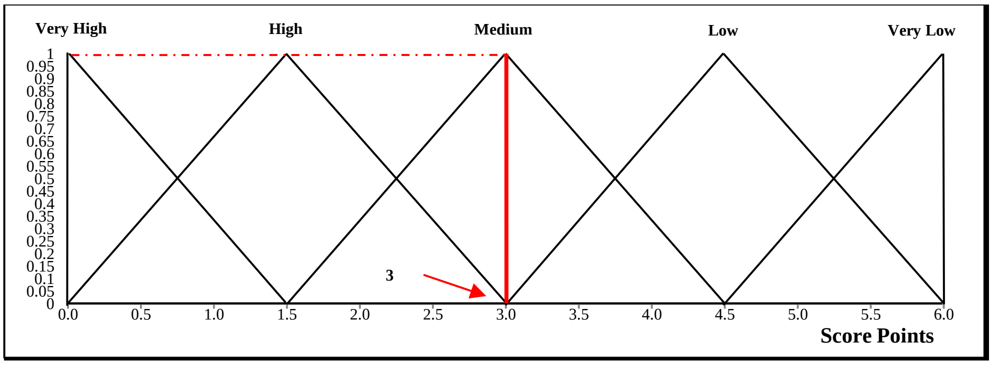

Figure 3.10: Membership functions for lawlessness

Based on Figure 3.10, the set for lawlessness in Malaysia is evaluated as:

LAWLESSNESS = {(Very Low, 0), (Low, 0), (Medium, 1), (High, 0), (Very High, 0)}

3.4.4.6 GDP per Employed Person

Based on the available data from the Total Economy Database™ (2013) produced by the Conference Board**,** GDP per Employed Person can be modelled. The GDP per Employed Person of the US is rated based on percentage, where a score of 100% or above equates to very low risk and a score of 0% to very high risk. Scores are uniformly distributed in the form of triangular membership functions. Based on the Total Economy Database™ (2013), the GDP per Employed Person of Malaysia is rated as 34.4%. By using Equation 3.18 and Figure 3.11, the belief degrees are calculated as follows.

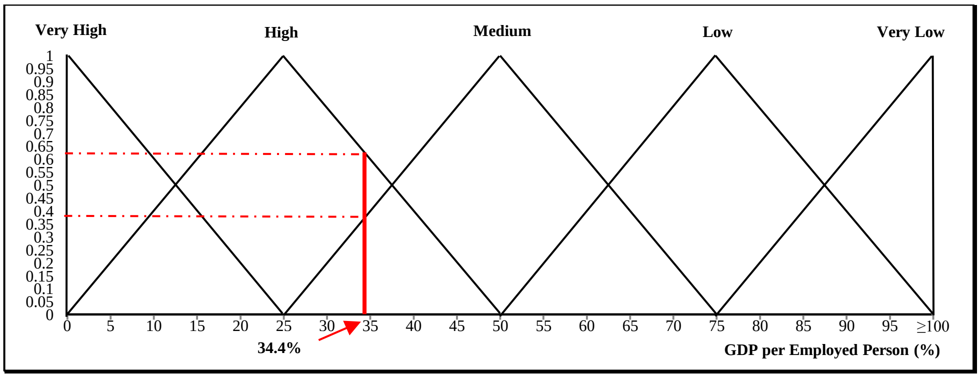

Figure 3.11: Membership functions for GDP per Employed Person

Based on Figure 3.11, the set for GDP per Employed Person in Malaysia is evaluated as:

GDP PPP = {(Very Low, 0), (Low, 0), (Medium, 0.38), (High, 0.62), (Very High, 0)}

3.4.4.7 Current Account to GDP

Based on the ICRG methodology, the current account to GDP of concerned countries can be modelled (PRS Group, 2012). Based on the ICRG methodology, the current account to GDP of 10% or more can be assessed as very low risk, -1% as low risk, -15% as medium risk, -23% as high risk and -40% as very high risk. The current account to GDP for Malaysia is assessed as 11.5%. Consequently, the belief degrees for current account to GDP are calculated as follows.

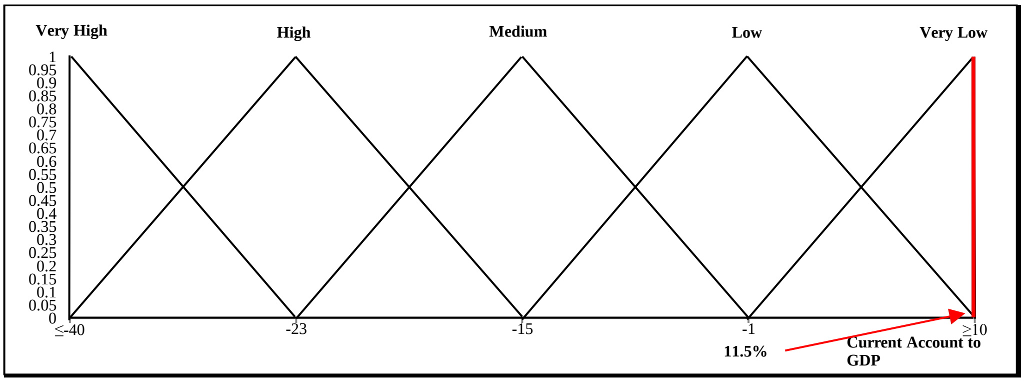

Figure 3.12: Membership functions for current account to GDP

Based on Figure 3.12, the set for current account to GDP in Malaysia is evaluated as:

CA to GDP = {(Very Low, 1), (Low, 0), (Medium, 0), (High, 0), (Very High, 0)}

3.4.4.8 Exchange Rate Fluctuation

Based on the ICRG methodology, the exchange rate fluctuation of a country can be modelled (PRS Group, 2012). Based on the ICRG methodology, the depreciation of currency against the US dollar between -0.1% and -4.9% can be considered as very low risk, between -15% and -17.4% as low risk, between -30% and -34.9% as medium risk, between -55% to -59.9% as high risk and -100% or below as very high risk. For the appreciation changes, a fluctuation between 0% and +9.9% can be assessed as very low risk, between +25% and +27.4% as low risk and +50% or more as medium risk. The linguistic variables “high risk” and “very high risk” are not applicable for the appreciation changes (i.e. based on the ICRG methodology). The exchange rate fluctuation for Malaysia is assessed as 10.8% (World Bank, 2012). Since range values are used to represent each linguistic variable, the trapezoidal membership functions are used. Consequently, the belief degrees for exchange rate fluctuation are calculated as follows.

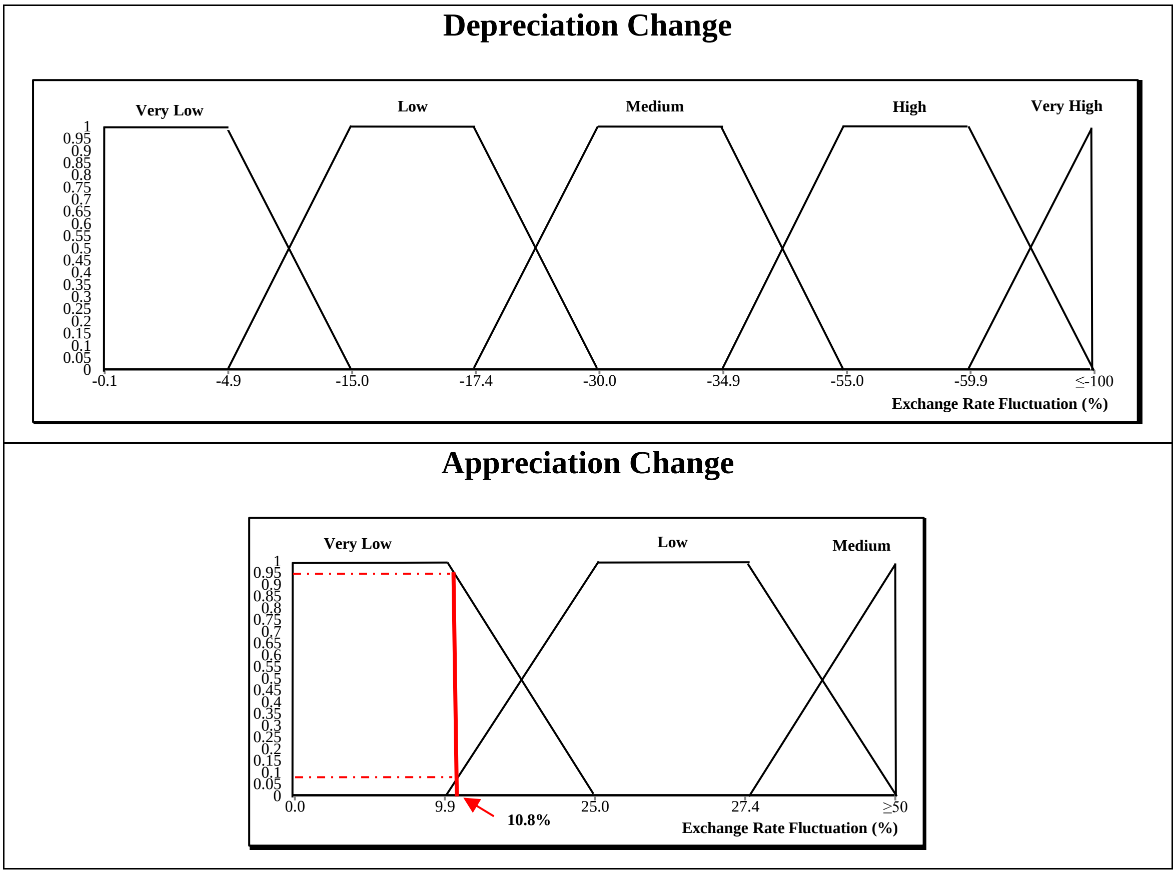

Figure 3.13: Membership functions for exchange rate fluctuation

Based on Figure 3.13, the set for exchange rate fluctuation in Malaysia is evaluated as:

ERF = {(Very Low, 0.94), (Low, 0.06), (Medium, 0), (High, 0), (Very High, 0)}

3.4.4.9 Inflation Rate

Based on the ICRG methodology, the inflation rate of concerned countries can be modelled (PRS Group, 2012). The estimated annual inflation rate (the un-weighted average of the Consumer Price Index) is calculated as percentage change. Based on the ICRG methodology, the percentage of 2% or below can be assessed as very low risk, between 8% and 9.9% as low risk, between 19% and 21.9% as medium risk, between 51% and 65.9% as high risk and 130% or more as very high risk. The inflation rate of Malaysia is assessed as 3.2% (World Bank, 2012). Since range values are used to represent each linguistic variable, the trapezoidal membership functions are used. Consequently, the belief degrees for inflation rate are calculated as follows.

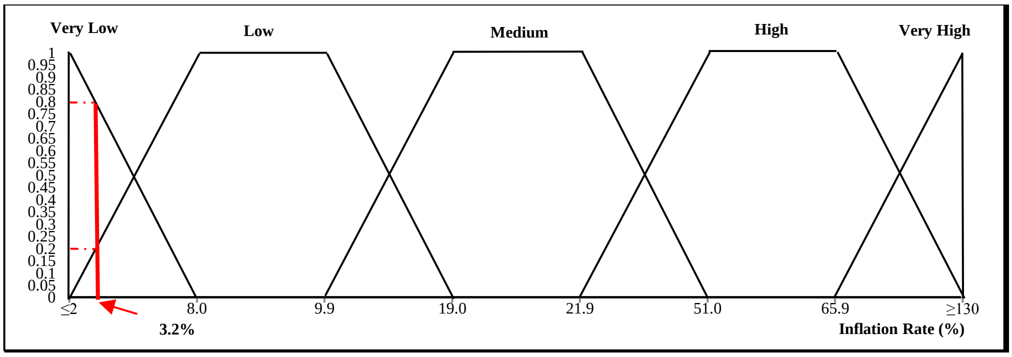

Figure 3.14: Membership functions for inflation rate

Based on Figure 3.14, the set for inflation rate in Malaysia can be evaluated as:

IR = {(Very Low, 0.80), (Low, 0.20), (Medium, 0), (High, 0), (Very High, 0)}

3.4.4.10 Industrial Production

Based on the Trading Economics (2012) database, the measurement for industrial production for Malaysia can be modelled. The percentage change of 20% or above can be assessed as very low risk, 10% as low risk, 0% as medium risk, -10% as high risk and -20% below as very high risk. Based on the Trading Economics (2012) database, the industrial production (year-over-year) of Malaysia is assessed as 3.7%. Consequently, the belief degrees for industrial production are calculated as follows.

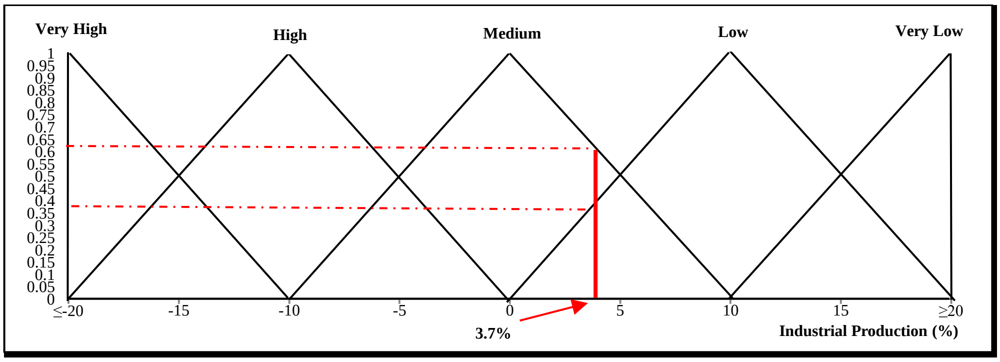

Figure 3.15: Membership functions for industrial production

Based on Figure 3.15, the set for industrial production in Malaysia is evaluated as:

IP = {(Very Low, 0), (Low, 0.37), (Medium, 0.63), (High, 0), (Very High, 0)}

3.4.4.11 Religious/Ethnic Tensions

Based on the ICRG methodology, a score point for religious/ethnic tensions can be selected (PRS Group, 2012). A score point of religious/ethnic tensions for Malaysia is 8 out of 12. A score of 12 points (i.e. highest point) equates to very low risk and a score of 0 (i.e. lowest point) to very high risk. Scores are uniformly distributed. Consequently, the belief degrees for religious/ethnic tensions are calculated as follows.

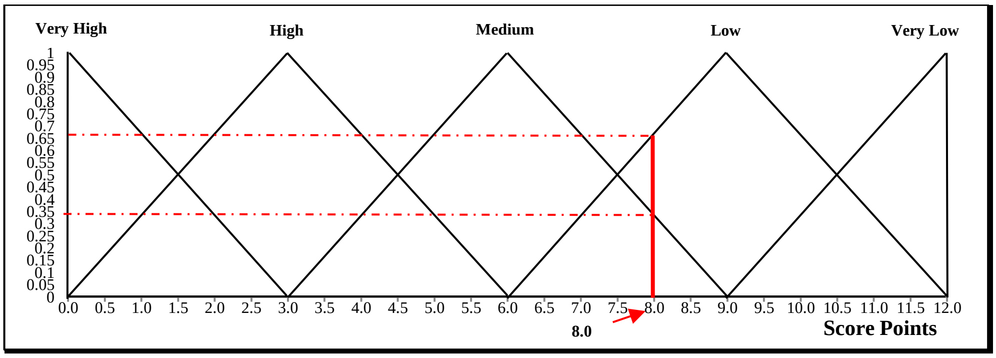

Figure 3.16: Membership functions for religious/ethnic tensions

Based on Figure 3.16, the set for religious/ethnic tensions in Malaysia is evaluated as:

$$RET = \{(\text{Very Low}, 0), (\text{Low}, 0.67), (\text{Medium}, 0.33), (\text{High}, 0), (\text{Very High}, 0)\}$$

3.4.5 Measuring Qualitative Criteria Using the Belief Degree (*Step 5*)

To assess a qualitative criterion, three domain experts (i.e. three out of five experts as listed in Sub-section 3.4.3) with 15 to 20 years of experience have been selected based on their experiences and expertise (in the Malaysian CLSI) and they are assigned an equal weight. As an example, three experts' judgements for the restriction in foreign enterprise policy in Malaysia are shown in Table 3.7.

Table 3.7: Experts' judgement for the restriction in foreign enterprise policy

Risk Factors	Expert	Risk Assessment Grades				
		Very Low	Low	Medium	High	Very High
Restriction in Foreign Enterprise Policy	Expert 1	0	0.4	0.6	0	0
	Expert 2	0	0.2	0.5	0.3	0
	Expert 3	0	0.3	0.2	0.5	0

After the risk assessment grades have been obtained from the experts, they need to be aggregated. The aggregation is done by using an ER algorithm (Equations 3.8-3.14), which has been explained in Sub-section 3.3.6. As a result:

$$\tilde{F}_{EP} = \tilde{F}_{EP\,1} \oplus \tilde{F}_{EP\,2} \oplus \tilde{F}_{EP\,3}$$

where $\tilde{F}_{EP\,1}$ and $\tilde{F}_{EP\,2}$ and $\tilde{F}_{EP\,3}$ are assessments that have been given for restriction in foreign enterprise policy by expert 1, expert 2 and expert 3 respectively. Based on Table 3.7:

$\tilde{F}_{EP\,1} = \{(0, very\ low), (0.4, low), (0.6, medium), (0, high), (0, very\ high)\}$
$\tilde{F}_{EP\,2} = \{(0, very\ low), (0.2, low), (0.5, medium), (0.3, high), (0, very\ high)\}$
$\tilde{F}_{EP\,3} = \{(0, very\ low), (0.3, low), (0.2, medium), (0.5, high), (0, very\ high)\}$

The weight for each expert is equally distributed, so $\omega_1 = \omega_2 = \omega_3 = 1/3$. From Equation 3.10, M_1^m, M_2^m and M_3^m are calculated as follows:

$m = 1$	M_1^1 = 1/3 x 0 = 0	M_2^1 = 1/3 x 0 = 0	M_3^1 = 1/3 x 0 = 0
$m = 2$	M_1^2 = 1/3 x 0.4 = 0.1333	M_2^2 = 1/3 x 0.2 = 0.0667	M_3^2 = 1/3 x 0.3 = 0.1
$m = 3$	M_1^3 = 1/3 x 0.6 = 0.2	M_2^3 = 1/3 x 0.5 = 0.1667	M_3^3 = 1/3 x 0.2 = 0.0667
$m = 4$	M_1^4 = 1/3 x 0 = 0	M_2^4 = 1/3 x 0.3 = 0.1	M_3^4 = 1/3 x 0.5 = 0.1667
$m = 5$	M_1^5 = 1/3 x 0 = 0	M_2^5 = 1/3 x 0 = 0	M_3^5 = 1/3 x 0 = 0

Based on Equations 3.11-3.12, individual remaining belief values (H_i) unassigned for M_1^m, M_2^m and M_3^m are calculated as follows:

$H_1 = \bar{H}_1 + \tilde{H}_1$ = (1-1/3) + 1/3(1-(0.4+0.6)) = 2/3 + 0 = 2/3
$H_2 = \bar{H}_2 + \tilde{H}_2$ = (1-1/3) + 1/3(1-(0.2+0.5+0.3)) = 2/3 + 0 = 2/3
$H_3 = \bar{H}_3 + \tilde{H}_3$ = (1-1/3) + 1/3(1-(0.3+0.2+0.5)) = 2/3 + 0 = 2/3

Then, the ER algorithm can be used to calculate the combined probability masses using Equation 3.13. First, $\tilde{F}_{EP\,1}$ and $\tilde{F}_{EP\,2}$ are aggregated as follows:

$$K_{(a)} = \left(1 - \sum_{T=1}^{5} \sum_{\substack{R=1 \\ R \neq 1}}^{5} M_{1(a)}^{T} M_2^R \right)^{-1}$$

$$= \left[1 - \sum_{\substack{R=1 \\ R \neq 1}}^{5} (M_1^1 M_2^R + M_1^2 M_2^R + M_1^3 M_2^R + M_1^4 M_2^R + M_1^5 M_2^R)\right]^{-1}$$

$$= [1 - (M_1^1 M_2^2 + M_1^1 M_2^3 + M_1^1 M_2^4 + M_1^1 M_2^5) + (M_1^2 M_2^1 + M_1^2 M_2^3 + M_1^2 M_2^4 + M_1^2 M_2^5) + (M_1^3 M_2^1 + M_1^3 M_2^2 + M_1^3 M_2^4 + M_1^3 M_2^5) + (M_1^4 M_2^1 + M_1^4 M_2^2 + M_1^4 M_2^3 + M_1^4 M_2^5) + (M_1^5 M_2^1 + M_1^5 M_2^2 + M_1^5 M_2^3 + M_1^5 M_2^4)]^{-1}$$

$= [1 - (0 \times 0.0667 + 0 \times 0.1667 + 0 \times 0.1 + 0 \times 0) + (0.1333 \times 0 + 0.1333 \times 0.1667 + 0.1333 \times 0.1 + 0.1333 \times 0) + (0.2 \times 0 + 0.2 \times 0.0667 + 0.2 \times 0.1 + 0.2 \times 0) + (0 \times 0 + 0 \times 0.6667 + 0 \times 0.1667 + 0 \times 0) + (0 \times 0 + 0 \times 0.0667 + 0 \times 0.1667 + 0 \times 0.1)]^{-1}$

$K_{(a)}$ =1.0739.

Then, $\beta^{m'} = K(M_1^m M_2^m + M_1^m H_2 + M_2^m H_1)$ is calculated as follows:

$\beta^{1'} = K_{(a)}(M_1^1 M_2^1 + M_1^1 H_2 + M_2^1 H_1)$ = 1.0739 (0×0 + 0×2/3 + 0×2/3) = 0

$\beta^{2'} = K_{(a)}(M_1^2 M_2^2 + M_1^2 H_2 + M_2^2 H_1)$ = 1.0739 (0.1333×0.0667 + 0.1333×2/3 + 0.0667×2/3) = 0.1528

$\beta^{3'} = K_{(a)}(M_1^3 M_2^3 + M_1^3 H_2 + M_2^3 H_1)$ = 1.0739 (0.2×0.1667 + 0.2×2/3 + 0.1667×2/3) = 0.2982

$\beta^{4'} = K_{(a)}(M_1^4 M_2^4 + M_1^4 H_2 + M_2^4 H_1)$ = 1.0739 (0×0.1 + 0×2/3 + 0.1×2/3) = 0.0716

$\beta^{5'} = K_{(a)}(M_1^5 M_2^5 + M_1^5 H_2 + M_2^5 H_1)$ = 1.0739 (0×0 + 0×2/3 + 0×2/3) = 0

$\bar{H}'_{U\,(a)} = K_{(a)}(\bar{H}_1 \bar{H}_2)$ = 1.0739(2/3 ×2/3) = 0.4773.
$\tilde{H}'_{U\,(a)} = K_{(a)}\left(\tilde{H}_1 \tilde{H}_2 + \tilde{H}_1 \bar{H}_2 + \tilde{H}_2 \bar{H}_1\right)$ = 1.0739 (0×0 + 0×2/3 + 0×2/3) = 0.

Now the above results for $\tilde{F}_{EP\,1}$ and $\tilde{F}_{EP\,2}$ are combined with $\tilde{F}_{EP\,3}$.

$$K_{(b)} = \left(1 - \sum_{T=1}^{5} \sum_{\substack{R=1 \\ R\neq 1}}^{5} M_{1(b)}^{T} M_3^{R}\right)^{-1}$$

$= [1 - (0 \times 0.1 + 0 \times 0.0667 + 0 \times 0.1667 + 0 \times 0) + (0.1528 \times 0 + 0.1528 \times 0.0667 + 0.1528 \times 0.1667 + 0.1528 \times 0) + (0.2982 \times 0 + 0.2982 \times 0.1 + 0.2982 \times 0.1667 + 0.2982 \times 0) + (0.0716 \times 0 + 0.0716 \times 0.1 + 0.0716 \times 0.0667 + 0.0716 \times 0) + (0 \times 0 + 0 \times 0.1 + 0 \times 0.0667 + 0 \times 0.1667)]^{-1}$

$K_{(b)}$ = 1.1457

$H_{(b)} = \bar{H}'_{U\,(a)} + \tilde{H}'_{U\,(a)}$ = 0.4773 + 0 = 0.4773.

$\beta^{1'} = K_{(b)}\left(M_{1(b)}^1 M_3^1 + M_{1(b)}^1 H_3 + M_3^1 H_{(b)}\right)$ = 1.1457 (0×0 + 0×2/3 + 0×0.4473) = 0

$\beta^{2'} = K_{(b)}\left(M_{1(b)}^2 M_3^2 + M_{1(b)}^2 H_3 + M_3^2 H_{(b)}\right)$ = 1.1457 (0.1528×0.1 + 0.1528×2/3 + 0.1×0.4473) = 0.1889

$\beta^{3'} = K_{(b)}\left(M_{1(b)}^3 M_3^3 + M_1^3 H_3 + M_3^3 H_{(b)}\right)$ = 1.1457 (0.2982×0.0667 + 0.2982×2/3 + 0.0667×0.4473) = 0.2870

$\beta^{4'}= K_{(b)}\left(M_{1(b)}^{4}M_{3}^{4} + M_{1(b)}^{4}H_{3} + M_{3}^{4}H_{(b)}\right)$ = 1.1457 (0.0716×0.1667 + 0.0716×2/3 + 0.1667×0.4473) = 0.1595

$\beta^{5'}= K_{(b)}\left(M_{1(b)}^{5}M_{3}^{5} + M_{1(b)}^{5}H_{3} + M_{3}^{5}H_{(b)}\right)$ = 1.1457 (0×0 + 0×2/3 + 0×0.4473) = 0

$\bar{H}'_{U\,(b)} = K_{(b)}\left(\bar{H}'_{U\,(a)}\bar{H}_{3}\right)$ = 1.1457(0.4773 ×2/3) = 0.3646
$\tilde{H}'_{U} = K_{(b)}\left(\tilde{H}_{1}\tilde{H}_{3} + \tilde{H}_{1}\bar{H}_{3} + \tilde{H}_{3}\bar{H}_{1}\right)$ = 1.1457 (0×0 + 0×2/3 + 0×0.4773) = 0.

Using Equation 3.14, the combination of degrees of belief is presented as follows:

$$\beta^{m} = \frac{\beta^{m'}}{1-\bar{H}'_{U\,(b)}} \quad (m = 1,2,3,4,5)$$

$$\beta^{1} = \frac{0}{1-0.3646} = 0$$

$$\beta^{2} = \frac{0.1889}{1-0.3646} = 0.2973$$

$$\beta^{3} = \frac{0.2870}{1-0.3646} = 0.4517$$

$$\beta^{4} = \frac{0.1595}{1-0.3646} = 0.2510$$

$$\beta^{5} = \frac{0}{1-0.3646} = 0$$

As a result, the aggregation result of restriction in foreign enterprise policy in Malaysia is evaluated as:

$\tilde{F}_{EP}$ = {(Very Low, 0), (Low, 0.2973), (Medium, 0.4517), (High, 0.2510), (Very High, 0)}

The above result is shown in Table 3.8. Furthermore, with the help of the IDS software, the aggregation results of expert judgements for all qualitative criteria, as illustrated in Table 3.8, are assessed.

Table 3.8: Assessment grades and aggregation values using IDS software

Risk Factors	Expert	Risk Assessment Grades				
		Very Low	**Low**	**Medium**	**High**	**Very High**
Restriction in Foreign Enterprise Policy	Expert 1	0	0.4	0.6	0	0
	Expert 2	0	0.2	0.5	0.3	0
	Expert 3	0	0.3	0.2	0.5	0
	Aggregation	0	0.2973	0.4517	0.2510	0
Customs-Related Risk	Expert 1	0.4	0.6	0	0	0
	Expert 2	0	0	0.2	0.8	0
	Expert 3	0	0.3	0.2	0.5	0
	Aggregation	0.1208	0.2991	0.1269	0.4532	0

Exchange Control Rules	Expert 1	0.2	0.6	0.2	0	0
	Expert 2	0	0	0.2	0.8	0
	Expert 3	0	0	0.7	0.3	0
	Aggregation	0.0608	0.1825	0.3855	0.3712	0
Excessive Bureaucracy in Trade	Expert 1	0.2	0.2	0.6	0	0
	Expert 2	0	0	0.2	0.8	0
	Expert 3	0	0.2	0.5	0.3	0
	Aggregation	0.0586	0.1230	0.4612	0.3572	0
Labour Cost	Expert 1	0	0	0.3	0.7	0
	Expert 2	0	0.2	0.3	0.5	0
	Expert 3	0	0.3	0.6	0.1	0
	Aggregation	0	0.1509	0.4096	0.4395	0
Freight Rate Fluctuation	Expert 1	0	0	0.6	0.2	0.2
	Expert 2	0	0	0.5	0.5	0
	Expert 3	0	0	0.7	0.3	0
	Aggregation	0	0	0.6367	0.3100	0.0533
Bunker Price Fluctuation	Expert 1	0	0.2	0.8	0	0
	Expert 2	0	0	0.2	0.8	0
	Expert 3	0	0.2	0.5	0.3	0
	Aggregation	0	0.1203	0.5301	0.3496	0
Labour Quality	Expert 1	0	0.2	0.6	0.2	0
	Expert 2	0	0	0.2	0.8	0
	Expert 3	0	0.3	0.6	0.1	0
	Aggregation	0	0.1522	0.4934	0.3544	0
Labour Availability	Expert 1	0	0.4	0.6	0	0
	Expert 2	0	0	0.6	0.4	0
	Expert 3	0	0.3	0.6	0.1	0
	Aggregation	0	0.2069	0.6516	0.1415	0
Working Cultures	Expert 1	0	0.2	0.6	0.2	0
	Expert 2	0	0	0.4	0.6	0
	Expert 3	0	0.3	0.7	0	0
	Aggregation	0	0.1471	0.6141	0.2388	0
Reputational Risk	Expert 1	0	0	0.7	0.2	0.1
	Expert 2	0	0.5	0.5	0	0
	Expert 3	0	0.4	0.5	0.1	0
	Aggregation	0	0.2756	0.6114	0.0854	0.0276
Earthquake	Expert 1	0	0.6	0.4	0	0
	Expert 2	0.9	0.1	0	0	0
	Expert 3	0	0.8	0.2	0	0
	Aggregation	0.2677	0.5419	0.1904	0	0
Tsunami	Expert 1	0	0.6	0.4	0	0
	Expert 2	0.9	0.1	0	0	0
	Expert 3	0	0.7	0.3	0	0
	Aggregation	0.2690	0.5038	0.2272	0	0
Severe Storms	Expert 1	0	0	0.3	0.5	0.2
	Expert 2	0	0.6	0.4	0	0
	Expert 3	0	0	0.7	0.3	0
	Aggregation	0	0.1764	0.5075	0.2573	0.0588
Tornadoes	Expert 1	0.4	0.6	0	0	0
	Expert 2	1	0	0	0	0
	Expert 3	0	0.7	0.3	0	0

	Aggregation	0.4692	0.4428	0.0880	0	0
Sea Surges	Expert 1	0.4	0.6	0	0	0
	Expert 2	0.8	0.2	0	0	0
	Expert 3	0	0.7	0.3	0	0
	Aggregation	0.3863	0.5285	0.0852	0	0
Coastal Flood	Expert 1	0.6	0.4	0	0	0
	Expert 2	0	0.6	0.4	0	0
	Expert 3	0	0	0.8	0.2	0
	Aggregation	0.1829	0.3415	0.4146	0.0610	0
Extreme Temperatures	Expert 1	0.6	0.4	0	0	0
	Expert 2	0	1	0	0	0
	Expert 3	0	0.2	0.6	0.2	0
	Aggregation	0.1786	0.5833	0.1786	0.0595	0
Climate Change	Expert 1	0.4	0.6	0	0	0
	Expert 2	0	1	0	0	0
	Expert 3	0	0.1	0.6	0.3	0
	Aggregation	0.1178	0.6171	0.1767	0.0884	0
Haze	Expert 1	0.6	0.4	0	0	0
	Expert 2	0	0.8	0.2	0	0
	Expert 3	0	0.3	0.7	0	0
	Aggregation	0.1747	0.5428	0.2825	0	0
Insect Infestation	Expert 1	0.9	0.1	0	0	0
	Expert 2	0	1	0	0	0
	Expert 3	0	0.6	0.4	0	0
	Aggregation	0.2651	0.6171	0.1178	0	0
Epidemic/Pandemic Diseases	Expert 1	0.8	0.2	0	0	0
	Expert 2	0.8	0.2	0	0	0
	Expert 3	0.2	0.6	0.2	0	0
	Aggregation	0.6320	0.3133	0.0547	0	0
Ash from Volcanic Eruption	Expert 1	0.8	0.2	0	0	0
	Expert 2	1	0	0	0	0
	Expert 3	0	0.8	0.2	0	0
	Aggregation	0.6322	0.3103	0.0575	0	0

3.4.6 Construction of ER calculation (*Step 6*)

After the assessments of all criteria are obtained, the ER algorithm is used to perform the aggregation process for the sub-sub-criteria, the sub-criteria, and the main criteria. Given the weights of the risk factors in Table 3.6, the aggregation of the macro political risk's subsets (i.e. government instability, domestic conflict, foreign conflict, restriction in foreign enterprise policy, corruption, and lawlessness), as shown in Table 3.9, is conducted using Equations 3.8-3.14.

Table 3.9: Aggregation result for macro political risks

Macro Political Risks	Very Low	Low	Medium	High	Very High	Weight
Government Instability	0	0.17	0.83	0	0	0.2109
Domestic Conflict	0.33	0.67	0	0	0	0.1781
Foreign Conflict	0.5	0.5	0	0	0	0.2055
Restriction in Foreign Enterprise Policy	0	0.2793	0.4517	0.2510	0	0.1442
Corruption	0	0	0.9	0.1	0	0.1373
Lawlessness	0	0	1	0	0	0.1240
Aggregation Result	**0.1496**	**0.2988**	**0.5097**	**0.0419**	**0**	**1**

With the same technique, firstly, all the sub-sub-criteria are aggregated to obtain their associated sub-criteria. Secondly, all the sub-criteria are aggregated to obtain their associated main criteria. As an example, Table 3.10 shows the aggregation result for political risk factors. Finally, all the main criteria are aggregated. Table 3.11 shows the aggregation result for the main criteria. The aggregation results for the other sub-sub-criteria and sub-criteria can be found in Appendix A-1.

Table 3.10: Aggregation result for political risks

Political Risks	Very Low	Low	Medium	High	Very High	Weight
Macro Political Risks	0.1496	0.2988	0.5097	0.0419	0	0.5000
Micro Political Risks	0.0674	0.1864	0.3417	0.4045	0	0.5000
Aggregation Result	**0.1006**	**0.2397**	**0.4544**	**0.2053**	**0**	**1**

Table 3.11: Aggregation result for main criteria

Main Criteria	Very Low	Low	Medium	High	Very High	Weight
Political Risks	0.1006	0.2397	0.4544	0.2053	0	0.2737
Economic Risks	0.3817	0.0854	0.3192	0.2106	0.0031	0.3201
Social Risks	0	0.2531	0.5783	0.1643	0.0043	0.1430
Natural Hazards	0.2489	0.5069	0.1986	0.0392	0.0062	0.2632
Goal Result	**0.2151**	**0.2556**	**0.3756**	**0.1508**	**0.0029**	**1**

3.4.7 Utility Value Calculation (*Step 7*)

Based on Table 3.11, the value of the BEBR assessment (i.e. Goal) for Malaysia is presented by the five linguistic terms as follows:

BEBR MALAYSIA = {(Very Low, 0.2151), (Low, 0.2556), (Medium, 0.3756), (High, 0.1508), (Very High, 0.0029)}

Based on Equations 3.15-3.16, as shown in Table 3.12, the utility value of the BEBR in Malaysia is evaluated as 0.3677.

Table 3.12: Utility value of the BEBR for the Malaysian CLSI

H_n	**Very Low**	**Low**	**Medium**	**High**	**Very High**
V_n	1	2	3	4	5
$u(H_n)$	$\frac{1-1}{5-1}=0$	$\frac{2-1}{5-1}=0.25$	$\frac{3-1}{5-1}=0.5$	$\frac{4-1}{5-1}=0.75$	$\frac{5-1}{5-1}=1$
β_n	0.2151	0.2556	0.3756	0.1508	0.0029
$\sum_{n=1}^{5}\beta_n = 0.2151+0.2556+0.3756+0.1508+0.0029 = 1-\beta_H = 0$					
$\beta_n \times u(H_n)$	0	0.0639	0.1878	0.1131	0.0029
$U_v = \sum_{n=1}^{5}\beta_n \times u(H_n) = \mathbf{0.3677}$					

3.4.8 Model and Result Validation (*Step 8*)

In the final step (i.e. step 8), the three axioms introduced in Sub-section 3.3.8 are used to test the logicality of the delivery of the analysis result. To carry out the SA, the belief degree associated with the highest linguistic term of each lowest-level criterion (Table 3.13) is increased by x and, simultaneously, the belief degree associated with the lowest linguistic term of the corresponding lowest-level criterion is decreased by x. However, if the belief degree (β_α) associated with the highest linguistic term is less than x, the remaining belief degree (i.e. $x - \beta_\alpha$) can be deducted from the belief degree of the next linguistic term. This can continue until x is used up.

Table 3.13: Fuzzy input sets

Lowest-Level Criterion	**Fuzzy Input Set**
Government Instability	{(Very low, 0), (Low, 0.17), (Medium, 0.83), (High,0), (Very high, 0)}
Domestic Conflict	{(Very low, 0.33), (Low, 0.67), (Medium, 0), (High, 0), (Very high, 0)}
Foreign Conflict	{(Very low, 0.50), (Low, 0.50), (Medium, 0), (High, 0), (Very high, 0)}
Restriction in Foreign Enterprise Policy	{(Very low, 0), (Low, 0.2792), (Medium, 0.4518), (High, 0.2510), (Very high, 0)}
Corruption	{(Very low, 0), (Low, 0), (Medium, 0.90), (High, 0.10), (Very high, 0)}
Lawlessness	{(Very low, 0), (Low, 0), (Medium, 1), (High, 0), (Very high, 0)}
Customs-Related Risk	{(Very low, 0.1208), (Low, 0.2991), (Medium, 0.1269), (High, 0.4532), (Very high, 0)}
Exchange Control Rules	{(Very low, 0.0608), (Low, 0.1825), (Medium, 0.3855), (High, 0.3712), (Very high, 0)}
Excessive Bureaucracy in Trade	{(Very low, 0.0586), (Low, 0.1230), (Medium, 0.4612), (High, 0.3572), (Very high, 0)}

GDP per Employed Person	{(Very low, 0), (Low, 0), (Medium, 0.38), (High, 0.62), (Very high, 0)}
Current Account to GDP	{(Very low, 1), (Low, 0), (Medium, 0), (High, 0), (Very high, 0)}
Exchange Rate Fluctuation	{(Very low, 0.94), (Low, 0.06), (Medium, 0), (High, 0), (Very high, 0)}
Inflation Rate	{(Very low, 0.80), (Low, 0.20), (Medium, 0), (High, 0), (Very high, 0)}
Industrial Production	{(Very low, 0), (Low, 0.37), (Medium, 0.63), (High, 0), (Very high, 0)}
Labour Cost	{(Very low, 0), (Low, 0.1509), (Medium, 0.4096), (High, 0.4395), (Very high, 0)}
Freight Rate Fluctuation	{(Very low, 0), (Low, 0), (Medium, 0.6367), (High, 0.3100), (Very high, 0.0533)}
Bunker Price Fluctuation	{(Very low, 0), (Low, 0.1203), (Medium, 0.5301), (High, 0.3496), (Very high, 0)}
Labour Quality	{(Very low, 0), (Low, 0.1522), (Medium, 0.4934), (High, 0.3544), (Very high, 0)}
Labour Availability	{(Very low, 0), (Low, 0.2069), (Medium, 0.6516), (High, 0.1415), (Very high, 0)}
Earthquake	{(Very low, 0.2677), (Low, 0.5419), (Medium, 0.1904), (High, 0), (Very high, 0)}
Tsunami	{(Very low, 0.2690), (Low, 0.5038), (Medium, 0.2272), (High, 0), (Very high, 0)}
Ash from Volcanic Eruption	{(Very low, 0.6322), (Low, 0.3103), (Medium, 0.0575), (High, 0), (Very high, 0)}
Severe Storms	{(Very low, 0), (Low, 0.1764), (Medium, 0.5075), (High, 0.2573), (Very high, 0.0588)}
Tornadoes	{(Very low, 0.4692), (Low, 0.4428), (Medium, 0.0880), (High, 0), (Very high, 0)}
Sea Surges	{(Very low, 0.3863), (Low, 0.5285), (Medium, 0.0852), (High, 0), (Very high, 0)}
Coastal Floods	{(Very low, 0.1829), (Low, 0.3415), (Medium, 0.4146), (High, 0.0610), (Very high, 0)}
Extreme Temperatures	{(Very low, 0.1786), (Low, 0.5833), (Medium, 0.1786), (High, 0.0595), (Very high, 0)}
Climate Change	{(Very low, 0.1178), (Low, 0.6171), (Medium, 0.1767), (High, 0.0884), (Very high, 0)}
Haze	{(Very low, 0.1747), (Low, 0.5428), (Medium, 0.2825), (High, 0), (Very high, 0)}
Insect Infestation	{(Very low, 0.2651), (Low, 0.6171), (Medium, 0.1178), (High, 0), (Very high, 0)}
Epidemic/Pandemic Disease	{(Very low, 0.6320), (Low, 0.3133), (Medium, 0.0547), (High, 0), (Very high, 0)}

The belief degree associated with the highest linguistic term of each lowest-level criterion, as shown in Table 3.13, is increased by 0.1, 0.2 and 0.3 respectively. As a result, the new goal's utility values (i.e. U_k, U_l, and U_m), as shown in Table 3.14, are evaluated. The variation of the new goal's utility values can be seen in Figure 3.17. Since U_k, U_l, and U_m are greater than 0.3677, the results are aligned with Axioms 1 and 2.

Table 3.14: Alteration of utility value due to increasing the belief degree associated with the highest linguistic term of each lowest-level criterion

Lowest-level Criterion	(Utility Value for Alteration by $k = 0.1$) (U_k)	(Utility Value for Alteration by $l = 0.2$) (U_l)	(Utility Value for Alteration by $m = 0.3$) (U_m)
Government Instability	0.3696	0.3711	0.3719
Domestic Conflict	0.3697	0.3718	0.3738
Foreign Conflict	0.3701	0.3724	0.3748
Restriction in Foreign Enterprise Policy	0.3689	0.3701	0.3712
Corruption	0.3681	0.3685	0.3689
Lawlessness	0.3681	0.3687	0.3688
Customs-Related Risk	0.3706	0.3729	0.3751
Exchange Control Rules	0.3731	0.3776	0.3809
Excessive Bureaucracy in Trade	0.3704	0.3725	0.3736
GDP per Employed Person	0.3695	0.3712	0.3731
Current Account to GDP	0.3730	0.3783	0.3837
Exchange Rate Fluctuation	0.3716	0.3756	0.3796
Inflation Rate	0.3708	0.3740	0.3772
Industrial Production	0.3703	0.3728	0.3754
Labour Cost	0.3690	0.3699	0.3706
Freight Rate Fluctuation	0.3685	0.3693	0.3701
Bunker Price Fluctuation	0.3702	0.3718	0.3731
Labour Quality	0.3703	0.3723	0.3738
Labour Availability	0.3685	0.3693	0.3697
Earthquake	0.3715	0.3754	0.3789
Tsunami	0.3715	0.3753	0.3789
Ash from Volcanic Eruption	0.3683	0.3690	0.3702
Severe Storms	0.3699	0.3720	0.3730
Tornadoes	0.3690	0.3720	0.3730
Sea Surges	0.3690	0.3702	0.3715
Flooding	0.3691	0.3704	0.3713
Extreme Temperature	0.3692	0.3706	0.3717
Climate Change	0.3693	0.3705	0.3717
Haze	0.3696	0.3705	0.3717
Insect Infestation	0.3684	0.3691	0.3697
Epidemic/Pandemic Disease	0.3698	0.3718	0.3740

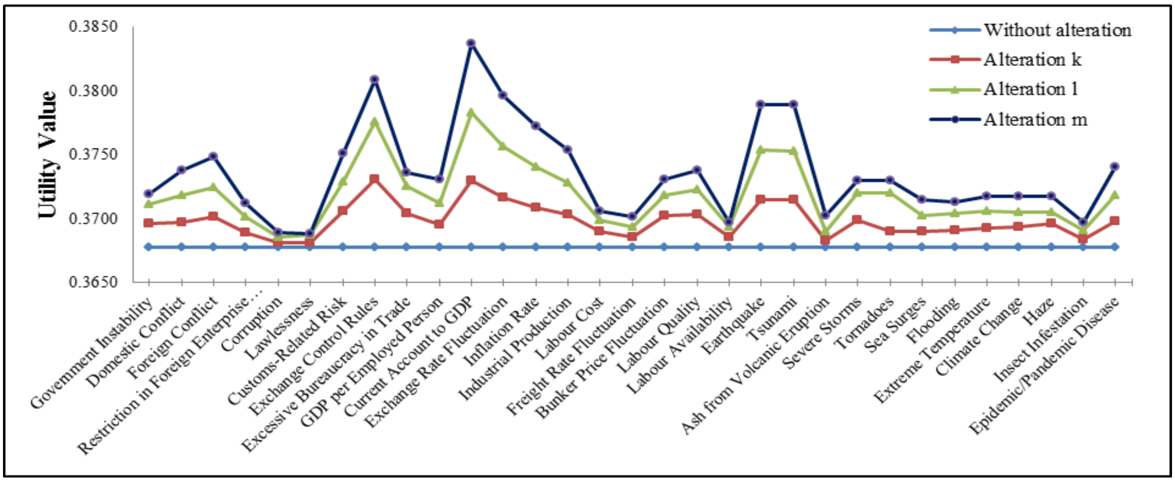

Figure 3.17: Representation of Axioms 1 and 2

To demonstrate Axiom 3, the belief degrees associated with the highest linguistic terms of all lowest-level criteria are increased by 0.2; the new utility value of the BEBR is evaluated as 0.5183. By selection of 17 lowest-level criteria (i.e. government instability, domestic conflict, foreign conflict, restriction in foreign enterprise policy, corruption, lawlessness, customs-related risk, exchange control rules, excessive bureaucracy in trade, GDP per employed person, current account to GDP, exchange rate fluctuation, inflation rate, industrial production, labour cost, freight rate fluctuation, and bunker price fluctuation) from 31 and by increasing the belief degrees associated with their highest linguistic terms (i.e. 17 criteria) by 0.2, the new goal's utility value of the model is obtained as 0.4602. In view of the fact that 0.5183 is greater than 0.4602, as shown in Figure 3.18, the result is aligned with Axiom 3.

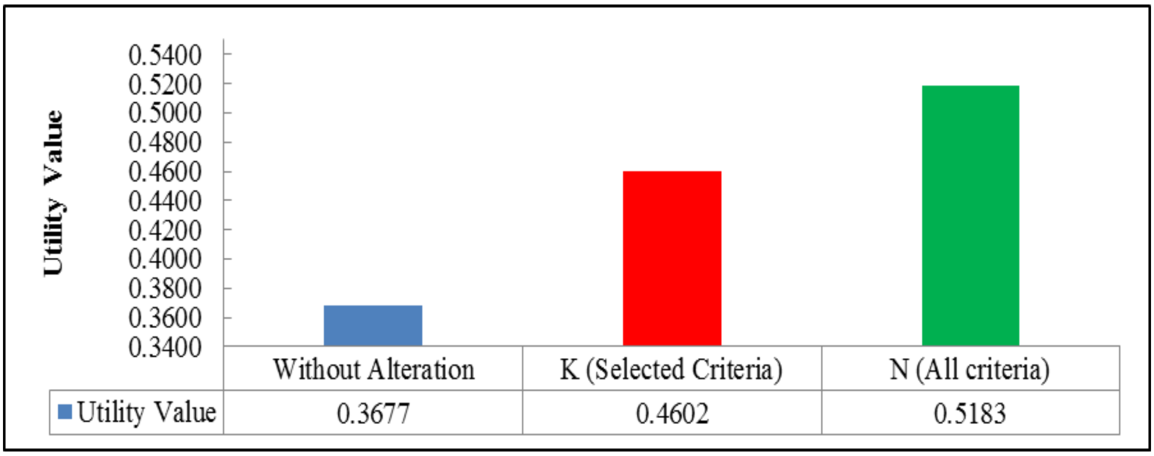

Figure 3.18: Representation of Axiom 3

By using the proposed methodology, the BEBR value in Malaysia was evaluated as 36.77%. To ensure that this result is logical within the industry, the result of the model needs be validated by using an external statistic for the comparison. Therefore, this result has been compared with a reliable country risk statistic provided by the Euromoney Country Risk (2013), and based on that the country risk value for Malaysia is indicated as 36.21%. As a result, the outcome of both models is aligned and this can be used as a validation of the proposed model. It is noteworthy to mention that different factors and perspectives are used in each assessment model.

3.5 Results and Discussion

The alteration of each criterion's value will eventually change the output value (i.e. utility value). The information in Table 3.14 can be plotted on a graph as shown in Figure 3.17. Based on Figure 3.17, the current account to GDP is found to be the most significant criterion in the BEBR model. The current account to GDP is directly proportional to the performance of CLSI as it indicates the level of international trade competitiveness of a country. A country that has a very good current account to GDP evidently provides a good indication level of international trades, especially for container export. For example, in 2010, Singapore and Malaysia were two countries that had strong performances in container trades and also recorded a current account to GDP of 23.7%, and 11% respectively (World Bank, 2012). These figures show that both countries recorded a strong performance on current account to GDP and indicate that their economies were heavily dependent on export trades. As a result, the demand for liner services simultaneously increased to support the export trades.

On the other hand, a deficit on the current account to GDP indicates a country with low saving rates and high personal consumption rates as the percentage of disposable incomes. This deficit discourages export trades and finally results in low demand for container liner services. It is noteworthy to mention that an increase in current account deficit will lead to a decrease in container demand, especially in the export trades. For example, in 2009 up to 2011, Greece recorded a deficit on current account to GDP as -10.9%, -10.1%, and -9.9% respectively (World Bank, 2012). As a result, the container port traffic for Port Piraeus was 935,076 TEUs, 1,165,185 TEUs and 1,980,605 TEUs respectively (World Bank 2012). As a result, decision-makers should be aware of the performance of current account to GDP of a particular country before making a decision on investments or operations in that country.

By considering 0% as “Very Low”, 25% as “Low”, 50% as “Medium”, 75% as “High” and 100% as “Very High”, the BEBR value in Malaysia (i.e. 36.77%) is noticeably as fairly low. The BEBR value in Malaysia (i.e. 36.77%) indicates that Malaysia is a fairly low risk country, enough to encourage LSOs to make investments and to establish shipping operations in Malaysia. Generally, Malaysia benefits from huge natural resources (i.e. crude oil, rubber, *etc.*), remarkable economic growth and a reliable multi-transport network (i.e. road, rail, air and water transports). Malaysia can be considered as relatively safe for LSOs operation, with fewer threats from natural disasters compared to its neighbour (i.e. Philippines and Indonesia). The risk level of natural hazards in Malaysia is assessed as relatively low (i.e. 28.18%). From the social point of view, Malaysia’s labour quality and availability is characterised as practically good skills and large number of specialised graduates. However, working cultures in Malaysia is considered as fairly poor quality, means LSOs will have to provide extra training for local employees. The risk level of social aspect in Malaysia is assessed as fairly medium (i.e. 48%). From political point of view, Malaysia is assessed as 44.11%, which is considered as relatively medium risk. Customs-related risk, exchange control rules and excessive bureaucracy in trade are three political risks that have been assessed as fairly high risk. From the economic point of view, the strong current account to GDP, low inflation rate and high stability in exchange rate are three criteria that have contributed significant impacts on the Malaysia's strong economy. Therefore, the economic risk in Malaysia is assessed as fairly low (i.e. 34.21%). As a result, it can be assumed that because of low BEBR value in Malaysia, it has becomes the second largest ship-owning country in South-East Asia (i.e. after Singapore) and fifth country with the highest LSCI in the world (UNCTAD, 2014).

In order to minimise the BEBR value and encourage the CLSI's activity in Malaysia, several key strategies can be implemented by the Malaysian government, which can be listed as follows:

- The performance of current account to GDP needs to be maintained to at least 10% in order to boost international trade activities (PRS Group, 2012).
- The exchange control rules need to be liberalised to the lowest possible level. However, the national interest needs to be considered.
- The possibility of corruption needs to be reduced by strengthening the corruption laws and increasing the related enforcement.
- The exchange rate fluctuation needs to be controlled and stabilised.
- The resilience to natural hazards needs to be enhanced by advancing detection technologies and launching holistic information sharing.

In addition, there are several recommendations for LSOs that can help to minimise the loss due to the BEBR in liner operations, which can be listed as follows:

- For existing LSOs, the BEBR level needs to be assessed frequently so mitigation strategies can be planned based on updated information.
- Information sharing between partners regarding external risks needs to be enhanced. This can improve transparency into and across the liner operations. Coordination between port operator, traffic control tower, authorities and LSOs need to be improved significantly.
- The knowledge management of employees needs to be enhanced so that they are able to resolve the BEBR at strategic, operational and tactical planning levels.
- To empower employees to proactively manage risk. Employees should be aware of sources of risk and be able to detect external risk in daily practices.

With today's complex environments and due to high uncertainties about future events, it is worth mentioning that existing LSOs in Malaysia should assess the BEBR regularly for frequent and updated information.

3.6 Conclusion

In this chapter, an appropriate mathematical model and decision support framework for assessing the BEBR value are proposed. Four main criteria, namely political risks, economic risks, social risks, and natural hazards, are investigated. For the assessment process, firstly, various risk factors affecting the LSOs' business performance are identified. Secondly, a generic model is developed in a hierarchical structure. Thirdly, the AHP method is used to establish the weight of criteria. Fourthly, FST and the belief degree concept are applied for transformation of a quantitative criterion to a qualitative criterion. Fifthly, subjective judgements are used to assess qualitative criteria. Sixthly, an ER algorithm is employed to synthesise experts' judgements and operation on subsets. Finally, the model is validated using SA. The entire assessment procedure is tested by choosing the CLSI in Malaysia as a focus of study.

The proposed BEBR assessment model is an organised methodology and data can be updated regularly. The BEBR assessment model can provide a useful model for LSOs to assess the BEBR value in a particular country before making a decision about investments and operations. Furthermore, it can be used for the assessment of the overall existing situation in a host country.

In the next chapter, the ORC of an LSO will be evaluated by considering five main criteria, namely operational reliability, financial capability, knowledge management, compliance with regulations and service quality capability. Furthermore, the influence of the BEBR on the organisational functions will be investigated. Malaysian LSOs will be selected as a case study for assessing their ORC under the influence of the BEBR. As a result, the relationship between the BEBR and the ORC will be revealed.

CHAPTER FOUR

A Proposed Fuzzy Bayesian Belief Network for Evaluating the Value of the Organisational Reliability and Capability of a Liner Shipping Operator

Summary

Reliability and capability have become significant concerns for LSOs to distinguish themselves from their competitors in the CLSI. Many organisations including LSOs have accepted that having a highly reliable and capable performance at the organisational level is an important element in the drive for better overall performance, and commitment to achieve a better competitive advantage. However, to understand how far LSOs are reliable, internal and external factors (i.e. exogenous influential factors) that determine the ORC should be evaluated. As a result, the aim of this study is to evaluate the value of the ORC of an LSO by considering five main criteria, namely operational reliability, financial capability, knowledge management, compliance with regulations and service quality capability. Furthermore, the influence of the BEBR on the organisational functions is investigated. This study makes uses of an FBBN for evaluating the value of ORC of an LSO. This method of assessment is capable of helping LSOs to conduct self-evaluation of the ORC for enhancing their business sustainability in the CLSI. In addition, maritime researchers will benefit from the proposed methodology for evaluating the value of the ORC of an LSO.

4.1 Introduction

Competition among LSOs continues to evolve as a result of structural changes within the industry (Bang *et al*., 2012). Historically, liner conferences (i.e. cartel agreements) were established in the 1970s purposely to restrict or eliminate competition by setting fixed prices and supply coordination among shipping lines. At the beginning of their establishment, these cartels were found to be useful, especially in indulging in retaliatory measures against independent LSOs which forced them to leave the trade route or join the cartel (Bang *et al*., 2012). However, this cartel structure is regarded as irrelevant in today's market due to evolution within the industry. As an example, changes in European Union (EU) regulations banned the liner conference from operating in European countries. In addition, these regulation changes have seen limitations on the extent to which alliance partners can exchange information with each other (Bang *et al*., 2012). As a result, the monopoly power of the liner conference in the CLSI has deteriorated.

Recently, many LSOs have practised low freight rate initiatives, especially during economic recession, which finally led to price wars among LSOs. Price wars are commercial rivalry due to the frequent cutting of prices among competitors. Price wars can adversely affect the sustainability of the CLSI since lower prices significantly reduce LSOs' profit margins and can threaten their survival. Therefore, practitioners and academicians suggest that low price-based competition should be limited, and mechanisms found to allow LSOs to provide a sustainable strategy according to the requirements of customer demand (Haralambides, 2007). One useful mechanism is competing through service performances. Under these new challenging circumstances, LSOs should seek high levels of operational and financial efficiencies for survival, generating the required level of cargo capacity with the minimum level of resources (Bang *et al*., 2012).

Nowadays, reliability and capability have become significant concerns for LSOs to distinguish themselves from their competitors in the CLSI. Many organisations including LSOs have accepted that having highly reliable and capable performances at organisational level (i.e. operational reliability, financial capability, knowledge management capability, compliance with regulations, and service quality capability) are important elements in the drive for better overall performance and commitment to achieve a better competitive advantage. In addition, reliable and capable performances of LSOs have often received central consideration from shippers to find the best carrier selection. Therefore, to understand how far an LSO is reliable and capable, internal and external factors (i.e. exogenous influential factors) that determine its ORC should be evaluated.

In this chapter, a new mathematical model for evaluating the value of ORC of an LSO is developed using a different combination of decision-making techniques such as a symmetric model, FL and BBN. Based on the extensive literature review and further consultation with domains experts in the CLSI, five main reliability elements - 1) operational reliability, 2) financial capability, 3) knowledge management capability, 4) compliance with regulations and 5) service quality capability - are considered in the evaluation model. This evaluation model is capable of helping LSOs to conduct a self-evaluation of their ORC for enhancing business sustainability in the CLSI. In addition, with the help of the proposed methodology, shippers will be able to evaluate LSOs in order to select a reliable operator to transport their goods consistently.

The remainder of this chapter is organised as follows. The literature review is explained in Section 4.2. Section 4.3 presents the methodology for evaluating the value of ORC of an LSO. The test case is conducted in Section 4.4. The results and discussion are explained in Section 4.5, and finally, the conclusion is given in Section 4.6.

4.2 Literature Review

Recent developments in maritime transportation have heightened the need for LSOs to enhance their reliability and capability management. Moreover, the global nature of today's supply chain networks has required LSOs to extend their geographical coverage and to offer highly reliable services (Bang *et al.*, 2012). In addition, shippers are increasingly looking for an LSO that is able to offer reliable global supply chain solutions whilst at the same time expecting a reduction in damage to goods. Therefore, having a mathematical tool for evaluating the value of ORC is essential for LSOs as well as shippers. However, the major challenge is how to develop a model and evaluate the value of ORC of an LSO in the domain of the scope, as mentioned. Quantifying the ORC of an LSO is a major challenge since the business nature of the CLSI is based on service orientation, which is different from physical production. On the other hand, the application of ORC requires complicated procedures including concept definition, factor identification, modelling, data collection, measurement, and quantification. These problems have not only resulted from the extension of the searching scope, but also originated from the uncertainty of the factors.

When investigating the key reliability factors of an LSO, a systematic approach is required to cluster them into functional entities comprising sub-systems and components. Development of the ORC model based on functional entities can provide a clear visualisation and recognition of all the ORC factors. Based on an extensive literature review, five main factors that determine the ORC of an LSO are identified: 1) operational reliability, 2) financial capability, 3) knowledge management capability, 4) compliance with regulations and 5) service quality capability. In addition, the influence of the BEBR on the ORC is investigated in the evaluation model in order to understand the relationship between ORC and external environments. The criteria selection follows the recommendation and adaptation of various studies in the literature, and further consultation with the domain experts in the CLSI (Parasuraman *et al.*, 1988, 1991; Durvasula *et al.*, 1999; Frost *et al*., 2001; Addicott *et al.*, 2006; Trucco *et al*., 2008; Celik *et al*., 2010; Gaonkar *et al*., 2011; Bang *et al.*, 2012; Riahi *et al*., 2012a; PWC, 2012; Liang *et al*., 2012; Drewry Shipping Consultants, 2013).

4.2.1 Operational Reliability

Operational reliability is a substantial element in an LSO's attempt to enhance its overall business performance. Operational reliability can be defined as the ability of an LSO's operations in delivering cargo in a safe, secure and timely manner. Frost *et al.* (2001) expressed that the impact of not managing an operation properly goes beyond direct financial losses. Moreover, unreliable operational continuity such as delay and disruption can cause distrust of an LSO and will lead to loss of its reputation among shippers. Several studies have been conducted on the subject of operational risk and reliability in maritime transportation, such as Hu *et al.* (2008), Trucco *et al.* (2008), Celik *et al.* (2010), Gaonkar *et al.* (2011) and Mokhtari *et al.* (2012). In this chapter, based on the available literature and further consultation with domain experts in the CLSI, four main criteria are selected to indicate the operational reliability of an LSO which are: vessel reliability, container management, schedule reliability and port reliability.

1. *Vessel reliability*. It is well accepted that vessel reliability is a prime factor that needs to be considered for the assessment of operational reliability of an LSO. Vessel reliability can be defined as the ability of a liner vessel to transport containers and crews in a safe, secure and timely manner. Gaonkar *et al.* (2011) assessed the safety criteria of vessel reliability based on age, technological up-gradation and emergency system onboard the vessels. The year of construction of the liner vessel would indicate its performance, as a younger vessel would perform better at sea than an older one. In addition, Gaonkar *et al.* (2011) also suggested that LSOs should upgrade their vessels with new technologies as this effort can improve performance and prolong the lifetime of a vessel. The performance of a ship's staff plays a major role in the safety of international trade and the maritime operation. In addition, a ship's staff are also responsible for ensuring the emergency systems onboard are monitored. Riahi *et al.* (2012a; 2012b) defined the reliability of a ship's staff as a measure of the possibility of his or her successful performance over a period of time (i.e. during his or her watch-keeping period of time). It is well accepted that, if a ship's staff are reliable, the reliability of their vessel and emergency systems is enhanced (Riahi *et al.*, 2012a; 2012b). As a result, three sub-elements that are considered to evaluate the value of vessel reliability are age of a vessel, technology up-gradation onboard and ship staff's reliability.
2. *Container management*. In liner operations, cargo moves from manufacturer to customer through a multi-modal network linking vessels, ports, trucks and trains. In this regard, shippers are concerned about the availability of their container at a port as promised (Drewry Shipping Consultants, 2013). As a result, the effectiveness of container management needs to be highlighted in determining the operational reliability of an LSO. Container management can be measured by calculating the percentage of

difference between a vessel's estimated time arrival (ETA) at a local port stated in the original booking confirmation and the actual time arrival (ATA) (Drewry Shipping Consultants, 2013).

3. *Schedule reliability*. Schedule unreliability can cause a negative impact on the operational performance of container shipping lines and, hinterland transport and logistics costs to the shippers (Carey, 1999; Fagerholt, 2004; Notteboom, 2006; Vennimen *et al.*, 2007; Chung and Chiang, 2011). Notteboom (2006) estimates that a one-day delay of a vessel carrying 4,000 TEUs from the Far East to Belgium (i.e. due to schedule unreliability) leads to an extra cost for the customer equal to EUR 57,000. As a result, schedule reliability becomes a main factor for shippers when selecting the shipping lines (e.g. local agent, liner services, *etc.*). Schedule reliability can be measured by the deviation between advertised vessel arrivals (AVA) at a destination port against the actual arrivals (Drewry Shipping Consultants, 2013).
4. *Port reliability*. Notteboom (2006) argued that port congestion is one of the factors that can affect the operational reliability of the shipping operations. Port congestion can happen at the port of loading (POL), port of transhipment, (POT) and port of destination (POD). As a result, operational reliability of the LSO requires efficient terminal handling, prearranged berth allocation and free flow of access roads at the local port (Chung and Chiang, 2011). In this chapter, from the LSO's perspectives, a port's reliability can be assessed by evaluating container dwell times. Dwell time can be defined as the amount of time a container remains stacked at a local port while awaiting shipment for export or onward transportation by either road or rail for import (Merckx, 2006).

4.2.2 Financial Capability

Financial capability can be defined as the ability of an LSO to conduct effective management of the finance and to control the effects of external risks on the finance conditions (AIRMIC *et al*., 2002). Also, it deals with the effectiveness of LSOs to manage and support a company's strategic objectives through short and long-term financial planning (Maiga and Jacobs, 2004). Empirical studies have found that a strong financial capability can contribute to a higher level of ORC value (Sun, 2010). On the other hand, financial capability also deals with the ability to control the effects of external risks (e.g. economic risks, *etc.*) on the financial capability of an LSO. In this chapter, financial capability can be assessed by three criteria: profitability ratio, finance structure ratio and liquidity ratio (PWC, 2012):

1. For assessing the profitability ratio of an LSO, Return on Net Operating Assets (RONOA) can be measured. RONOA is a key indicator for measuring returns on investments in the LSO's organisation as it measures returns on operating activities of the company (PWC, 2012).
2. For assessing the finance structure ratio, a solvency ratio can be estimated by dividing shareholders' equity by total assets (PWC, 2012). A solvency ratio indicates the ability of the LSO's organisation to pay long-term liabilities.
3. For assessing the liquidity ratio, current ratio of an LSO can be measured by dividing current assets by current liabilities. As financial managers are working with banks and other short-term lenders, an understanding of liquidity is essential (Sun, 2010).

4.2.3 Knowledge Management

Knowledge management can be defined as a set of processes for transferring data and information into valuable knowledge. Knowledge management efforts typically focus on achieving an organisation's strategic objectives such as performance enhancement, better competitive advantage, innovation, knowledge sharing and continuous improvement of the organisation (Gupta and Sharma, 2004). In supply chain management, knowledge management is considered to be an important tool as there is evidence of a positive link between knowledge management and supply chain performance (Yang *et al*., 2009; Marra *et al.*, 2012). In the CLSI, knowledge management is concerned with the effectiveness of the LSO to manage and make a decision on human resources, innovation and communication thereof. Strategically, knowledge management can help LSOs to minimise unnecessary costs, increase profit margins, and add value to tangible and intangible assets (Alavi and Leidner, 2001). Based on Liang *et al*. (2012), market competitiveness, human resource management (HRM) efficiency, organisation management and service innovation are four crucial factors in assessing knowledge management capability:

1. *Market competitiveness.* This aspect chiefly focuses on the ability of an LSO to enhance competitiveness in the international shipping market. This ability can be assessed by: the ability to reduce shipping costs and expenses; improvement of employees' efficiency; and strengthening of the shipping market penetration ability.
2. *Human resource management (HRM) efficiency.* This aspect focuses on the ability of an LSO to improve HRM efficiency in shipping operation and management. This ability can be assessed by: fast and effective solution of repeated, routine and common problems; improvement of employees' ability to apply information to support decision-

making; and standardisation of working procedures to improve employees' business-handling ability.

3. *Service innovation.* This aspect focuses on the ability of an LSO to improve shipping service quality and organisational innovation. This ability can be assessed by: improvement of the innovative abilities of the organisation and its high-level managers through knowledge sharing; improvement of the shipping's online service quality; and improvement of communication channels with ports, agents and customers.
4. *Organisation management.* This aspect focuses on the ability of an LSO to improve knowledge learning, which can be assessed by: how effective the application of knowledge management to the overall shipping operation management system is in order to boost shipping competitiveness; and effective leadership in organisations.

4.2.4 Compliance with Regulations

Frost *et al.* (2001) claimed that failure to comply with safety and environmental regulations can reduce the overall reliability and capability at the strategic management level. It has been recognised that the best way of improving security and safety levels in maritime operations is by complying with all international regulations introduced in the shipping industry. The International Maritime Organization (IMO) is a well-known international body that adopts regulations (i.e. Conventions) related to maritime safety, marine environment protection, legal enforcement, development in shipping and others related to the maritime transportation system. There are many conventions adopted by the IMO; however, the three major conventions are International Convention for the Safety of Life at Sea (SOLAS), International Convention for the Prevention of Pollution from Ships (MARPOL) and International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) (IMO, 2014). By considering the complexity in segregating all regulations, for assessing the effectiveness of an LSO to comply with regulations, three groups of compliances are formed, namely security and safety compliances, environmental compliances and miscellaneous compliances (i.e. other compliances: those not related to security, safety and environment).

1. *Security and safety compliances*. Security and safety has become a compelling and essential factor with which LSOs should comply. After the September 11, 2001 terrorist attacks, a number of laws and regulations were forged at international and national levels. There are two main regulatory frameworks for maritime security and safety: IMO packages and US initiatives. The IMO packages include The International Ship and Port Facility Security (ISPS) Code, SOLAS and STCW, while the US

initiatives include container security initiatives (CSI), C-PTAT and the 24-h rule. The effectiveness of the LSO in complying with the security and safety regulations can be measured by accident ratio (i.e. number of accidents/total number of vessels).

2. *Environmental compliances*. Marine environmental pollution can be in the form of oil-spills, sewage, noises, air emissions, ballast water, *etc*. It is well accepted that the main source of marine pollution is shipping operations. In this regard, the international community has concentrated mainly on the ship and port industry because of the well-known marine accidents in this area. MARPOL is the main convention that adopted pollution regulations for maritime transportation. The effectiveness of the LSO in complying with MARPOL regulations can be measured by event ratio (i.e. number of pollution events/total number of vessels).
3. *Miscellaneous compliances*. IMO has adopted many conventions, not only ISPS, SOLAS and STCW, but many other conventions and regulations for LSOs to obey. In this study, miscellaneous compliances will cover all the regulations not related to security, safety and environmental regulations. To measure the effectiveness of the LSO in complying with miscellaneous regulations, record of involvement in accidents is taken into account. The effectiveness of the LSO in complying with the miscellaneous regulations can be measured by event ratio (i.e. number of events/total number of vessels).

4.2.5 Service Quality Capability

In the international logistic systems, service quality capability could serve as a strategic weapon. Offering high-quality and reliable services are key strategies by which an LSO can distinguish itself from its competitors, building a close relationship with customers and attaining a better competitive advantage (Durvasula *et al.*, 1999). Due to this increasing awareness, the global nature of today's supply chain networks has entailed LSOs to offer high-quality services (Bang *et al.*, 2012). As a result, service quality capability needs to be considered in assessing the value of ORC for an LSO. For assessing service quality capability specifically for an LSO, four aspects are considered, namely claim responsiveness, documentation issues, customer relationship management (CRM) and asset and facility:

1. *Claim responsiveness*. Most LSOs make their best effort to provide quality services to customers; however, errors and accidents can happen during operations which can cause damage to goods. Due to that, the claim department is responsible for settling any customer claims as fast as possible. Based on Chen *et al.*'s (2010) study, which

obtained data from 210 respondents (i.e. 110 responses came from forwarders and 100 responses were from shippers), the result shows that the LSOs give their worst performance in settlement of cargo claims. The settlement of cargo claims should be improved in order to enhance the service quality capability. Claim responsiveness can be assessed by measuring the difference between submissions of a claim by a customer and settlement date of that claim.

2. *Documentation issue*. One of the documentation issues that received high attention from shippers is bill of lading (BL) issuance. Shippers are happy if they receive a BL as soon as the shipping instruction (SI) has been submitted. As a result, BL issuance can be considered as one of the elements in determining an LSO's service quality capability. Based on Drewry Shipping Consultants (2013), BL issuance's performance can be assessed by measuring the difference between submissions of SI and receiving date of confirmed BL.
3. *Customer Relationship Management (CRM).* CRM has been seen as a crucial organisational strategy to enhance competitive advantage (Plakoyiannaki and Tzokas, 2002). CRM entails all aspects of interaction a company has with its customer, whether the company is product or service-related. The most important CRM attributes in the shipping industry are use of phone calls, e-mails, and personal visits to communicate with customers; promptly responds to customers' problems, suggestions, and complaints; actively responds to customer enquiries about their services; actively provides transportation-related information to customers; and actively understands customers' service requirements and expectations (Shang and Lu, 2012). Furthermore, CRM is often used as a business strategy that enables LSOs to understand their customers, attract new customers, win new clients and contracts, and retain customers through better customer experiences. As a result, having a strong relationship with customers can ensure continuity and improve the service quality capability of an LSO.
4. *Asset and facility*. Parasuraman *et al.* (1988; 1991) claimed that asset and facility tangibility are found to be valuable in determining an organisation's service quality. In addition, tangibility can be described as how far physical facilities are visually appealing (e.g. ownership of vessels) and how well employees are neat in appearance (e.g. employees' skills) (Parasuraman *et al.*, 1988; 1991). In the CLSI, key assets and facilities for liner operations are vessels, container depots, containers, offices, warehouse, front desk employees, *etc.* From the shipper's point of view, clear tangibility of the LSO assets and facility could create high confidence to deal with that particular LSO.

4.2.6 Bayes' Theorem

Bayes' theorem is a mathematical formula for calculation of posterior probabilities (i.e. probability of each state of a node in a BBN when other variables' values are known) (Jensen, 1996). One of the main advantages of BBNs is that they allow interference based on observed evidence using Bayes' theorem. Bayes' theorem is represented as follows (Hayes, 1998):

$$P(X_a|X_b) = \frac{P(X_b|X_a)P(X_a)}{\sum_{all..i} P(X_b|X_a = x_i)P(X_a = x_i)} \tag{4.1}$$

where "|" means "on the condition of" or "given that". Assume that node "X_b" is observed to be in state x_j, "$P(X_a)$" is called the probability of "X_a" occurring, whereas "$P(X_a|X_b)$" is called posterior probability of "X_a" occurring given that the condition "X_b" occurred. "$P(X_b|X_a)$" is called the likelihood distribution (conditional probability) of "X_a" occurring given that "X_b" occurs too. By applying Equation 4.1 to each state of "X_a", the probability distribution "$P\left(X_a|X_b = x_j\right)$" is calculated by using Equation 4.2 as follows:

$$P(X_a|X_b = x_i) = \frac{P\left(X_b = x_j|X_a\right)P(X_a)}{\sum_{all..i} P\left(X_b = x_j|X_a = x_i\right)P(X_a = x_i)} \tag{4.2}$$

By using the same calculation, the posterior probability distribution for a large model can be computed. However, updating probability value using this method is practical only if the model is simple and each node has only a few states. In this regard, several software tools (e.g. *Hugin*, *Netica*, *etc*.) have been developed to solve complex problems which consist of multi-level nodes, many node states and complex dependency.

4.3 Methodology

In this chapter, in order to evaluate the value of ORC of an LSO, a generic model is constructed and a combination of different decision-making methods such as a symmetric model, FL and BBN are used. An AHP is employed to quantify the importance of attributes and is adapted into a deterministic weight vector (Saaty, 1980). A symmetric model is used to determine the conditional probabilities by synthesising the AHP methodology (Riahi *et al*., 2012b). A FL is used by exploiting membership functions, belief degrees and *If-Then* rules for assessing the ORC factors. Furthermore, a BBN is employed to demonstrate the fundamental concept of a probabilistic graphical model and to calculate marginal probabilities with the help of Bayes' chain rule. For the evaluation of the ORC, as illustrated in Figure 4.1, seven steps are followed.

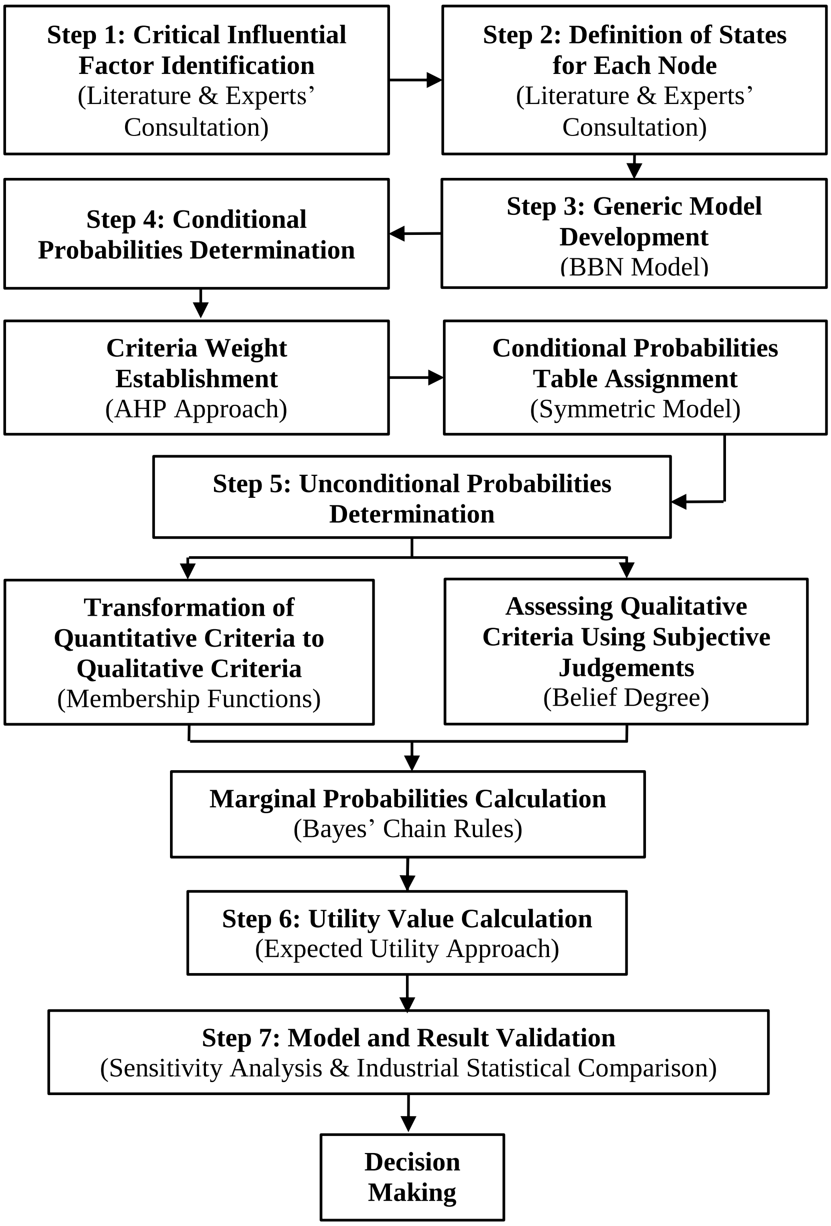

Figure 4.1: Framework for assessing the ORC of an LSO

Step 1: The critical influential factors were critically identified using several techniques including literature review and experts' consultation.

Step 2: States of each node were defined by using literature review and experts' consultation.

Step 3: A generic model for the ORC of an LSO is constructed using a BBN model.

Step 4: The strength of direct dependence of each child node to its associated parents is quantified by assigning each child node a conditional probability table (CPT) by using a symmetric model.

Step 5: The unconditional probabilities are determined by assessing all the root nodes in the model.

Step 6: The utility value is evaluated by using the expected utility approach.

Step 7: The model will be validated by using sensitivity analysis (SA) and the result by using industrial statistical comparison.

4.3.1 Identifying the Critical Influential Factors of the ORC of an LSO (*Step 1*)

In step 1, the process of identifying the critical influential factors for evaluating the ORC involves the listing of key factors and then classifying them into appropriate criteria in the categorisation system. Every significant factor needs to be carefully reviewed. Extensive literature review and consultations with domain experts have been used to identify the potential factors for evaluating the ORC of an LSO. The summary of identified factors for evaluating the ORC of an LSO (i.e. Agency) is presented in Table 4.1. It is noteworthy to mention that these identified factors (i.e. five main criteria, 18 sub-criteria and 17 sub-sub-criteria) can be used in a generic model where it can be modified or adjusted based on decision-makers' preferences for their decision-making process.

Table 4.1: Summary of identified factors for evaluating the ORC of an LSO

Main Criteria	Sub-criteria	Sub-sub-criteria
Operational Reliability	Vessel Reliability	Age of Vessel, Technology Up-gradation, Ship Staff's Reliability
	Container Management	
	Schedule Reliability	
	Port Reliability	
Financial Capability	Profitability Ratio	
	Finance Structure	
	Liquidity Ratio	
Knowledge Management	Market Competitiveness	Shipping Cost and Expense Reduction, Employee Efficiency Improvement, Market Penetration Ability.
	Human Resource Management Efficiency	Routine and Common Problem Solution, Standard Operation Procedure
	Organisation Management	Knowledge Management Application, Leadership.
	Service Innovation	Innovation Improvement Ability, Online Communication.

Compliance with Regulations	Security and Safety Compliances Environmental Compliances Miscellaneous Compliances	
Service Quality Capability	Claim Responsiveness	
	Documentation Issuance	
	Customer Relationship Management	Communication with customers, Customer Inquiry Response, Customer Requirement Understanding.
	Asset and Facility	Appeal of Facilities, Employees' Appearance.

4.3.2 Defining the States of the Nodes (*Step 2*)

This step explains the states of the nodes in the BBN model established for the assessment of the ORC of an LSO. The purpose of defining the states of the nodes is to appropriately assign the prior probabilities (Yang, 2006). Assume that a node is denoted with uppercase letter (X) and the specific states of the node are denoted with lowercase (x). The specific states of the node must be admissible under the BBN algorithm by following two axioms as follows (Yang, 2006):

- ***Completeness of states:*** For any node (X), the set for node states $\{(x_i)\}$ must be probabilistically complete, where $\sum_i P\{(X_i)\} = 1$. A probability is a real number less than or equal to 1.
- ***Mutually exclusive states:*** For any node (X), the set for node states $\{(x_i)\}$ must be mutually exclusive (i.e. the member set states do not correspond to each other) where $P\left(X = (x_i)\ or\ X = (x_j)\right) = P(X = (x_i)) + P(X = (x_j))$. In a condition when x_i and x_j cannot occur, the probability that either one of them occurs is equal to the sum of the probabilities of their individual occurrences.

In step 2, the number of states of each node is identified by using an extensive literature review. A discrete fuzzy set membership function can be applied to define states of each node. A consistent numbers of states of each node can provide simplicity in the process of evaluation as decision-makers can perform the evaluation based on identical number and term of linguistic variables. It is worth mentioning that the number of states of each node used in the model can affect the complication of the calculations (i.e. CPT and Bayes' chain rule); therefore, it needs to be carefully defined. As a result, in this chapter, three states are used for all nodes in the model and have been defined as "high", "medium" and "low".

4.3.3 Developing the Generic ORC Model (*Step 3*)

A generic evaluation model is developed and can be used within a specified industry or organisation. The kernel of the generic model is that it can be modified or adjusted to be used for a particular firm or industry. In this study, the justified factors as listed in Table 4.1 are used to develop a generic model for the ORC of an LSO. As a result, a generic model for the ORC of an LSO is constructed using a BBN model, as shown in Figure 4.2, and the abbreviations are listed in Table 4.2.

As shown in Figure 4.2, the structure of an LSO is directed by headquarters (i.e. main branch) while sub-branches in different places (e.g. country region) are represented by their agencies. The overall ORC (OORC) can be obtained by aggregating the values of all agencies, which are operated under their headquarters' directions. Based on Figure 4.2, the OORC can be assessed by aggregating the ORC value of $Agency_a$, $Agency_b$ and $Agency_n$ (i.e. n^{th} agency).

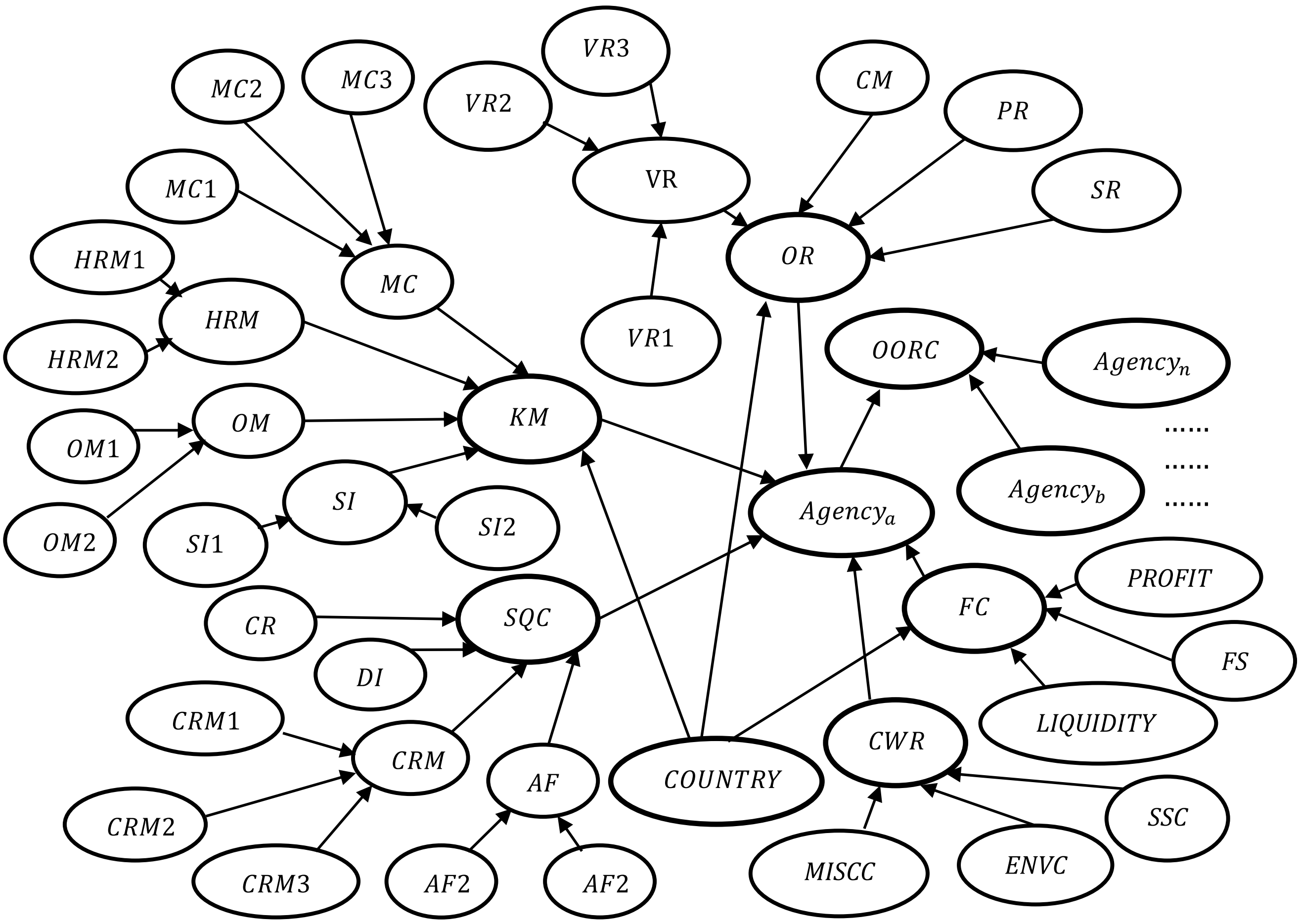

Figure 4.2: A generic FBBN model for assessing the value of the ORC of an LSO

Table 4.2: Abbreviations of the ORC criteria in a generic model

Abbreviation	Description
OORC	Overall Organisational Reliability Capability
Agencya	Agency A
Agencyb	Agency B
Agencyn	n^{th} agency
OR	Operational Reliability
FC	Financial Capability
KM	Knowledge Management
CWR	Compliance with Regulations
SQC	Service Quality Capability
COUNTRY	Country Reliability
VR	Vessel Reliability
CM	Container Management
PR	Port Reliability
SR	Schedule Reliability
PROFIT	Profitability Ratio
FS	Finance Structure
LIQUIDITY	Liquidity
MC	Market Competitiveness
HRM	Human Resource Management Efficiency
OM	Organisation Management
SI	Service Innovation
SSC	Safety and Security Compliances
ENVC	Environmental Compliances
MISCC	Miscellaneous Compliances
CR	Claim Responsiveness
DI	Documentation Issues
CRM	Customer Relationship Management
AF	Asset and Facilities
VR1	Ship Staff's Reliability
VR2	Age of Vessels
VR3	Technology Up-Gradation
MC1	Shipping Cost and Expenses Reduction
MC2	Employee Efficiency Improvement
MC3	Market Penetration Ability
HRM1	Routine and Common Problem Solution
HRM2	Standard Operation Procedure (SOP)
OM1	Knowledge Management Application
OM2	Leadership
SI1	Innovation Improvement Ability
SI2	Online Communications
CRM1	Communication with Customers
CRM2	Customer Inquiry Response
CRM3	Customer Requirement Understanding
AF1	Appeal of Facilities
AF2	Employees' Appearance

4.3.4 Determining the Conditional Probabilities (*Step 4*)

Conditional probability distributions are a set of distributions to represent the dependency of a child node to its parent node (nodes). The dependency of a child node to its parent node can be classified into three categories, namely full dependence, partial dependence and independence, which are explained as follows (Shrinath, 1991):

- *Full dependence:* If the conditional probability value between child node(s) and a parent node is equal to "1", then it is termed full dependence.
- *Partial dependence:* If the conditional probability value between child node(s) and a parent node lies between "0" and "1", then it is termed partial dependence.
- *Independence:* If the conditional probability value between child node(s) and a parent node is equal to "0", then it is termed independence.

Joint probability distributions (JPDs) can be used to present the causal relationship in the FBBN model (Riahi *et al.*, 2013; 2014). The local JPDs represent the BBN ability which is attached to each variable in the model's network purposely to quantify the strength of causal relationships in the FBBN model. The JPDs can be obtained using the combination of qualitative and quantitative relationship to assign possible value of parent nodes. The structure and the local JPDs of the FBBN, and the JPD of the domain of "n" nodes can be computed as follows (Riahi *et al.*, 2013):

$$P(X_1, X_2, \dots \dots, X_n) = \prod_{i=l}^{n} P(X_i | Pa_i) \tag{4.3}$$

where Pa_i denotes the set of direct parents of variable X_i. However, $P(X_i|Pa_i)$ is not straightforward to obtain, as the Bayesian approach requires much data in the form of prior probability. Riahi *et al.* (2013; 2014) claimed that most values of $P(X_i|Pa_i)$ in a form of prior probability could be acquired through performance database or empirical experiments. They also argued that experiments may be difficult to design and to conduct correctly, and historical data do not often satisfy the requirements of the Bayesian approach. There is one possible way to obtain information: by relying on expert judgements as a rational expression of an individual's degree of belief (Yang, 2006).

For modelling a framework for assessing the value of ORC of an LSO, the diverging and converging connections are more often used than serial connections for representing the networks in the FBBN model. To demonstrate the JPDs for the converging connections, assume 'X_1' and 'X_2' are the two parent nodes of their single child, 'X_3'. Based on Equation 4.3, it can be calculated as follows:

$$P(X_1, X_2, X_3) = P(X_1)P(X_2)P(X_3|X_1, X_2) \quad (4.4)$$

To demonstrate the JPDs for the diverging connections, let us assume 'X_3' is a parent node and 'X_1' and 'X_2' are the two child nodes. Based on Equation 4.3, it can be calculated as follows:

$$P(X_1, X_2, X_3) = P(X_1|X_3)P(X_2|X_3)P(X_3) \quad (4.5)$$

By comparing the results, since $P(X_3|X_1, X_2)$ cannot be further decomposed, Riahi *et al.* (2014) argued that this situation created difficulties for academicians and experienced analysts to solve this problem. Several researchers in the research field associated with BBNs have developed different methodologies to implement reasonable estimations of conditional probability distributions given multiple parents, such as "Noisy-Or" approaches. However, these approaches have many constraints in dealing with the conditional probability combination of having multi-state parents (Yang, 2006). In this regard, the symmetric model is used to implement precise estimations of conditional probability distributions. The symmetric model will be further explained in Sub-sub-section 4.3.4.1.

4.3.4.1 The Symmetric Model

The symmetric model has been proposed by Riahi (2010) and Riahi *et al.* (2012b; 2013; 2014) to determine the conditional probabilities by synthesising the AHP methodology. The difference between the "Noisy-Or" and symmetric model is the fact that in the "Noisy-Or" approach the expert's opinion is distributed by likelihood, and in the symmetric model the expert's opinion is distributed by relative importance of each parent node for its associated child node (Riahi *et al.*, 2012b; 2013; 2014). The advantage of a symmetric model is that it can deal with the conditional probability combination of multi-state parents. In addition, this model is capable of calculating a CPT of parent nodes having a different number of states. In a symmetric model, to determine the dependency of each child node to its associated parents, their normalised weights ($\omega_1, \omega_2, \omega_3 \dots \omega_n$) need to be assigned. The kernel of the symmetric model can be described as follows (Riahi *et al*., 2012b; 2013; 2014):

In the normalised space, based on the influence of each parent node, the conditional probability of a child node Y, given each parent node, X_r where $r = 1,2,3 \ldots . n$, can be estimated as follows:

$$P(Y = Present|X_1 = Present) = \omega_1$$
$$P(Y = Present|X_2 = Present) = \omega_2$$
$$\vdots$$
$$P(Y = Present|X_n = Present) = \omega_n \tag{4.6}$$

$$\sum_{r=1}^{n} \omega_r = 1$$

Based on Equation 4.6 in the situation of the symmetry approach (i.e. normalised space), the probability of node Y conditional upon 'n' parent nodes, X_r where $r = 1,2,3 \ldots . n$, can be estimated as follows (Riahi *et al.*, 2012b; 2013; 2014):

$$P(Y|X_1, X_2, \ldots \ldots, X_n) = \sum_{r=1}^{n} \widetilde{\omega}_r \tag{4.7}$$

$\widetilde{\omega}_r = \omega_r$: If the state of the *"rth parent node"* is identical to the state of its child.
$\widetilde{\omega}_r = 0$: If the state of the *"rth parent node"* is different from the state of its child.

To demonstrate the calculation of CPT using the symmetric model, assume that two subjects, Mathematics (X_1) and English (X_2), are variables used to determine the performance of the class (Y). Each parent and its child nodes have two states, namely "Good" and "Bad".

Based on Equation 4.6, weights for X_1 and X_2 (i.e. obtained from AHP) are listed as follows (Table 4.3):

$P(Y = Good|X_1 = Good) = \omega_1$ = 0.35
$P(Y = Good|X_2 = Good) = \omega_2$ = 0.65
$\sum_{r=1}^{n} \omega_r = 1$

Table 4.3: CPT using a symmetric model

If		***Then***	
MATHEMATICS (X_1)	ENGLISH (X_2)	Class = Good	Class =Bad
Good	Good	1	0
Good	Bad	0.35	0.65
Bad	Good	0.65	0.35
Bad	Bad	0	1

Consequently, the application of the symmetric model is used to quantify a CPT for each child node in this study. Further explanation of the symmetric model can be found in Riahi (2010) and Riahi *et al*. (2012b; 2013; 2014).

4.3.5 Determining the Unconditional Probabilities (*Step 5*)

For determining the unconditional probabilities of the root nodes, all evaluation criteria (i.e. 29 root nodes) need to be assessed. While dealing with reliability and capability evaluations, quantitative data are a prime input. For assessing the ORC of an LSO, quantitative data can be obtained from financial, safety and management records of the targeted LSO. There are 15 criteria that need to be assessed quantitatively. From these 15 quantitative criteria, six criteria (i.e. PROFIT, FS, LIQUIDITY, SSC, ENVC and MISCC) will be assessed by using membership functions and later transformed into a qualitative estimate (i.e. high, medium and low). A process of transferring quantitative data to qualitative estimates is explained in Sub-section 3.4.4. On the other hand, the other nine criteria (i.e. VR2, CM, SR, PR, CRM1, CRM2, CRM3, CR and DI) will be assessed by using *If-Then* rules. The membership functions and *If-Then* rules for assessing all 15 quantitative criteria are constructed (i.e. by using the literature and consultation with domain experts in the CLSI) and can be found in Appendix B-1.

In a situation where there is a lack of existing data in the literature and imprecise information about past events, qualitative data can be obtained for assessing 13 criteria in the ORC model (i.e. VR1, VR3, MC1, MC2, MC3, HRM1, HRM2, OM1, OM2, SI1, SI2, AF1 and AF2). There are various methods of qualitative data collection in the nature of information; one of them is through expert judgements. Qualitative data can be presented by linguistic variables (i.e. linguistic terms and their corresponding belief degrees), and simultaneously act as states of the variable. Consequently, based on Sub-section 4.3.2, states for each qualitative criterion in the ORC model can be presented by three linguistic terms (i.e. low, medium and high).

After the values of conditional and unconditional probabilities have been obtained, the marginal probabilities of the child node (nodes) can be calculated with the help of Bayes' chain rule. To demonstrate the calculation of the Bayes' chain rule, let us assume that two subjects, Mathematics (X_1) and English (X_2), are variables used to determine the performance of a class (Y). Based on Table 4.2, weights for Mathematic and English are 0.35 and 0.65 respectively. Each parent node has two states, namely "Good" and "Bad". Based on the investigations, 80% of students in class (Y) have good marks in Mathematics and 60% of students in class (Y) have good marks in English. Based on Bayes' chain rule, the marginal probability of the class (Y) performance can be calculated as follows:

P(Class = Good) = P(Class = Good|Mathematics = Good, English = Good) × *P(Mathematics = Good)* × *P(English = Good)* + *P(Class = Good|Mathematics = Good, English = Bad)* × *P(Mathematics = Good)* × *P(English = Bad)* + *P(Class = Good|Mathematics = Bad, English = Good)* × *P(Mathematics = Bad)* × *P(English = Good)* + *P(Class = Good|Mathematics = Bad, English = Bad)* × *P(Mathematics = Bad)* × *P(English = Bad)*

= (1 × 0.8 × 0.6) + (0.35 × 0.8× 0.4) + (0.65 × 0.2 × 0.6) + (0 × 0.2 × 0.4)

P (Class = Good) = 0.67

P (Class = Bad) = 1 - 0.67 = 0.33

In this study, the probability values of each node in the FBBN model will be computed by using the *Netica* software tool. The *Netica* software can be used as a robust FBBN programme for modelling and interference. This can also deal with a complex network model involving multi-parents of nodes.

4.3.6 Evaluation of Utility Value (*Step 6*)

The explanation about the utility value calculation can be found in Sub-section 3.3.7.

4.3.7 Validation of the Model and Result (*Step 7*)

For validating the ORC model, SA (i.e. explained in Sub-section 3.3.8) can be used. In order to ensure the methodology is consistent, the SA must at least meet the following axioms:

Axiom 1: A slight increment or decrement in the rate of probability associated with any states of an input node will certainly result in a relative increment or decrement in the rate of probability of the linguistic variable and preference degrees of the model output.

Axiom 2: A decrement in the rate of probability associated with the highest preference state on an input node by l and m will simultaneously result in the effect of increment of the rate of probability associated with its lowest preference state by l and m $(1 > m > l)$. The utility values of the model are evaluated as U_l and U_m respectively; then U_l should be greater than U_m.

Axiom 3: If K input nodes from N input nodes ($K < N$) are selected and the rate of probability associated with the highest preference state of each of such N and K input nodes is decreased by the same amount (i.e. simultaneously the rate of probability associated with the lowest preference state of each of such N and K input nodes is increased by the same amount) and the utility values of the model output are evaluated as U_K and U_N respectively, then U_K should be greater than U_N.

For validating the result obtained from the ORC model, a further validation can be conducted by using an industrial statistical comparison. Based on a reliable database (i.e. LSO ranking), if the ranking order of LSO 'A' is higher than 'B', then the utility value of LSO 'A' (U_A) should be greater than LSO 'B' (U_B).

4.4 Test Case: The ORC of the Agency 'A'

Within the previous chapter, the Malaysian CLSI has been selected as a test case for assessing the BEBR from an LSO's point of view. To ensure that the ORC evaluation is conducted in a similar environment, one LSO's agency based in Malaysia and named Agency 'A' is chosen in this test case. The assessment of Agency 'A' is based on its operation for the previous six months. Agency 'A' is one of the agencies under a Malaysian LSO. This Malaysian LSO was established in 1993 and is a public company listed on the main board of the Bursa Malaysia. The group has developed into a major regional shipping line principally involved in the provision of containerised shipping services. LSO 'A' currently operates a fleet of 10 containerships and they are currently deployed to provide services between ports in Malaysia, Singapore, Brunei, Hong Kong, China, Vietnam, Myanmar, Indonesia, India, Papua New Guinea, Thailand, Cambodia, Japan and Korea. In this test case, an internal team is appointed by headquarters (i.e. LSO 'A') to assess one of their agencies, named Agency 'A'. The ORC assessment will be conducted based on the developed model which has been explained in Sub-section 4.3.

4.4.1 Critical Influential Nodes, States and the Model of the ORC of Agency 'A' (*Steps 1, 2 and 3*)

Based on the generic model for the ORC in Figure 4.2, a specific model of the ORC of Agency 'A' is constructed, as shown in Figure 4.3. Since the purpose of this test case is to evaluate the ORC of Agency 'A', the node $Agency_a$ will become a goal or leaf node, while the other agencies (i.e. $Agency_b$ and $Agency_n$) and the overall organisational reliability and capability (i.e. OORC) will not be assessed. Based on Sub-sections 4.3.1, 4.3.2 and 4.3.3, for assessing the ORC of Agency 'A', the critical influential factors and their abbreviations and states are listed in Table 4.4.

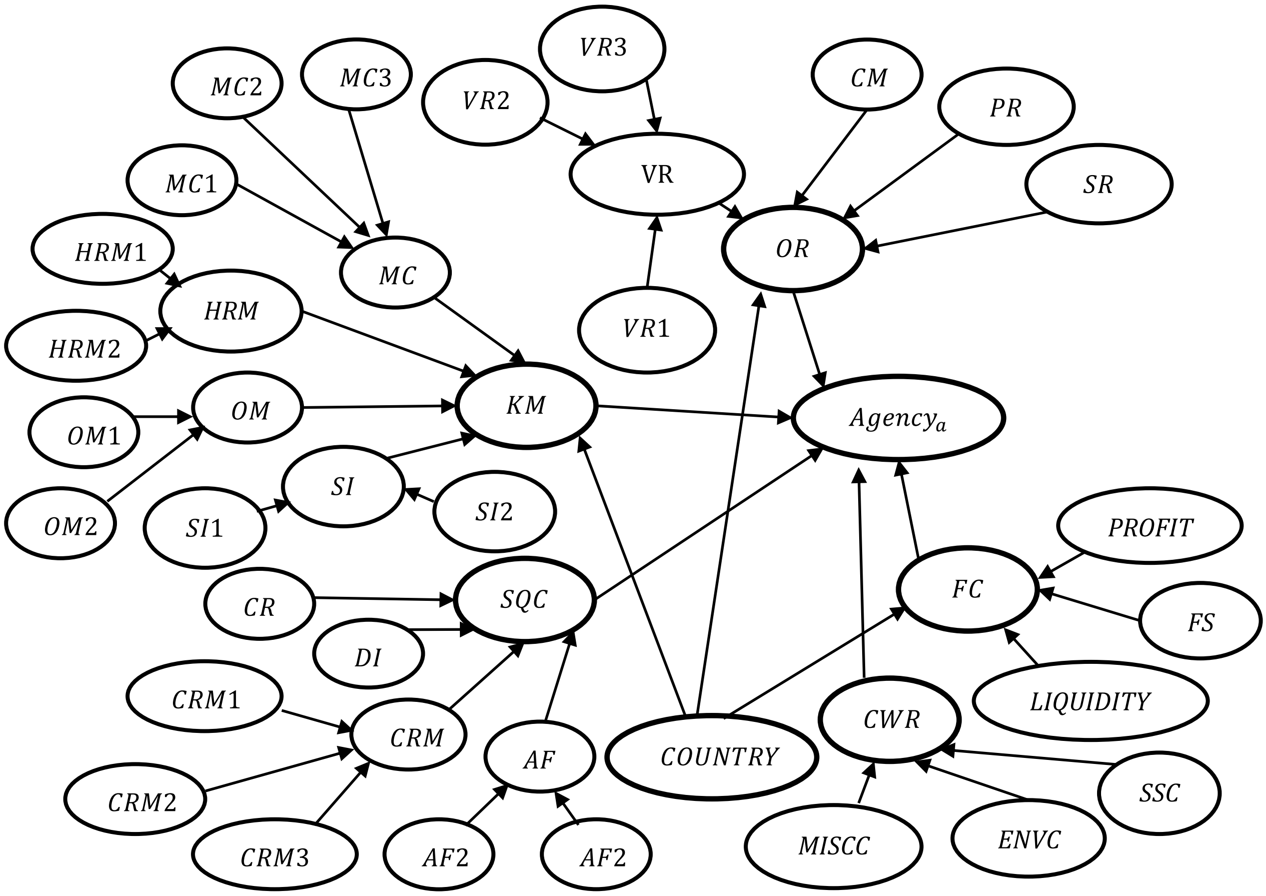

Figure 4.3: A specific model for assessing the ORC of Agency 'A'

As shown in Figure 4.3, the leaf node "Agency$_a$" has five parent nodes: "operational reliability (OR)", "financial capability (FC)", "knowledge management (KM)", "compliance with regulations (CWR)" and "service quality and capability (SQC)". The parent nodes that influence the node "OR" consist of "vessel reliability (VR)", "container management (CM)", "schedule reliability (SR)", "port reliability (PR)" and "country reliability (COUNTRY)". The node "VR" is influenced by three parent nodes, which are: "ship staff's reliability (VR1)", "age of vessels" (VR2)" and "technology up-gradation (VR3)". The node "FC" is influenced by four parent nodes, which are: "profitability ratio (PROFIT)", "finance structure (FS)", "liquidity ratio (LIQUIDITY)" and "COUNTRY". The node "CWR" is influenced by three parent nodes, which are: "security and safety compliance (SSC)", "environmental compliance (ENVC)" and "miscellaneous compliance (MISCC)". The node "KM" has five parent nodes: "market competitiveness (MC)", "human resource management (HRM)", "organisation management (OM)", "service innovation (SI)" and "COUNTRY". The node "MC" is influenced by three parent nodes, which are: "shipping cost and expenses reduction (MC1)", "employee efficiency improvement (MC2)" and "market penetration ability (MC3). The node "HRM" is influenced by two parent nodes, which are: "routine and common problem solution (HRM1)" and "standard operation procedure (HRM2)". The node "OM" is influenced by two parent nodes, which are: "knowledge management application (OM1)" and "leadership (OM2)". The node "SI" is influenced by two parent nodes, "innovative improvement ability (SI1)" and "online communications (SI2)". The node "SQC" has four parent nodes: "claim responsiveness (CR)", "documentation issues (DI)", "customer relationship management (CRM)" and "asset and facilities (AF)". The node "CRM" is influenced by three parent nodes, which are: "communication with customers (CRM1)", "customer inquiry response (CRM2)" and "customer requirement understanding (CRM3). The node "AF" is influenced by two parent nodes, which are: "appeal of facilities (AF1)" and "employees' appearance (AF2)".

Table 4.4: The list of influential factors and states in the specific model

No.	Abbreviation	Description	States
1	$Agency_a$	Agency 'A'	High, Medium, Low
2	OR	Operational Reliability	High, Medium, Low
3	FC	Financial Capability	High, Medium, Low
4	KM	Knowledge Management	High, Medium, Low
5	CWR	Compliance with Regulations	High, Medium, Low
6	SQC	Service Quality Capability	High, Medium, Low
7	COUNTRY	Country Reliability	High, Medium, Low
8	VR	Vessel Reliability	High, Medium, Low
9	CM	Container Management	High, Medium, Low
10	PR	Port Reliability	High, Medium, Low
11	SR	Vessel's Schedule Reliability	High, Medium, Low
12	PROFIT	Profitability Ratio	High, Medium, Low
13	FS	Finance Structure	High, Medium, Low
14	LIQUIDITY	Liquidity Ratio	High, Medium, Low
15	MC	Market Competitiveness	High, Medium, Low
16	HRM	Human Resource Management	High, Medium, Low
17	OM	Organisation Management	High, Medium, Low
18	SI	Service Innovation	High, Medium, Low
19	SSC	Security and Safety compliance	High, Medium, Low
20	ENVC	Environment compliance	High, Medium, Low
21	MISCC	Miscellaneous compliance	High, Medium, Low
22	CR	Claim Responsiveness	High, Medium, Low
23	DI	Documentation Issues	High, Medium, Low
24	CRM	Customer Relationship Management	High, Medium, Low
25	AF	Asset and Facilities	High, Medium, Low
26	VR1	Ship Staff's Reliability	High, Medium, Low
27	VR2	Age of Vessels	High, Medium, Low
28	VR3	Technology Up-Gradation	High, Medium, Low
29	MC1	Shipping Cost and Expenses Reduction	High, Medium, Low
30	MC2	Employee Efficiency Improvement	High, Medium, Low

31	MC3	Market Penetration Ability	High, Medium, Low
32	HRM1	Routine and Common Problem Solution	High, Medium, Low
33	HRM2	Standard Operation Procedure (SOP)	High, Medium, Low
34	OM1	Knowledge Management Application	High, Medium, Low
35	OM2	Leadership	High, Medium, Low
36	SI1	Innovation Improvement Ability	High, Medium, Low
37	SI2	Online Communications	High, Medium, Low
38	CRM1	Communication with Customers	High, Medium, Low
39	CRM2	Customer Inquiry Response	High, Medium, Low
40	CRM3	Customer Requirement Understanding	High, Medium, Low
41	AF1	Appeal of Facilities	High, Medium, Low
42	AF2	Employees' Appearance	High, Medium, Low

4.4.2 Conditional Probability Table (CPT) (*Step 4*)

The aforementioned symmetric model (Sub-sub-section 4.3.4.1) is used to quantify a CPT for each child node in this study. Eight experts (i.e. five industrial experts and three academic members) who have more than 15 years' experience in the CLSI are selected to give the relative importance of each parent node for its associated child nodes through an AHP approach (Mokhtari *et al*., 2012). The following eight experts are listed as follows:

1. A company director who has been involved in the maritime industry for more than 16 years.
2. A general manager and also shareholder of LSO 'A' who has more than 16 years' experience in the maritime industry.
3. A branch manager who worked at LSO 'A' who has more than 15 years' experience in the maritime industry.
4. A branch manager who works at LSO 'A' who has more than 16 years' experience in the maritime industry.
5. A senior manager who works at LSO 'A' who has more than 16 years' experience in the maritime industry.
6. A senior research fellow from the Maritime Institute of Malaysia who has been involved in the maritime industry for more than 15 years.
7. A senior lecturer who has been involved in the maritime industry for more than 20 years.
8. A senior lecturer who has been involved in Malaysian maritime policy for more than 15 years.

The explanation about the AHP and its calculation can be found in Sub-section 3.3.3.

Table 4.5: Relative importance of each parent node for its associated child node

Goal	Main Criteria	Weights	Sub-criteria	Weights	Sub-sub-criteria	Weights
Agency A	Operational Reliability (OR)	0.2160	Vessel Reliability (VR)	0.2968	Ship Staff's Reliability (VR1)	0.3333
					Age of Vessels (VR2)	0.3333
					Technology Up-Gradation (VR3)	0.3333
			Container Management (CM)	0.1632	NA	
			Schedule Reliability (SR)	0.2416		
			Port Reliability (PR)	0.1897		
			Country Reliability (COUNTRY)	0.1087		
	Financial Capability (FC)	0.2362	Profitability Ratio (PROFIT)	0.2619		
			Finance Structure (FS)	0.1857		
			Liquidity Ratio (LIQUIDITY)	0.4222		
			Country Reliability (COUNTRY)	0.1302		
	Knowledge Management (KM)	0.1199	Market Competitiveness (MC)	0.2880	Shipping Cost and Expenses Reduction (MC1)	0.3333
					Employee Efficiency Improvement (MC2)	0.3333
					Market Penetration Ability (MC3)	0.3333
			Human Resource Management (HRM)	0.1738	Routine and Common Problem Solution (HRM1)	0.5000
					Standard Operation Procedure (HRM2)	0.5000
			Organisation Management (OM)	0.1901	Knowledge Management Application (OM1)	0.5000
					Leadership (OM2)	0.5000
			Service Innovation (SI)	0.1969	Innovation Improvement Ability (SI1)	0.5000
					Online Communications (SI2)	0.5000
			Country Reliability (COUNTRY)	0.1512	NA	
	Compliance with Regulations (CWR)	0.2135	Security and Safety Compliances (SSC)	0.5009		
			Environment Compliances (ENVC)	0.2989		
			Miscellaneous Compliances (MISCC)	0.2002		
	Service Quality Capability (SQC)	0.2144	Claim Responsiveness (CR)	0.1067		
			Documentation Issues (DI)	0.1405		
			Customer Relationship Management (CRM)	0.4134	Communication with Customers (CRM1)	0.3333
					Customer Inquiry Response (CRM2)	0.3333
					Customer Requirement Understanding (CRM3)	0.3333
			Asset and Facility (AF)	0.3394	Appeal of Facilities (AF1)	0.5000
					Employees' Appearance (AF2)	0.5000

These AHP results (i.e. Table 4.5) are then used to formulate conditional probability distributions through a symmetric model. For example, based on Equation 4.7, the CPT for the child node "CWR" is constructed as shown in Table 4.6.

Table 4.6: CPT for the child node "CWR"

If			***Then* CWR**		
SSC	ENVC	MISCC	High	Medium	Low
High	High	High	1	0	0
High	High	Medium	0.7998	0.2002	0
High	High	Low	0.7998	0	0.2002
High	Medium	High	0.7011	0.2989	0
High	Medium	Medium	0.5009	0.4991	0
High	Medium	Low	0.5009	0.2989	0.2002
High	Low	High	0.7011	0	0.2989
High	Low	Medium	0.5009	0.2002	0.2989
High	Low	Low	0.5009	0	0.4991
Medium	High	High	0.4991	0.5009	0
Medium	High	Medium	0.2989	0.7011	0
Medium	High	Low	0.2989	0.5009	0.2002
Medium	Medium	High	0.2002	0.7998	0
Medium	Medium	Medium	0	1	0
Medium	Medium	Low	0	0.7998	0.2002
Medium	Low	High	0.2002	0.5009	0.2989
Medium	Low	Medium	0	0.7011	0.2989
Medium	Low	Low	0	0.5009	0.4991
Low	High	High	0.4991	0	0.5009
Low	High	Medium	0.2989	0.2002	0.5009
Low	High	Low	0.2989	0	0.7011
Low	Medium	High	0.2002	0.2989	0.5009
Low	Medium	Medium	0	0.4991	0.5009
Low	Medium	Low	0	0.2989	0.7011
Low	Low	High	0.2002	0	0.7998
Low	Low	Medium	0	0.2002	0.7998
Low	Low	Low	0	0	1

Based on Equation 4.7, data that need to be inserted in the CPTs for the child nodes "VR", "MC", "HRM", "OM", "SI", "CRM", "AF", "OR", "FC", "KM", "CWR", "SQC" and Agency 'A' are respectively 81, 81, 27, 27, 27, 81, 27, 729, 243, 729, 81, 243 and 729 (i.e. 3105 data in total).

4.4.3 Assessing Reliability and Capability Values for Determining Unconditional Probabilities of the Root Nodes (*Step 5*)

The aforementioned reliability and capability values for determining the unconditional probabilities of the root nodes (i.e. Sub-section 4.3.5) are assessed and obtained from both qualitative and quantitative data.

4.4.3.1 Quantitative Data

The construction of membership functions and *If-Then* rules for evaluating quantitative criteria in the ORC model can be found in Appendix B-1. Based on the constructed membership functions and obtained data, the unconditional probabilities of all the root nodes are assessed as follows:

For assessing the current ratio (i.e. the node "LIQUIDITY"), based on the 2013 financial report of Agency 'A', it can be calculated as follows:

$$Current\ Ratio = \frac{RM\ 268{,}847{,}000}{RM\ 182{,}257{,}000} = 1.4751 \approx 1.48$$

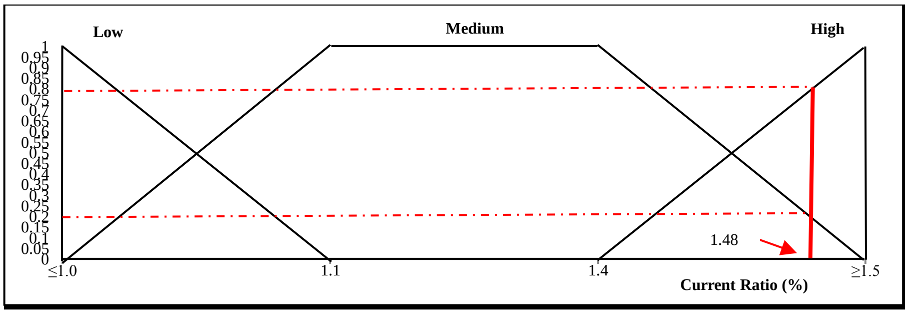

Figure 4.4: Membership functions for the node "LIQUIDITY" (test case)

1. H_n is Medium
2. H_{n+1} is High
3. h_i = 1.48, $h_{n,i}$ = 1.4 and $h_{n+1,i}$ = 1.5
4. $\beta_{n,i}$ = (1.5-1.48) / (1.5-1.4) = 0.2 with Medium and $\beta_{n+1,i}$ = 1-0.2 = 0.8 with High

This quantitative estimate can be transformed to qualitative data by using Equation 3.18. As a result, based on Figure 4.4, the set for the node "LIQUIDITY" is evaluated as:

LIQUIDITY = {(Low, 0), (Medium, 0.2), (High, 0.8)}

By using the same technique, the membership functions for the root nodes "PROFIT", "FS", "SSC", "ENVC" and "MISCC" are assessed.

For assessing the RONOA (i.e. the node "PROFIT"), based on the 2013 financial report of Agency 'A', it can be calculated as follows:

$$RONOA = \frac{RM917{,}000}{RM760{,}413{,}000}\ X\ 100\% = 0.1206\% \approx 0.12\%$$

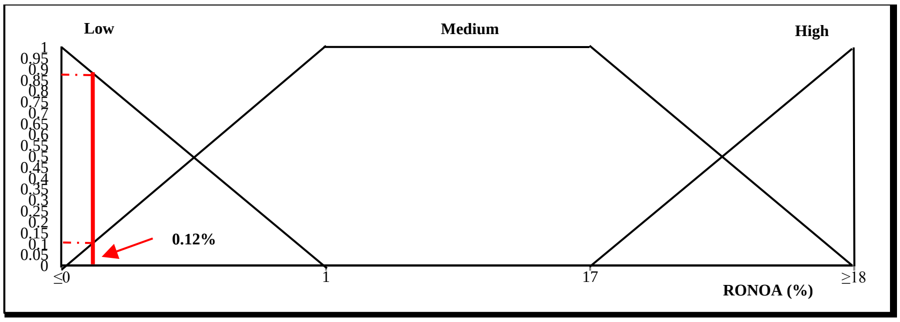

Figure 4.5: Membership functions for the node "PROFIT" (test case)

Based on Figure 4.5, the set for the node "PROFIT" is evaluated as:

PROFIT = {(Low, 0.88), (Medium, 0.12), (High, 0)}

For assessing solvency ratio (i.e. the node "FS"), based on the 2013 financial report of Agency 'A', it can be calculated as follows:

$$Solvency\ Ratio = \frac{RM\ 627{,}894{,}000}{RM\ 961{,}839{,}000} = 65.28\%$$

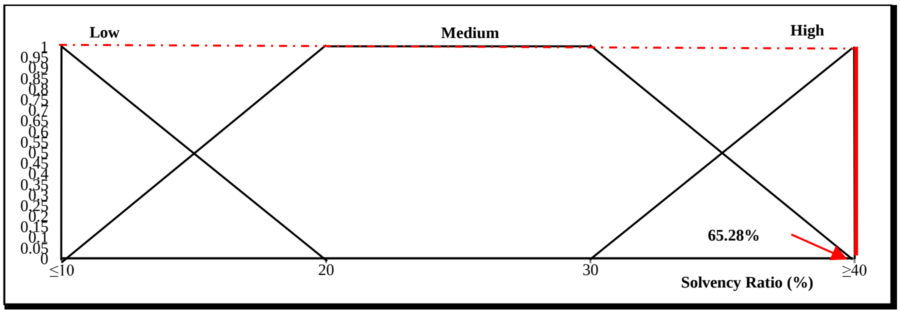

Figure 4.6: Membership functions for the node "FS" (test case)

Based on Figure 4.6, the set for the node "FS" is evaluated as:

FS = {(Low, 0), (Medium, 0), (High, 1)}

For assessing the node "SSC", based on data obtained by using a questionnaire, it can be calculated as follows:

$$SSC\ Accident\ Ratio = \frac{0\ event}{10\ vessels} = 0$$

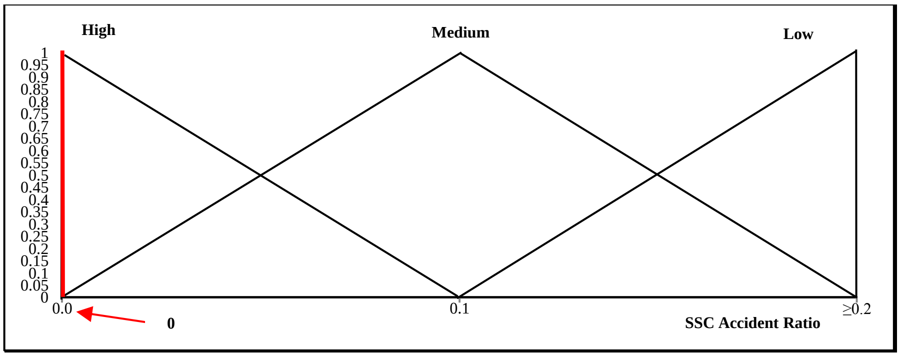

Figure 4.7: Membership functions for the node "SSC" (test case)

Based on Figure 4.7, the set for the node "SSC" is evaluated as:

$$SSC = \{(\text{Low}, 0), (\text{Medium}, 0), (\text{High}, 1)\}$$

For assessing the root node "ENVC", based on data obtained by using a questionnaire, it can be calculated as follows:

$$ENVC\ Event\ Ratio = \frac{0\ event}{10\ vessels} = 0$$

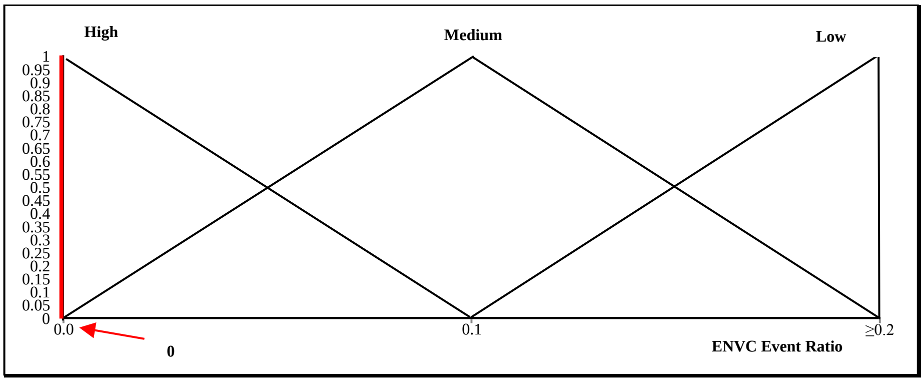

Figure 4.8: Membership functions for the node "ENVC" (test case)

Based on Figure 4.8, the set for the node "ENVC" is evaluated as:

$$ENVC = \{(\text{Low}, 0), (\text{Medium}, 0), (\text{High}, 1)\}$$

For assessing the root node "MISCC", based on data obtained by using a questionnaire, it can be calculated as follows:

$$MISCC\ Event\ Ratio = \frac{0\ event}{10\ vessels} = 0$$

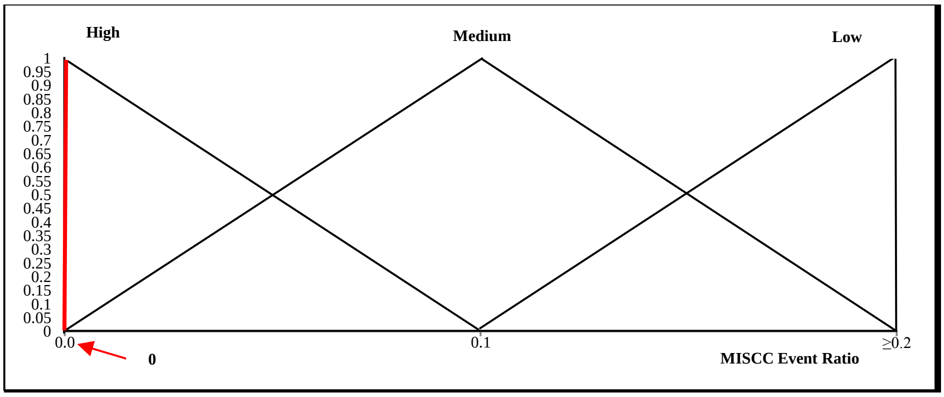

Figure 4.9: Membership functions for the node "MISCC" (test case)

Based on Figure 4.9, the set for the node "MISCC" is evaluated as:

MISCC = {(Low, 0), (Medium, 0), (High, 1)}

For evaluating the root nodes VR2, CM, SR, PR, CRM1, CRM2, CRM3, CR and DI, *If-Then* Rules as demonstrated in Appendix B-1 are used. For example, an evaluation of age of vessel (VR2) is presented in the following rules:

If a vessel is 10 (or less) years old, *then* the reliability is 100% high.
If a vessel is between 11-20 years old, *then* the reliability is 100% medium.
If a vessel is 20 (or more) years old, *then* the reliability is 100% low.
If n vessels, k of them are 10 (or less) years old, l of them are between 11-20 years old and m of them are 20 (or more) years old:
Then, $\frac{k}{n} \times 100$ = % high, $\frac{l}{n} \times 100$ = % medium and $\frac{m}{n} \times 100$ = % low.

Ten liner vessels are currently operated in liner services under Agency 'A'. All of these vessels are between 11-20 years old. As a result, the reliability set for age of vessel is calculated (i.e. $\frac{10}{10} \times 100$ = 100% medium) and presented as:

VR2 = {(Low, 0), (Medium, 1), (High, 0)}

By using the same technique (i.e. *If-Then* Rules), the membership functions of nine quantitative criteria are constructed and presented in Table 4.7.

Table 4.7: *If-Then* Rules and results of quantitative datasets

Quantitative Datasets	*If*	*Then* the reliability is	Obtained Results
1. Age of Vessel	A vessel is 10 (or less) years old	High	0
	A vessel is between 11-20 years old	Medium	1
	A vessel is 21 (or more) years old	Low	0
2. Container Management	ETA-ATA is within 1 day or less,	High	0.3
	ETA-ATA is more than 1 and up to 2 days	Medium	0.3
	ETA-ATA is more than 2 days	Low	0.4
3. Schedule Reliability	AVA-ATA is within 1 day or less,	High	0.3
	AVA-ATA is more than 1 and up to 2 days	Medium	0.3
	AVA-ATA is more than 2 days	Low	0.4
4. Port Reliability	Dwell Time is within 4 days or less	High	0.3
	Dwell Time is more than 4 and up to 7 days	Medium	0.3
	Dwell Time is more than 7 days	Low	0.4
5. Communication with Customers	Once or more every week	High	0.2
	Once or more every month	Medium	0.7
	Once or more for more than a month	Low	0.1
6. Response to Customer Inquiry	Response is within 1 day or less	High	0.5
	Response is more than 1 day and up to 2 days	Medium	0.4
	Response is more than 2 days	Low	0.1
7. Customer Requirement Understanding	Session is done every 3 months	High	0.1
	Session is done only once every 3 – 6 months	Medium	0.3
	Session is done only once every 6 – 12 months	Low	0.6
8. Claim Responsiveness	Settlement is within 3 months or less	High	0.85
	Settlement is more than 3 months and up to 6 months	Medium	0.1
	Settlement is more than 6 months	Low	0.05
9. Documentation Issues	SI-BL is within 3 days or less	High	0.85
	SI-BL is more than 3 and up to 5 days	Medium	0.1
	SI-BL is more than 5 days	Low	0.05

4.4.3.2 Qualitative Data

For assessing qualitative data, three evaluators act as an internal team that have been selected based on their 15 to 20 years' experience in LSO 'A'. A profile of the three evaluators is listed as follows:

1. A general manager and also main shareholder of LSO 'A' who has 15 years' experience in the CLSI.
2. A branch manager of Agency 'A' who has 15 years' experience in the CLSI.

3. A senior operations manager of Agency 'A' who has 25 years' experience in the CLSI.

These three evaluators have to assess every reliability or capability set under a fuzzy environment; for example, a HRM of the Agency 'A' has been assessed as follows:

Table 4.8: HRM assessment under a fuzzy environment

Reliability Criteria	Measurement Criteria	Weight	Assessment Grades Agency 'A'			
			Source	Low	Medium	High
Human Resource Management (HRM)	Routine and Common Problem Solution (HRM1)	0.5	Expert 1	0	0.6	0.4
			Expert 2	0	0.7	0.3
			Expert 3	0	0.1	0.9
			Aggregation (ER)	0	0.4571	0.5429
	Standard Operation Procedure (HRM2)	0.5	Expert 1	0	0.7	0.3
			Expert 2	0	0.7	0.3
			Expert 3	0	0.1	0.9
			Aggregation (ER)	0	0.4989	0.5011

Based on Table 4.8, for assessing the value of HRM efficiency, two questions have been asked during interviews (i.e. 1. How capable are your shore-based employees to solve routine and common problems? 2. How capable is your organisation to standardise the Standard Operation Procedure (SOP) so as to improve employees' business handling ability?). Three linguistic terms are set up from low, medium and high for each question. Each question and expert will have an equal weight in order to avoid pre-judgement. Based on Table 4.8, for assessing the ability of shore-based employees to solve routine and common problems (i.e. question 1), expert 1 has assessed it based on proportional value between medium (i.e. 60%) and high (i.e. 40%), expert 2 has assessed it as 70% medium and 30% high, and expert 3 has assessed it as 10% medium and 90% high. These assessments are then aggregated by using an ER algorithm to obtain the reliability estimate of question 1 as {(Low, 0), (Medium, 0.4571), (High, 0.5429)}. The same technique is applied for assessing the organisation's ability to standardise the SOP (i.e. question 2) and the obtained result is {(Low, 0), (Medium, 0.4989), (High, 0.5011)}. By using the same technique, all 13 qualitative datasets are obtained and presented in Table 4.9.

Table 4.9: Aggregation values of the qualitative datasets

Qualitative Reliability Criteria	Assessment Grades Agency 'A'			
	Source	Low	Medium	High
VR1	Expert 1	0.3	0.7	0
	Expert 2	0	0.7	0.3
	Expert 3	0	0	1
	Aggregation (ER)	0.0884	0.4845	0.4271

VR3	Expert 1	0.3	0.7	0
	Expert 2	0	0.7	0.3
	Expert 3	0	0	1
	Aggregation (ER)	0.0884	0.4845	0.4271
MC1	Expert 1	0	1	0
	Expert 2	0	0.7	0.3
	Expert 3	0	0.3	0.7
	Aggregation (ER)	0	0.7063	0.2937
MC2	Expert 1	0	1	0
	Expert 2	0.7	0.3	0
	Expert 3	0	0.1	0.9
	Aggregation (ER)	0.2172	0.5035	0.2793
MC3	Expert 1	0	1	0
	Expert 2	0	0	1
	Expert 3	0	0.2	0.8
	Aggregation (ER)	0	0.7867	0.2133
HRM1	Expert 1	0	0.6	0.4
	Expert 2	0	0.7	0.3
	Expert 3	0	0.1	0.9
	Aggregation (ER)	0	0.4571	0.5429
HRM2	Expert 1	0	0.7	0.3
	Expert 2	0	0.7	0.3
	Expert 3	0	0.1	0.9
	Aggregation (ER)	0	0.4989	0.5011
OM1	Expert 1	0	1	0
	Expert 2	0	0.7	0.3
	Expert 3	0	0.2	0.8
	Aggregation (ER)	0	0.6680	0.3320
OM2	Expert 1	0.2	0.8	
	Expert 2		0.7	0.3
	Expert 3		0.1	0.9
	Aggregation (ER)	0.0571	0.05619	0.3810
SI1	Expert 1	0.3	0.7	0
	Expert 2	0	0.7	0.3
	Expert 3	0	0.2	0.8
	Aggregation(ER)	0.0850	0.5693	0.3457
SI2	Expert 1	0	0.3	0.7
	Expert 2	0	0	1
	Expert 3	0	0.2	0.8
	Aggregation (ER)	0	0.1262	0.8738
AF1	Expert 1	0	0.6	0.4
	Expert 2	0	0.5	0.5
	Expert 3	0	0.3	0.7
	Aggregation (ER)	0	0.4587	0.5413
AF2	Expert 1	0	0.3	0.7
	Expert 2	0	0.7	0.3
	Expert 3	0	0.3	0.7
	Aggregation (ER)	0	0.4175	0.5825

4.4.3.3 The influence of the BEBR on the ORC of Agency 'A'

The aforementioned BEBR (i.e. Chapter 3) has a profound influence on the reliability and capability of an LSO. An unhealthy business environment will adversely affect liner shipping in the context of operational reliability, knowledge management and financial capability (CLSCM, 2003; Riahi *et al*., 2014). In this chapter, the BEBR can be considered as the reliability of a country that influenced the value of the ORC of Agency 'A'.

In Chapter 3, the BEBR grades are designed to be five linguistic terms (i.e. very low, low, medium, high and very high) and the preferred linguistic term for the BEBR is very low, while the country reliability grades are designed as three linguistic terms (i.e. low, medium and high) and the preferred linguistic term for the country reliability is high. As a result, the BEBR value needs to be transformed into country reliability grades to have all the data and information in the same universe. Therefore, for transferring the BEBR estimate (in terms of five linguistic variables) into country reliability estimate (in terms of three linguistic variables), a mapping process is used. The relationship between fuzzy input and fuzzy output can be evaluated by Equations 4.8 and 4.9. It is worth mentioning that the sum of the belief degrees from linguistic variable has to be equal to 1. In addition, in order to avoid a bias in the judgement, belief degrees are distributed uniformly.

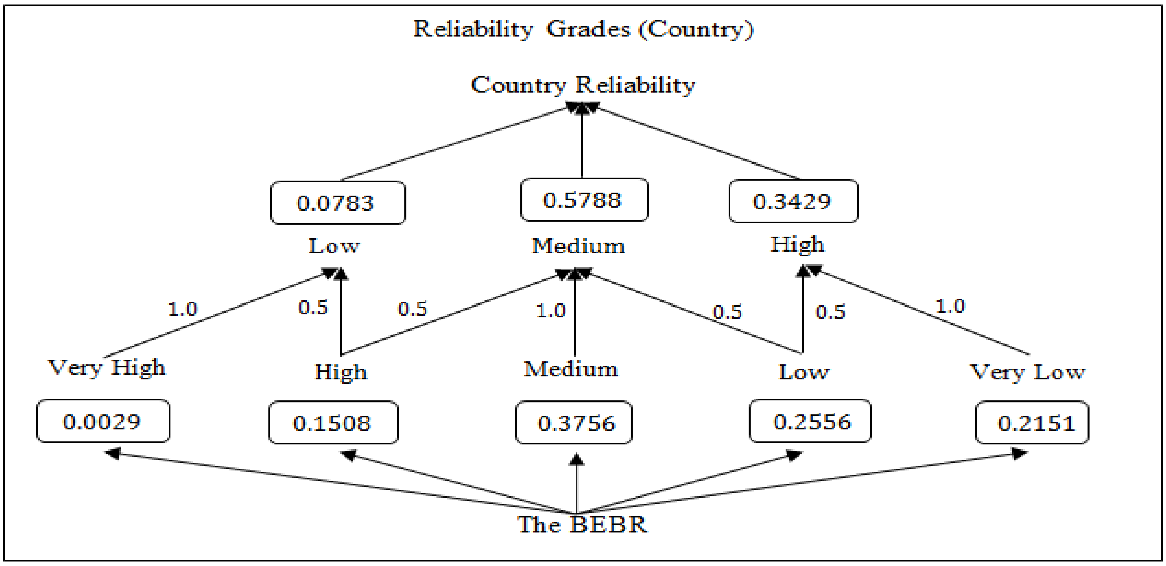

Figure 4.10: Mapping process from the BEBR to the country reliability

$$u^j = \sum_{i=1}^{5} l^i \beta_i^j \; (j = 1, 2, 3) \qquad (4.8)$$

$$\sum_{i=1}^{5} l^i = 1 \tag{4.9}$$

Based on Figure 4.10 and Equation 4.8, the value of country reliability is calculated as follows:

Low = (0.0029 × 1) + (0.1508 × 0.5) = 0.0783
Medium = (0.1508 × 0.5) + (0.3756 × 1) + (0.2556 × 0.5) = 0.5788
High = (0.2556 ×0.5) + (0.2151 × 1) = 0.3429

As a result, the set for the root node "COUNTRY" is evaluated as:

COUNTRY = {(Low, 0.0783), (Medium, 0.5788), (High, 0.3429)}

The fairness of this mapping process can be checked by calculating utility values of both BEBR and "COUNTRY". The BEBR utility is 0.3677 and "COUNTRY" is (1-0.6323=0.3677). As a result, the above mapping process is reasonable.

After all the reliability values have been obtained by using quantitative assessment, qualitative assessment and mapping process (i.e. country reliability), these sets will be used to determine the unconditional probability distributions for root nodes as listed in Table 4.10:

Table 4.10: The belief degrees of all root nodes

No.	Root Nodes	Assessment Grade (Agency 'A')		
		Low	Medium	High
1.	VR1	0.0884	0.4845	0.4271
2.	VR2	0	1	0
3.	VR3	0.0884	0.4845	0.4271
4.	CM	0.4	0.3	0.3
5.	SR	0.4	0.3	0.3
6.	PR	0.4	0.3	0.3
7.	PROFIT	0.88	0.12	0
8.	FS	0	0	1
9.	LIQUIDITY	0	0.2	0.8
10.	MC1	0	0.7063	0.2937
11.	MC2	0.2172	0.5035	0.2793
12.	MC3	0	0.7867	0.2133
13.	HRM1	0	0.4571	0.5429
14.	HRM2	0	0.4989	0.5011
15.	OM1	0	0.6680	0.3320
16.	OM2	0.0571	0.5619	0.3810
17.	SI1	0.0850	0.5693	0.3457
18.	SI2	0	0.1262	0.8738
19.	SSC	0	0	1

20.	ENVC	0	0	1
21.	MISCC	0	0	1
22.	CR	0.05	0.1	0.85
23.	DI	0.05	0.1	0.85
24.	CRM1	0.1	0.7	0.2
25.	CRM2	0.1	0.4	0.5
26.	CRM3	0.6	0.3	0.1
27.	AF1	0	0.4587	0.5413
28.	AF2	0	0.4175	0.5825
29.	COUNTRY	0.0783	0.5788	0.3429

4.4.3.4 Marginal Probability Calculation

After all the values of conditional and unconditional probabilities have been obtained, the marginal probabilities of the child node (nodes) can be calculated based on Bayes' chain rule. For example, the marginal probability value of the node "Compliance with Regulations = High" is calculated as follows:

$P(CWR = High) = P(CWR = High|SSC, ENVC, MISCC)$

$P(WR = High) = P(CWR = High|SSC = High, ENVC = High, MISCC = High) \times$

$P(SSC = High) \times P(ENVC = High) \times P(MISCC = High) +$

$P(CWR = High|SSC = High, ENVC = High, MISCC = Medium) \times P(SSC = High) \times$

$P(ENVC = High) \times P(MISCC = Medium) +$

$P(CWR = High|SSC = High, ENVC = High, MISCC = Low) \times P(SSC = High) \times$

$P(ENVC = High) \times P(MISCC = Low) +$

$P(CWR = High|SSC = High, ENVC = Medium, MISCC = High) \times P(SSC = High) \times$

$P(ENVC = Medium) \times P(MISCC = High) +$

$P(CWR = High|SSC = High, ENVC = Medium, MISCC = Medium) \times P(SSC =$

$High) \times P(ENVC = Medium) \times P(MISCC = Medium) +$

$P(CWR = High|SSC = High, ENVC = Medium, MISCC = Low) \times P(SSC = High) \times$

$P(ENVC = Medium) \times P(MISCC = Low) +$

$P(CWR = High|SSC = High, ENVC = Low, MISCC = High) \times P(SSC = High) \times$

$P(ENVC = Low) \times P(MISCC = High) +$

$P(CWR = High|SSC = High, ENVC = Low, MISCC = Medium) \times P(SSC = High) \times$

$P(ENVC = Low) \times P(MISCC = Medium) +$

$P(CWR = High|SSC = High, ENVC = Low, MISCC = Low) \times P(SSC = High) \times$

$P(ENVC = Low) \times P(MISCC = Low) +$

$P(CWR = High) =$

$P(CWR = High|SSC = Medium, ENVC = High, MISCC = High) \times P(SSC =$

$Medium) \times P(ENVC = High) \times P(MISCC = High) +$

$P(CWR = High|SSC = Medium, ENVC = High, MISCC = Medium) \times P(SSC = Medium) \times P(ENVC = High) \times P(MISCC = Medium) +$

$P(CWR = High|SSC = Medium, ENVC = High, MISCC = Low) \times P(SSC = Medium) \times P(ENVC = High) \times P(MISCC = Low) +$

$P(CWR = High|SSC = Medium, ENVC = Medium, MISCC = High) \times P(SSC = Medium) \times P(ENVC = Medium) \times P(MISCC = High) +$

$P(CWR = High|SSC = Medium, ENVC = Medium, MISCC = Medium) \times P(SSC = Medium) \times P(ENVC = Medium) \times P(MISCC = Medium) +$

$P(CWR = High|SSC = Medium, ENVC = Medium, MISCC = Low) \times P(SSC = Medium) \times P(ENVC = Medium) \times P(MISCC = Low) +$

$P(CWR = High|SSC = Medium, ENVC = Low, MISCC = High) \times P(SSC = Medium) \times P(ENVC = Low) \times P(MISCC = High) +$

$P(CWR = High|SSC = Medium, ENVC = Low, MISCC = Medium) \times P(SSC = Medium) \times P(ENVC = Low) \times P(MISCC = Medium) +$

$P(CWR = High|SSC = Medium, ENVC = Low, MISCC = Low) \times P(SSC = Medium) \times P(ENVC = Low) \times P(MISCC = Low) +$

$P(CWR = High) = P(CWR = High|SSC = Low, ENVC = High, MISCC = High) \times P(SSC = Low) \times P(ENVC = High) \times P(MISCC = High) +$

$P(CWR = High|SSC = Low, ENVC = High, MISCC = Medium) \times P(SSC = Low) \times P(ENVC = High) \times P(MISCC = Medium) +$

$P(CWR = High|SSC = Low, ENVC = High, MISCC = Low) \times P(SSC = Low) \times P(ENVC = High) \times P(MISCC = Low) +$

$P(CWR = High|SSC = Low, ENVC = Medium, MISCC = High) \times P(SSC = Low) \times P(ENVC = Medium) \times P(MISCC = High) +$

$P(CWR = High|SSC = Low, ENVC = Medium, MISCC = Medium) \times P(SSC = Low) \times P(ENVC = Medium) \times P(MISCC = Medium) +$

$P(CWR = High|SSC = Low, ENVC = Medium, MISCC = Low) \times P(SSC = Low) \times P(ENVC = Medium) \times P(MISCC = Low) +$

$P(CWR = High|SSC = Low, ENVC = Low, MISCC = High) \times P(SSC = Low) \times P(ENVC = Low) \times P(MISCC = High) +$

$P(CWR = High|SSC = Low, ENVC = Low, MISCC = Medium) \times P(SSC = Low) \times P(ENVC = Low) \times P(MISCC = Medium) +$

$P(CWR = High|SSC = Low, ENVC = Low, MISCC = Low) \times P(SSC = Low) \times P(ENVC = Low) \times P(MISCC = Low)$

= (1 × 1 × 1 × 1) + (0.7998 × 1 × 1 × 0) + (0.7998 × 1 × 1 × 0) + (0.7011 × 1 × 0 × 1) + (0.5009 × 1 × 0 × 0) + (0.5099 × 1 × 0 × 0) + (0.7011 × 1 × 0 × 1) + (0.5099 × 1 × 0 × 0) + (0.5099 × 1 × 0 × 0)) + (0.4991 × 0 × 1 × 1)) + (0.2989 × 0 × 1 × 0) + (0.2989 × 0 × 1 × 0) + (0.2002 × 0 × 0 × 1) + (0 × 0 × 0 × 0) + (0 × 0 × 0 × 0) + (0.2002 × 0 × 0 × 1) + (0 × 0 × 0 × 0) + (0 × 0 × 0 × 0) + (0.4991 × 0 × 1 × 1)) + (0.2989 × 0 × 1 × 0) + (0.2989 × 0 × 1 × 0) + (0.2002 × 0 × 0 × 1) + (0 × 0 × 0 × 0) + (0 × 0 × 0 × 0) + (0.2002 × 0 × 0 × 1) + (0 × 0 × 0 × 0) + (0 × 0 × 0 × 0)

= *P (CWR = High)* = 1.

The above calculation for the marginal probability value of the node "CWR = High" is known to be 1. Consequently, the marginal probability value of the node "CWR = Medium and Low" is indicated as zero.

Due to the complexity of manual calculation of Bayes' chain rule, a computer software tool called *Netica* is used to calculate the marginal probability of the ORC value of Agency 'A'. Therefore, as shown in Figure 4.11, the set for the ORC of Agency 'A' is computed as {(Low, 0.146), (Medium, 0.284), (High, 0.571)}.

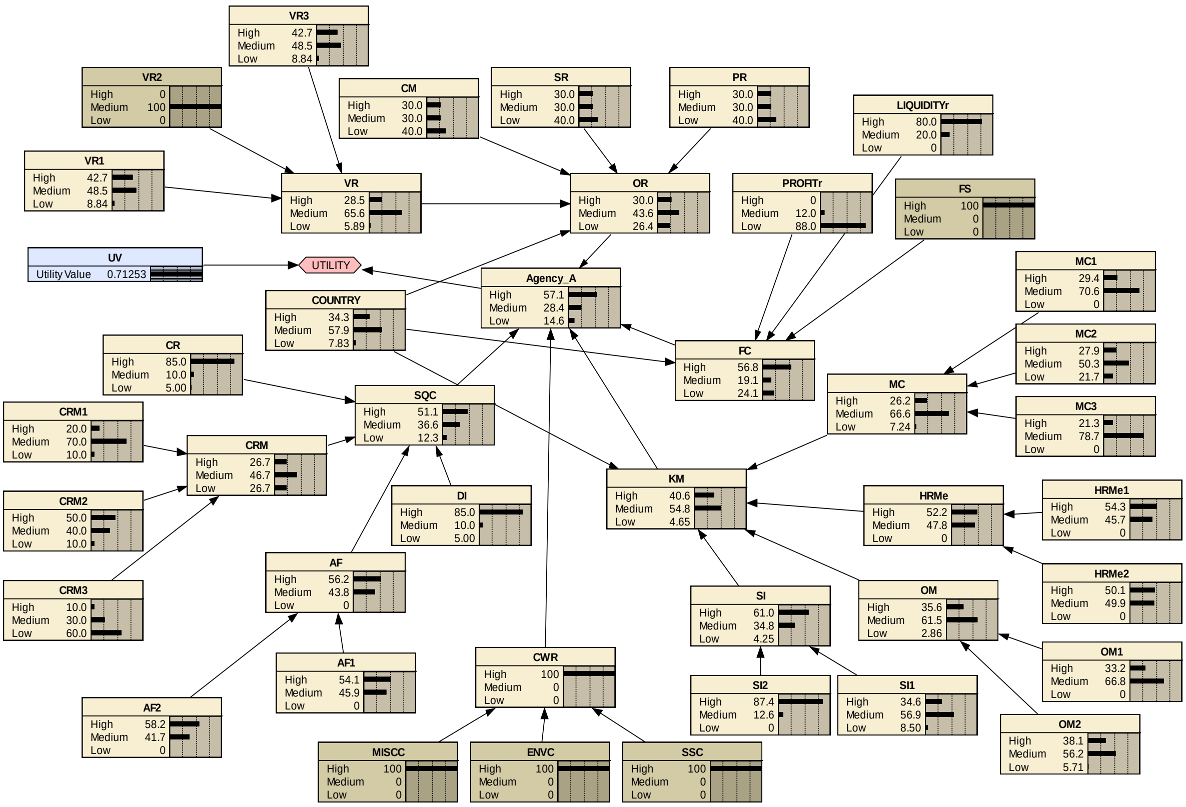

Figure 4.11: The ORC value of Agency 'A'

4.4.4 Expected Utility Calculation (*Step 6*)

Since Agency 'A' has been assigned by three linguistic terms, the highest preference is given to the 'high' reliability grade and the lowest preference is given to the 'low' reliability grade. Based on Equations 3.15-3.16, as shown in Table 4.11, the utility value of ORC of Agency 'A' is calculated as 71.25% reliable as compared to the most desirable reliability benchmark which is 100% reliable.

Table 4.11: Utility value of the ORC of Agency 'A'

H_n	**Low**	**Medium**	**High**
V_n	1	2	3
$u(H_n)$	$\frac{1-1}{3-1}=0$	$\frac{2-1}{3-1}=0.50$	$\frac{3-1}{3-1}=1$
β_n	0.14569	0.28356	0.57075
$\beta_n \times u(H_n)$	0	0.14178	0.57075
$U_v = \sum_{n=1}^{5} \beta_n \times u(H_n) = 0.71253 \approx 71.25\%$			

4.4.5 Validation of the Model (*Final Step*)

In this chapter, the three Axioms described in Sub-section 4.3.7 are used to test the logicality of the delivery of the analytical result. To validate the model using Axiom 1, the rate of probability with the highest preference linguistic variable (P_n) of each root node is decreased by k as shown in Table 4.12. This reduction will certainly result in the effect of a relative increase of the rate of probability associated with the lowest preference linguistic variables (i.e. low) of the corresponding root nodes by k. However, if P_n is less than k, the remaining rate of probability (i.e. $k - P_n$) can be deducted from the rate of probability of the next linguistic term (i.e. medium), this process continues until k is consumed. The decrement of the highest preference linguistic variable of an input will also result in the relative decrement of the goal's utility value. In Axiom 1, the new goal's utility value (U_k) for Agency 'A' (i.e. after decrement of P_n of the root nodes by 0.1) has been compared against 0.7125 (i.e. actual utility value). Consequently, the results are obtained and shown in Table 4.12. The new goal's utility value (U_k) is smaller than the actual utility value, the result is aligned with Axiom 1.

Table 4.12: Decrement of reliability value of the root node by 0.1

Root Nodes	Reliability Value							
	Without Decrement				Decrement by 0.1 (k)			
	Low	Medium	High	Utility Value	Low	Medium	High	New Goal's Utility Value for (U_k)
VR1	0.0884	0.4845	0.4271	**0.7125**	0.1884	0.4845	0.3271	**0.7104**
VR2	0	1	0	**0.7125**	0.1	0.9	0	**0.7115**
VR3	0.0884	0.4845	0.4271	**0.7125**	0.1884	0.4845	0.3271	**0.7104**
CM	0.4	0.3	0.3	**0.7125**	0.5	0.3	0.2	**0.7090**
SR	0.4	0.3	0.3	**0.7125**	0.5	0.3	0.2	**0.7073**
PR	0.4	0.3	0.3	**0.7125**	0.5	0.3	0.2	**0.7084**
PROFIT	0.88	0.12	0	**0.7125**	0.98	0.02	0	**0.7094**
FS	0	0	1	**0.7125**	0.1	0	0.9	**0.7081**
LIQUIDITY	0	0.2	0.8	**0.7125**	0.1	0.2	0.7	**0.7026**
MC1	0	0.7063	0.2937	**0.7125**	0.1	0.7063	0.1937	**0.7114**
MC2	0.2172	0.5035	0.2793	**0.7125**	0.3172	0.5035	0.1793	**0.7114**
MC3	0	0.7867	0.2133	**0.7125**	0.1	0.7867	0.1133	**0.7114**
HRM1	0	0.4571	0.5429	**0.7125**	0.1	0.4571	0.4429	**0.7115**
HRM2	0	0.4989	0.5011	**0.7125**	0.1	0.4989	0.4011	**0.7115**
OM1	0	0.6680	0.3320	**0.7125**	0.1	0.6680	0.2320	**0.7114**
OM2	0.0571	0.5619	0.3810	**0.7125**	0.1571	0.5619	0.2810	**0.7114**
SI1	0.0850	0.5693	0.3457	**0.7125**	0.1850	0.5693	0.2457	**0.7114**
SI2	0	0.1262	0.8738	**0.7125**	0.1	0.1262	0.7738	**0.7114**
SSC	0	0	1	**0.7125**	0.1	0	0.9	**0.7018**
ENVC	0	0	1	**0.7125**	0.1	0	0.9	**0.7062**
MISCC	0	0	1	**0.7125**	0.1	0	0.9	**0.7083**
CR	0.05	0.1	0.85	**0.7125**	0.15	0.1	0.75	**0.7102**
DI	0.05	0.1	0.85	**0.7125**	0.15	0.1	0.75	**0.7095**
CRM1	0.1	0.7	0.2	**0.7125**	0.2	0.7	0.1	**0.7096**
CRM2	0.1	0.4	0.5	**0.7125**	0.2	0.4	0.4	**0.7096**
CRM3	0.6	0.3	0.1	**0.7125**	0.7	0.3	0	**0.7096**
AF1	0	0.4587	0.5413	**0.7125**	0.1	0.4587	0.4413	**0.7089**
AF2	0	0.4175	0.5825	**0.7125**	0.1	0.4175	0.4825	**0.7089**
COUNTRY	0.0783	0.5788	0.3429	**0.7125**	0.1783	0.5788	0.2429	**0.7053**

The alteration of the utility value of the goal due to decreasing the P_n (by 0.1, 0.2 and 0.3 respectively) of the 29 input variables is tabulated in Table 4.13 and shown in Figure 4.12. All the results obtained are in line with Axiom 2.

Table 4.13: Alteration of the utility value of the goal due to the same variation of the 29 input root nodes

Root Nodes	Alteration of the ORC of Agency 'A' value due to the following decrease in the rate of probability associated with the highest linguistic term of the fuzzy set of each root node.		
	0.1 (Alteration k) (U_k)	**0.2 (Alteration l) (U_l)**	**0.3 (Alteration m) (U_m)**
VR1	0.7104	0.7083	0.7061
VR2	0.7115	0.7104	0.7093
VR3	0.7104	0.7083	0.7061

CM	0.7090	0.7055	0.7020
SR	0.7073	0.7021	0.6969
PR	0.7084	0.7043	0.7002
PROFIT	0.7094	0.7088	0.7088
FS	0.7081	0.7038	0.6994
LIQUIDITY	0.7026	0.6926	0.6826
MC1	0.7114	0.7102	0.7091
MC2	0.7114	0.7102	0.7092
MC3	0.7114	0.7102	0.7096
HRM1	0.7115	0.7105	0.7094
HRM2	0.7115	0.7105	0.7094
OM1	0.7114	0.7103	0.7091
OM2	0.7114	0.7103	0.7091
SI1	0.7114	0.7102	0.7090
SI2	0.7114	0.7102	0.7090
SSC	0.7018	0.6912	0.6805
ENVC	0.7062	0.6998	0.6934
MISCC	0.7083	0.7040	0.6997
CR	0.7102	0.7080	0.7057
DI	0.7095	0.7065	0.7035
CRM1	0.7096	0.7066	0.7051
CRM2	0.7096	0.7066	0.7037
CRM3	0.7096	0.7081	0.7066
AF1	0.7089	0.7053	0.7016
AF2	0.7089	0.7053	0.7016
COUNTRY	0.7053	0.6981	0.6808

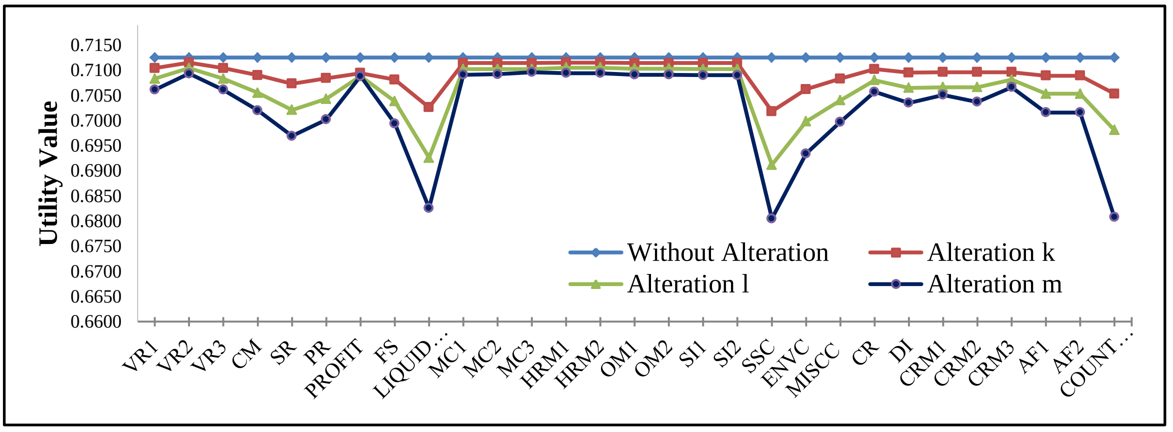

Figure 4.12: Representation of Axiom 2

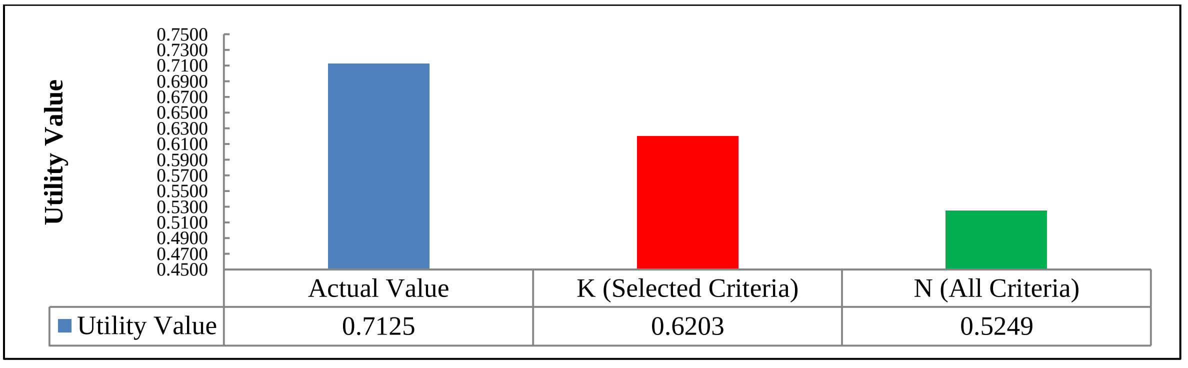

Figure 4.13: Representation of Axiom 3

To demonstrate Axiom 3, if P_n of each root node is decreased by 0.2, the new utility value of the model (i.e. Agency 'A') is 0.5249. By selection of 14 of the root nodes (i.e. VR1, VR2, VR3, CM, SR, PR, CR, CRM1, CRM2, CRM3, AF1, AF2, DI and COUNTRY) from the 29 root nodes and by decreasing the P_n of those selected root nodes (i.e. 14 criteria) by 0.2, the new goal's utility value of the model is evaluated as 0.6203. As shown in Figure 4.13, in view of the fact that 0.6203 is greater than 0.5249, the result is aligned with Axiom 3.

For industrial statistical comparison, the result of Agency 'A' is compared with Agency 'B' (i.e. Agency in Malaysia from a different LSO), as shown in Figure 4.14. An assessment of the ORC is again conducted on Agency 'B' (Appendix B-2). The utility values of Agencies 'A' and 'B' are 0.7125 and 0.7283 respectively; it means that the utility value of Agency 'B' is greater than that of Agency 'A'. Based on the database provided by Alphaliner (2013), as shown in Figure 4.14, the ranking orders of Agency 'A' and Agency 'B' are 83rd and 44th respectively. In view of the fact that the utility value of Agency 'B' is greater than that of Agency 'A' and the ranking order of LSO 'B' is better than LSO 'A', it can be concluded that the developed result in this research is further validated.

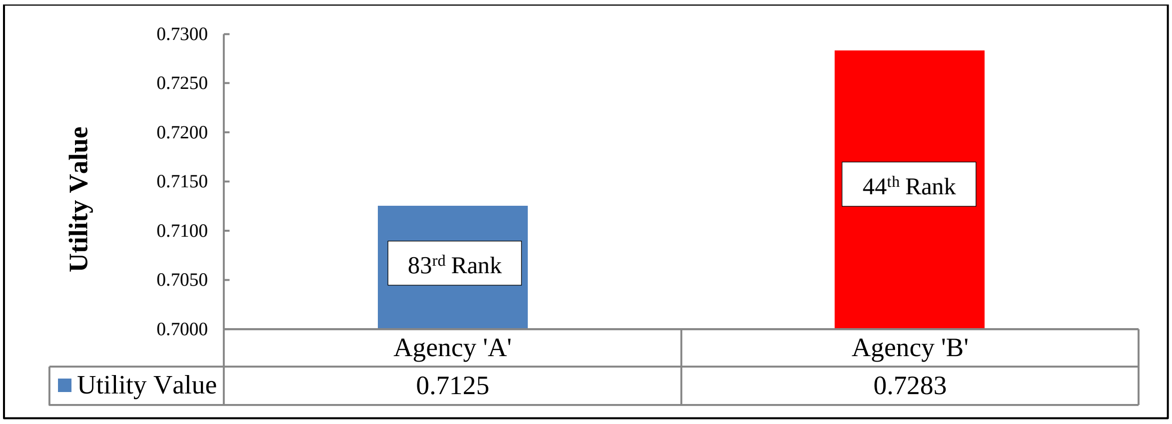

Figure 4.14: ORC values versus Alphaliner orders ranking for Agency 'A' and 'B'

4.5 Results and Discussion

The assessment model of the ORC involved taking many criteria into consideration, namely operational reliability, financial capability, knowledge management, compliance with regulations and service quality capability. Based on Table 4.11, the utility value of Agency 'A' is 71.25%. Therefore, it is recommended that Agency 'A' should take several actions to improve its ORC value, which can be listed as follows:

- Improving operational reliability and its various parameters such as vessel reliability, container management and schedule reliability. Based on Figure 4.11, operational reliability (OR) for Agency ‘A’ is only assessed as 51.8% reliable (i.e. calculated by using a utility value approach). From the customers’ point of view, they are more concerned about the operational reliability of an LSO. As a result, highly reliable operations need to be achieved.
- Improving vessel reliability by enhancing ship staff’s reliability (VR1) and upgrading the technology onboard vessels (VR3), as discussed in Sub-section 4.2.1. Since the age of all operated vessels is between 11-20 years, these vessels are still reliable to operate. However, the maintenance department should monitor the vessels frequently in order to avoid any breakdown (e.g. engine breakdown, navigational technical failure, *etc.*) during operations.
- Improving the reliability of scheduling and container management (i.e. SR and CM). Based on Figure 4.11, the average reliability value of these two criteria is 45% reliable (i.e. calculated by using a utility value approach), which can be considered as fairly low. Only 30% on-time performance has been achieved during the evaluation period. Therefore, these parameters need to be improved in order to achieve a highly reliable performance.
- Improving the knowledge management (KM) of the LSO as discussed in Sub-section 4.2.3. Strategically, knowledge management is the foundation for any firm to enhance its sustainability in the industry. Agency ‘A’ should improve its market competitiveness, shipping innovation and organisation management in order to establish a competitive advantage and good market positioning.
- Taking advantage from strong financial capability to improve the overall internal ORC by investing for improving operational reliability and knowledge management.

To ensure the result of ORC is pertinent with the industrial benchmark, it has been cross-validated with the LSO’s global ranking statistic by comparison with another LSO, namely Agency ‘B’. In a view of the fact that the ORC value of Agency ‘B’ is greater than ‘A’, it can be assumed that the assessment model of the ORC of the LSO is validated and aligned with the industry benchmark. In addition, it is assumed that the LSO which has a high level of ORC value may perform better in the CLSI. Moreover, the LSO with a high level of ORC value may have a better rank than other LSOs which have a lower ORC value.

Based on Table 4.5, it is worth mentioning that the financial capability is a strong indicator for the internal ORC of the LSOs. It can be seen that the financial capability value was closely associated with the perspective of experts' judgement. Experts suggested that financial capability is a core foundation for the LSO to enhance its ORC. Empirical studies have found that a strong financial capability can contribute to a higher value of the overall performance (Sun, 2010). As a result, a strong financial capability is found to be the most significant element for the LSO to enhance its ORC.

Based on Figure 4.12, the model output is more sensitive respectively to the security and safety compliances than the other 28 input variables. This indicates that decrease of security and safety levels during operations can cause huge impacts on the value of the ORC of Agency 'A'. This impact can be in the form of human injuries or loss, asset and infrastructure damage, supply chain disruptions, reputational risks and, finally, serious financial consequences. Due to the significance of security and safety aspects, recent studies in the field of maritime transportation have focussed on these aspects, such as the studies of Trucco *et al.* (2008), Bakshi and Gans (2010), Riahi (2010), Mokhtari (2011), Knapp and Velden (2011), Gaonkar *et al.* (2011), Moktari *et al.* (2012) and Riahi *et al.* (2013; 2014).

The maritime industry has seen a number of accidents due to failure of vessels which can be listed as follows (Riahi, 2010):

- Collision between P&O Nedlloyd Vespucci (i.e. the containership) and Wahkuna (i.e. the yacht). The contributing factors for this collision are: 1) Wahkuna's skipper misunderstood the collision regulations that are applicable in fog; 2) The Master of the containership accepted a small passing distance; 3) The yacht's skipper was unable to use the radar effectively; 4) The failure of both vessels to keep an effective radar lookout; 5) The container vessel maintained high speed; and 6) Poor bridge resources management.
- P&O Nedlloyd Genoa (Loss of cargo containers). The contributing factors for this loss are: 1) The cargo-planning programme used by the "Blue Star Ship Management" met statutory requirements, but it did not provide the Chief Officer with the information necessary to identify weaknesses in the loading plan; 2) No mechanism existed for verifying declared container weights; and 3) The current container inspection requirements do not consider structural strength and rigidity.
- Collision between Skagern and Samskip Courier. The contributing factors for this loss are: 1) Failure to apply long-established methods concerning collision avoidance by the

Masters and Pilots of both vessels; 2) Both Masters were highly confident and over-reliant on the Pilots; and 3) The communication and interaction was poor among the bridge teams.

From these three accidents, it can be seen that the security and safety compliances (i.e. STCW, SOLAS and COLREG) have often not been effectively obeyed. Based on the available historical failure data and statistical analysis, losses from these accidents are considerably catastrophic and have become substantial issues in the CLSI.

4.6 Conclusion

The ORC is a foundation for an LSO to establish a competitive advantage and market positioning in the CLSI. It needs to be regularly assessed by the LSO to comprehend how strong it is internally. Within this chapter, a methodology for evaluating the ORC of an LSO by using an FBBN method has been developed. Firstly, the influential factors of the ORC of an LSO were critically identified by using literature and consultation with domain experts in the CLSI. Secondly, states of each node were defined by using literature and expert discussions. Thirdly, a generic model for the ORC was constructed using a BBN model. Fourthly, the strength of direct dependence of each child node to its associated parents was quantified by assigning each child node a CPT by using a symmetric model. Fifthly, unconditional probabilities were determined by assigning assessment grades to all the root nodes in the graph. Those assessment grades could be either quantitative or qualitative. To have all the data and information in the same universe, each quantitative criterion was transformed to a qualitative criterion by using membership functions. Sixthly, the utility value of the model was evaluated by using an expected utility approach. Finally, the model and result were validated by using sensitivity analysis and industrial statistical comparison.

This FBBN method is capable of helping LSOs to conduct self-evaluation of their ORC. The value of the ORC can be used for developing a strategy to establish a better competitive advantage and market positioning in the CLSI. In addition, maritime researchers will benefit from this study for evaluating the value of the ORC of an LSO.

Within this chapter, a model for evaluating the value of ORC of an LSO was developed. In the next chapters (i.e. Chapters 5 and 6), the ORC of an agency will be considered as one of the main factors in analysing the punctuality of liner vessels under uncertain environments.

CHAPTER FIVE

Adopting a Fuzzy Rule-Base in the Fuzzy Bayesian Belief Network Model for Analysing and Predicting Vessel Punctuality in Liner Operations: Arrival Punctuality

Summary

One of the biggest concerns in container liner shipping operations is punctuality of containerships. LSOs have to ensure that their vessels operate on-time as per schedule. Managing the time factor has become a crucial issue in today's liner shipping operations. A statistic in 2013 showed that schedule reliability for overall containerships only reached an on-time performance of up to 64%. Schedule reliability depends on vessel punctuality during arrival at and departure from ports of call. Vessel punctuality is affected by many factors such as the port conditions, vessel conditions and process management efficiency (i.e. agency) and knock-on effects of delays. This chapter will focus on analysing and predicting the arrival punctuality of liner vessels at ports of call under uncertain environments by using a hybrid technique of FRB and BBN methods. This method is capable of helping LSOs to analyse the arrival punctuality of their vessel at a particular port of call.

5.1 Introduction

In today's liner shipping operations, managing the time factor has become a critical task for LSOs. A statistic in 2013 showed that the overall schedule reliability for containerships only reached an on-time performance of up to 64% (Drewry Shipping Consultants, 2014). Vessel delay leads to significant handling interruption and underutilisation of resources for both port and LSO, which finally results in high financial consequences. Vessels may be delayed due to port congestion, port inefficiency, poor vessel conditions, rough weather, incapability and unreliability of an agency that represents the LSO at each port of call. These uncertainties are some of the reasons that may impede LSOs from providing on-time services to their customers. As a result, this chapter will focus on analysing and predicting the arrival punctuality of a liner vessel at a port of call under uncertain environments.

For analysing the punctuality of liner vessels, two aspects are considered: the arrival and departure of vessels to/from a port of call. In liner shipping operations, these two aspects are interrelated. If a vessel is delayed during her arrival at a particular port of call, there will be a delay in her departure from the same port. Therefore, two different models need to be developed, one for analysing the arrival punctuality (i.e. model 1) and one for analysing the departure punctuality (i.e. model 2). The first model will be developed within this chapter, and the second model will be developed in the next chapter (i.e. Chapter 6).

This chapter is formulated in the following sequence. The literature review and background are explained in Section 5.2. A methodology for analysing and predicting the arrival punctuality is demonstrated in Section 5.3. A test case is presented in Section 5.4. Results are discussed in Section 5.5, and finally, this chapter is completed with a conclusion in Section 5.6.

5.2 Literature Review

With the growing complexity in global transport networks, managing the time factor in liner shipping operations is not an easy task. LSOs are keen to achieve the timings as announced in their official schedule. Delays, however, not only reduce the reliability value of the liner operations but also incur logistic costs to the customer as a consequence of additional inventory costs and in some cases additional production cost (Notteboom, 2006). For analysing and predicting vessel punctuality in this chapter, two aspects have been considered: vessel's arrival and departure at/from port of call.

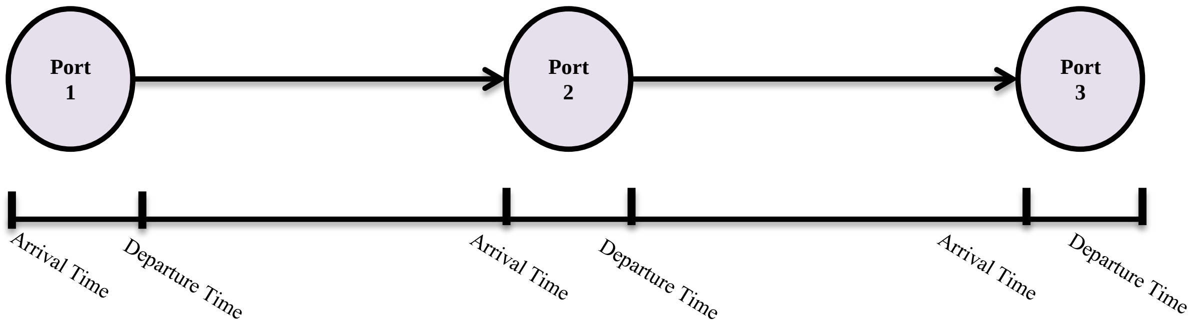

Figure 5.1: Arrival and departure time at ports of call

Recently, on-time arrival and departure performances have become an area of interest following various initiatives by many LSOs. Many LSOs (e.g. Maersk Line, MSC Shipping, Hamburg Süd Group and CMA CGM) have developed a policy for future sustainability that focuses on guaranteed punctual arrivals and departures. With today's marketing structures and strategies in the CLSI, LSOs must ensure that their vessels can carry containers around the network within a threshold or scheduled time. In other words, liner vessels that operate in the network must arrive and depart at/from ports of call on-time.

Figure 5.1 shows the starting point of arrival and departure time for a vessel to/from ports of call. Drewry Shipping Consultants (2012) stated that the vessel is considered as having an "on-time arrival" if the diversion between Actual Time Arrival (ATA) and Estimated Time Arrival (ETA) is within one day or less. In the meantime, Drewry Shipping Consultants (2012) also stated that the vessel is considered as having an "on-time departure" if the diversion between Actual Time Departure (ATD) and Estimated Time Departure (ETD) is within one day or less. The deviation of estimated time of arrival/departure compared to the actual time of arrival/departure can be formulated as follows:

$$\Delta\, Arrival = \mathrm{ATA} - \mathrm{ETA} \tag{5.1}$$

$$\Delta\, Departure = \mathrm{ATD} - \mathrm{ETD} \tag{5.2}$$

Based on Drewry Shipping Consultants (2012), if a vessel can arrive/depart at/from a port of call within the same day (i.e. 24 hours) of its estimated time of arrival/departure, then the punctuality of the vessel's arrival and departure is assessed as on-time (i.e. as long as a vessel arrives/departs within 24 hours). As an example, if $Vessel_A$ and $Vessel_B$ respectively arrive at the named port of call 1 hour and 23 hours after ETA, both vessels are still assessed as on-time. To overcome the aforementioned drawback in this chapter, a precise model for analysing the punctuality under a Bayesian probabilistic model will be formulated.

A performance on punctuality depends on many factors: port conditions, vessel conditions, process management efficiency (i.e. agency) and knock-on effects of delays. These components are further discussed as follows:

5.2.1 Port Conditions

Port congestion has a profound influence on both arrival and departure punctuality. Notteboom (2006) claimed that port congestion remains the major cause of vessel delay by far, where the density of service input has exceeded the maximum capacity of a port's normal operation. In addition, Gurning (2011) investigated that port congestion is a significant event occurring in the Australian and Indonesian wheat supply chain. Gurning (2011) also argued that port congestion can cause three consequences for the port operations that result in the unreliability of the liner operations. Firstly, it can minimise the accessibility and availability of various port and shipping services by generating delays or additional waiting time for ships and cargos. Secondly, port congestion can reduce the utilisation of port facilities. Finally, port congestion ultimately diminishes the availability of essential services such as cargo handling operations at berth, yard, warehouse and open-shed, hinterland connection and inland container depot.

Due to the increase in volume and capacity constraints in many ports around the globe, berth availability on arrival at a port is not always guaranteed (Notteboom, 2006). Vessels can be interrupted even before (un)loading at berth due to restrictive tidal window, delay of pilotage and towage, and weather condition at a port (Jason *et al*., 2002; Merrick and Dorp, 2006; Gurning, 2011). In some conditions, the access channel is clear but the vessel is still unable to berth on-time due to poor terminal performance (e.g. inefficiency of administration process and inland corridor congestion) and congestion, leading to long queues of vessels.

Terminal performance is a significant factor for determining both arrival and departure punctuality. Arrival and departure delays at ports of call mainly happen because of low terminal performance (Notteboom, 2006). For determining the performance of a terminal, two main areas (i.e. berthing area and port yard conditions) need to be assessed (Gurning, 2011). Berthing area can be assessed using berth occupancy ratio (BOR), while port yard can be assessed using yard utilisation (Mwasenga, 2012).

Instead of port channel conditions and terminal performance, several factors such as administration process, inland corridors and country reliability can cause a delay to a vessel's arrival and departure (Sawhney and Sumukadas, 2005; Lewis *et al.*, 2006; Woodburn; 2007; Gurning, 2011). Gurning (2011) argued that customs procedures and port clearance processes are still very severe logistic hindrances. Vessel delay and vessel rerouting may occur due to slow tracking including inspection of cargo handled by customs at ports. Gurning (2011) also claimed that inland access roads must always flow freely in order to ensure that a port is operating smoothly. Due to a lack of inland accessibility, a port cannot move outward cargo from the port and inward cargo to the port, and this leads to port congestion. In some cases, country unreliability ranging from political, economic, social and natural hazards may cause an unexpected delay at a port (e.g. strikes, terrorism, riot, earthquake, heavy rains, *etc*.). Although the impacts of these factors on liner operations are indirect, in order to produce an accurate model these factors (i.e. named miscellaneous factors) need to be investigated.

5.2.2 Vessel Conditions

Vessel conditions also have a profound influence on arrival and departure punctuality. Delays can happen due to the unreliability of vessels. When a vessel is unable to transport containers and crew in a safe, secure and timely manner, it is called unreliable. In this chapter, vessel conditions were grouped into three clusters: maritime passages, vessel operational performance and unforeseen events.

Maritime passages are the set of routes that are used by liner vessels in order to travel through specific locations. Maritime routes correspond to open sea, coastal area, capes, straits and canals that are naturally or artificially formed. Maritime routes are strategic places for ocean vessels; however, physical constraints such as coasts, wind, marine currents, depth, reefs and ice may delay the speed and reduce the vessel operations (Rodrigue and Notteboom, 2013). The arrival punctuality of a vessel can be affected due to unreliability of the passage used. Three aspects which can be considered in assessing maritime passages for determining the arrival punctuality are: en-route weather condition, en-route traffic condition and possibility of missing a convoy at a canal (Notteboom, 2006; Gaonkar *et al.*, 2011; Rodrigue and Notteboom, 2013).

Gaonkar *et al.* (2011) claimed that weather conditions are a well-known reality, sudden and difficult to predict. Rough weather conditions (i.e. severe storms, tornadoes and hurricanes) drastically influence the visibility, safety and speed of a vessel. In 2005, ports in Europe and the US east coast were disrupted for more than a week due to rough weather in the Atlantic Ocean. In some cases, the consequences are even worse, leading to significant losses for the vessels involved or even the loss of the cargo and humans altogether. For example, on April 16, 2005, the Bahamas-registered passenger vessel *Norwegian Dawn* suffered heavy-weather damage while returning to New York on the last leg of a regularly scheduled roundtrip cruise between New York and Miami, Florida, with stops in Port Canaveral, Florida, and the Bahamas. The National Transportation Safety Board (2005) determined that the probable cause of the damage to the *Norwegian Dawn* and the injuries suffered by its passengers was due to the severe weather. All these aspects affect the reliability of a maritime passage.

En-route traffic condition is a movement of vessels along a passage. Traffic becomes congested especially in the chokepoints or bottleneck areas due to capacity constraints where the shipping lane tends to be shallow and narrow, impairing navigation and imposing capacity limits on vessels (e.g. Malacca Strait). En-route traffic condition can affect the speed of vessels due to their slow movement (Notteboom, 2006).

A canal is an artificial waterway constructed to allow the passage of boats or vessels. The Suez Canal and the Panama Canal are two canals that play a significant role in the liner operation (Notteboom, 2006). There are shipping lanes with several passing areas. Due to the limited width of the canal, ship convoys are formed on either side. If the liner vessel arrives late at the canal, it misses the convoy of which it was planned to be part, leading to an unexpected delay of up to 12 hours (Notteboom, 2006). As a result, the situation at canals in maritime passage needs to be taken into consideration.

Vessel operational performance is also influenced by the vessel's overall condition. Three criteria are considered under vessel operational performances: speed, machinery breakdown and ship staff's reliability. There is an obvious trend in the modern ship designs towards higher speeds and increasing speed level, primarily for maintaining a tight sailing schedule with good frequency and reliability (Notteboom, 2006). A container vessel is designed to sail with desired service speed, which is between 22-23 knots. However, due to poor maritime passage conditions the speed of the vessel may become slower, and finally result in arrival delay.

Williams and Treadaway (1992) and Shrivastava (1993) claimed that, although port congestion was the main source of schedule unreliability in the liner operation, machinery breakdown also contributed a minor proportion to the unreliability of the network. Machinery breakdown (e.g. engine failure) could happen during a voyage or during a port stay. If it happens during a voyage, the probability of arrival delay is high while if it happens during a port stay and is not fixed immediately, the probability of departure delay is high.

Gaonkar *et al.* (2011) stated that some areas are prone to unforeseen events such as dangerous events (e.g. pirate attacks, armed robbery, looting and ship hijacking, *etc.*) and other unexpected delays (e.g. war, ship captain or crew deaths, detained by port authority, *etc.*). These events can cause unexpected waiting time and lead to arrival and departure delays or stoppage. Although the likelihood of these unforeseen events is occasional, they have the potential to disrupt vessel condition.

5.2.3 Agency

Container shipping lines can improve their vessel punctuality by improving process management efficiency such as having good coordination of market players (e.g. port authority, customs, forwarder and shippers), enhancing staff's sense of mission and having an efficient local strategy at different ports of call. At each port of call, an agency plays all these roles on behalf of its LSO. An agency is designated for handling shipments and cargo at a port on behalf of its LSO. In other words, agencies are referred to as cargo brokers or port agents; those rendering specific services on behalf of the LSO they represent. Agencies play important roles in the liner operation and they have to quickly and efficiently take care of all the regular routine tasks. They have to ensure that essential supplies, crew transfers, customs documentation and waste declarations are all arranged with the local port without delay. Agencies also provide LSOs with updates and reports on activities at the destination port so that LSOs can have the latest information available at all times while goods are in transit. Based on observations in the CLSI, the duties of the agent shall include the following items (Ting, 2013):

1. To provide office premises equipped with suitable office and telecommunication facilities and install necessary computer systems of both software and hardware, as well as maintain all systems of the shipping line within the territory for business running and electronic data exchange with the LSO, other agencies, and third parties relating to its shipping operation.
2. To provide qualified staff for carrying out all shipping line services and business activities.
3. To exercise shipping line marketing policy and activities, such as conducting marketing research, providing periodical market analysis and reports in accordance with requirements of the shipping line, soliciting cargo and placing advertisements in the local media generally used by major shipping lines.
4. To arrange container traffic and provide good customer service, such as receiving cargo bookings, issuing BL, keeping shipping line customers advised of vessel schedule, cargo status, coordinating delivery of inward shipments and receipt of outward shipments and cargo, and rendering enough information and assistance to respond to customers' requests.
5. To arrange pilotage and towage, mooring, and other necessary requirements for vessel arrival and departure.
6. To receive, process and settle claims in accordance with LSO instructions.
7. To keep operations smooth and punctual, including preparing all necessary shipping documents correctly in time for meeting the operation and customs/authorities' formal requirements.
8. To arrange quick dispatch of the vessel, coordinating and supervising the terminal, port and other service vendors and cooperating with LSO partners in accordance with the joint service working procedures to ensure efficient operation, keeping close contact with the LSO, other colleague agents, feeder carrier, truck, railroads or other transport operators to ensure smooth receiving, delivering, shipping and transhipment of cargoes.

9. To liaise with parties concerned to arrange adequate supply of container seals, labels and documents and arrange matters such as bunkering, repairs, crew changes, ship stores, spares parts, technical supports, navigation aids, medical assistance and consular requirements.
10. To report and provide revisions on the exchange control regulation, official tariff, other local tariffs and shipping circulars and practice to the LSO in an accurate and timely manner.

Based on the above duties, agencies play an important role in maintaining the reliability of the liner operation as well as ensuring the smoothness of a vessel's arrival and departure. If agencies are not performing well in fulfilling their duties, the liner operation may be affected, which results in delay to the vessel's arrival as well as its departure. Therefore, agency reliability capability needs to be considered in this model. Agencies can be assessed by using the ORC evaluation model which has been developed in Chapter 4.

5.2.4 Knock-on Effects of a Delay

One of the main factors influencing arrival and departure punctuality at/from port of call is formed by knock-on effects of a delay (Vernimmen *et al*., 2007). A knock-on effect of a delay is described as when a delay suffered in the previous port of call may also cause a delay at the next ports of call. For example, a departure delay occurring in the previous port of call (i.e. $Port_A$) will usually cause an arrival delay at the next port of call (i.e. $Port_B$). Based on Smedts' (2011) research, for every one-hour departure delay from the previous port, 0.57 hour's arrival delay at the next port of call is expected (Smedts, 2011). Moreover, the knock-on effects of a delay will spread throughout the whole network if there is no strategy is place to address this. As a result, the knock-on effects of delays will be considered in both arrival and departure punctuality models.

5.2.5 A Fuzzy Rule-Base (FRB) and Bayesian Belief Network (BBN)

A background of FRB and BBN can be found in Sub-sub-section 2.6.2.2 and Sub-section 2.6.4 respectively.

A basic FRB formula can be formed using Equation 5.3 as follows (Yang *et al*., 2009):

$$IF\ A_1,\ A_2\ and\ \ldots\ A_N, THEN\ B \tag{5.3}$$

where $A_i(i = 1, 2, \ldots, N)$ is the *i*th piece of evidence and B is a hypothesis suggested by evidence. Each A_i and the hypothesis (B) of a rule are propositional statements. Later, the FRB is able to incorporate with belief rule-base and can be defined as follows (Yang *et al*., 2006; Yang *et al*., 2009; Zhou *et al.*, 2011):

$$\begin{aligned} R_k&: \ IF\ X_1^k,\ X_2^k\ and\ \ldots X_M^k, \\ &THEN\ \{(\beta_{1k}, Y_1), (\beta_{2k}, Y_2), \ldots (\beta_{Nk}, Y_N)\} \end{aligned} \tag{5.4}$$

where X_j^k $(j \in \{1, 2, \ldots, M\}; k \in \{1, 2, \ldots, L\})$ is the referential value of the *j*th antecedent attribute in the *k*th rule, *M* is the number of *antecedent* attributes used in the *k*th rule and *L* is the number of rules in the rule-base. β_{ik} $(i \in \{1,2, \ldots, N\};\ k = \{1, 2, \ldots, L\}$, with L as the number of the rules in the rule-base) is a belief degree to Y_i $(i \in 1, 2, \ldots, N)$, called the *consequent* if, in the *k*th packet rule, the input satisfies the packet antecedents $X^k = \{X_1^k, X_2^k, \ldots, X_M^k\}$.

For determining the CPT by using an FRB, Equation 5.4 can be further expressed as shown in Equation 5.5 (Yang *et al*., 2008; Zhou *et al.*, 2011):

$$P\left(Y_i \middle| X_1^k,\ X_2^k, \ldots, X_M^k\right) = \beta_{ik} \qquad i = 1, 2, \ldots, N. \tag{5.5}$$

The FRB approach can be applied for combining rules and generating a final conclusion which can be calculated by using Bayes' chain rules (i.e. Equations 4.3-4.5).

5.3 Methodology

For developing the model for analysing and predicting the arrival punctuality of a vessel by using a hybrid technique which is a combination of FRB and a BBN methods (i.e. FBBN), as shown in Figure 5.2, six steps are followed.

Step 1: The critical influential factors for analysing and predicting arrival punctuality are identified through literature review and expert consultations.

Step 2: States of each node are defined by reviewing the literature as well as consulting with experts.

Step 3: The model for analysing and predicting the arrival punctuality is constructed using a BBN model.

Step 4: The strength of direct dependence of each child node to its associated parents is quantified by assigning each child node a CPT by using the FRB.

Step 5: Unconditional probabilities are determined by assigning assessment grades to all the root nodes in the graph. Those assessment grades could be either quantitative or qualitative.

Final step (Step 6): The arrival punctuality model and its outcomes are validated by using sensitivity analysis and prediction errors.

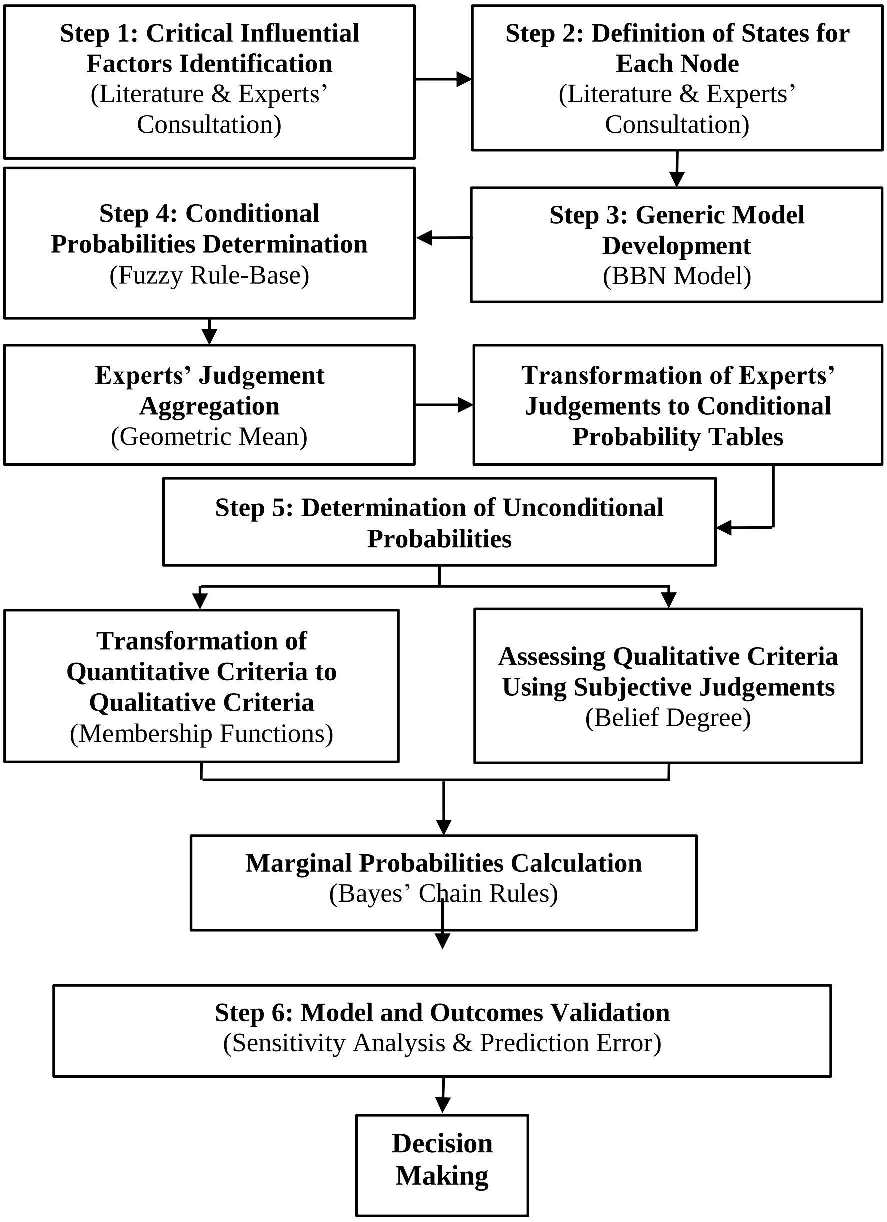

Figure 5.2: The procedure for analysing arrival punctuality

5.3.1 Identification of Critical Factors for Analysing Arrival Punctuality (*Step 1*)

Based on Section 5.2, the critical factors for analysing and predicting arrival punctuality are identified through an extensive literature review and further consultation with domain experts in the CLSI. Table 5.1 shows the identified factors which have been considered for analysing and predicting the arrival punctuality of a liner vessel.

Table 5.1: Summary of identified factors for analysing arrival punctuality

Arrival Model			
Main Criteria	**Sub-criteria**	**Sub-sub-criteria**	**References**
Port Conditions	Port Channel Conditions	Access Channel – Punctuality of Pilotage Operation for Arrival Process, Tidal Window and Weather Condition at Port	Jason *et al*. (2002), Sawhney and Sumukadas (2005), Lewis *et al.* (2006), Merrick and Dorp (2006), Notteboom (2006), Woodburn (2007), Gurning (2011).
	Terminal Conditions	Berthing Area Condition	
		Port Yard Condition	
		Miscellaneous Factors	
	Miscellaneous Factors	Port Administration Process	
		Inland Corridors	
		Country Reliability (Chapter 3)	
Vessel Conditions	Maritime Passage	En-Route Traffic Condition	Williams and Treadaway (1992), Shrivastava (1993), National Transportation Safety Board (2005), Notterboom (2006), Gaonkar *et al.* (2011), Rodrigue and Notteboom (2013).
		Possibility of Canal Miss	
		En-Route Weather Condition	
	Vessel Operational Performance	Speed	
		Machinery Breakdown	
		Ship Staff's Reliability	
	Unforeseen Events	Dangerous Events	
		Other Unexpected Delays	
Departure Punctuality from Previous Port			Vernimmen *et al*. (2007).
Agency			Refer to Chapter 4.

5.3.2 Definition of Node States (*Step 2*)

This step explains the states of each node in the established model. The process of establishing states for nodes can be found in Sub-section 4.3.2 (i.e. Chapter 4). By reviewing the literature and consulting with the domain experts from the CLSI, the states of each node in the arrival model are described in Table 5.2.

Table 5.2: List of nodes and states in the arrival model

Arrival Model		
No	**Nodes**	**States**
1.	Arrival Punctuality	On-time, Delay, Serious Delay
2.	Port Condition	Smooth, Crowded, Densely Congested
3.	Vessel Condition	Good, Average, Poor
4.	Agency	Highly Reliable, Medium Reliable, Lowly Reliable
5.	Departure Punctuality from Previous Port	On-time or Resolved, Delay, Serious Delay
6.	Port Channel Conditions	Smooth, Crowded, Densely Congested
7.	Terminal Conditions	Smooth, Crowded, Densely Congested
8.	Miscellaneous Factors	Smooth, Average, Poor
9.	Maritime Passage Condition	Excellent, Moderate, Poor
10.	Vessel Operational Performance	High, Medium, Low
11.	Unforeseen Events	Not Occurred, Occurred
12.	Access Channel Condition	Smooth, Average, Poor
13.	Berthing Area Condition	Smooth, Crowded, Densely Congested
14.	Port Yard Condition	Smooth, Crowded, Densely Congested
15.	Port Administration Process	Highly Efficient, Medium Efficient, Lowly Efficient
16.	Inland Corridors	Free Flow, Crowded, Densely Congested
17.	Country Reliability	High, Medium, Low
18.	En-Route Traffic Condition	Less Traffic, Normal Traffic, Dense Traffic
19.	Missing a Convoy at a Canal	No problem or Not related, Missed convoy
20.	En-Route Weather Condition	Excellent, Moderate, Rough
21.	Speed	Planned Speed, Slow, Disrupted
22.	Ship Staff's Reliability	Highly Reliable, Medium Reliable, Lowly Reliable
23.	Machinery Breakdown	Not Occurred, Minor Breakdown, Major Breakdown
24.	Dangerous Events	Not Occurred, Occurred
25.	Other Unexpected Delays	Not Occurred, Occurred
26.	Weather Condition at Port	Excellent, Moderate, Rough
27.	Punctuality of Pilotage Operation for Arrival Process	On-time, Delay, Serious Delay
28.	Tidal window	Not Restrictive, Restrictive

5.3.3 Development of a Model for Arrival Punctuality (*Step 3*)

The explanation regarding the process of developing a generic model can be found in Sub-sections 3.9.2 and 4.4.3. Based on the identified factors and their states as discussed in Sub-sections 5.3.1 and 5.3.2, a BBN model for analysing and predicting the arrival punctuality of a liner vessel to a port of call is shown in Figure 5.3. As shown in Figure 5.3, the leaf node "arrival punctuality (AP)" has four parent nodes: "departure punctuality from previous port (DPfPP)", "port conditions (PC)", "vessel conditions (VC)" and "agency

(AGENCY)”. The parent nodes that influence the node “PC” consist of “port channel conditions (PCC)”, “terminal conditions (TC)” and “miscellaneous factors (MISC)”. The node “PCC” is influenced by “access channel conditions (ACC)” and “TC”. The parent nodes that influence the node “ACC” consist of “punctuality of pilotage operation for arrival process (PPfAP)”, “tidal window (TW)” and “weather condition at port (WCaP)”. The node “TC” has two parent nodes, namely “berth area condition (BAC)” and “port yard condition (PYC)”; whereas the node “MISC” has three parent nodes, namely “port administration process (PAP)”, “inland corridors (IC)” and “country reliability (CR)”. The node “vessel conditions” has three parent nodes: “maritime passage condition (MPC)”, “vessel operational performance (VOP)” and “unforeseen events (UE)”. The node “MPC” has three parent nodes: “en-route traffic condition (ERTC)”, “possibility of canal miss (PoCM)” and “en-route weather condition (ERWC)” and, at the same time, the node “MPC” influences the node “speed (SPEED)”. “SPEED”, “machinery breakdown (MB)” and “ship staff’s reliability (SSR)” are the three parent nodes of the node “VOP”. Finally, “dangerous events (DE)” and “other unexpected delays (OUD)” are the two parent nodes that influence the node “UE”.

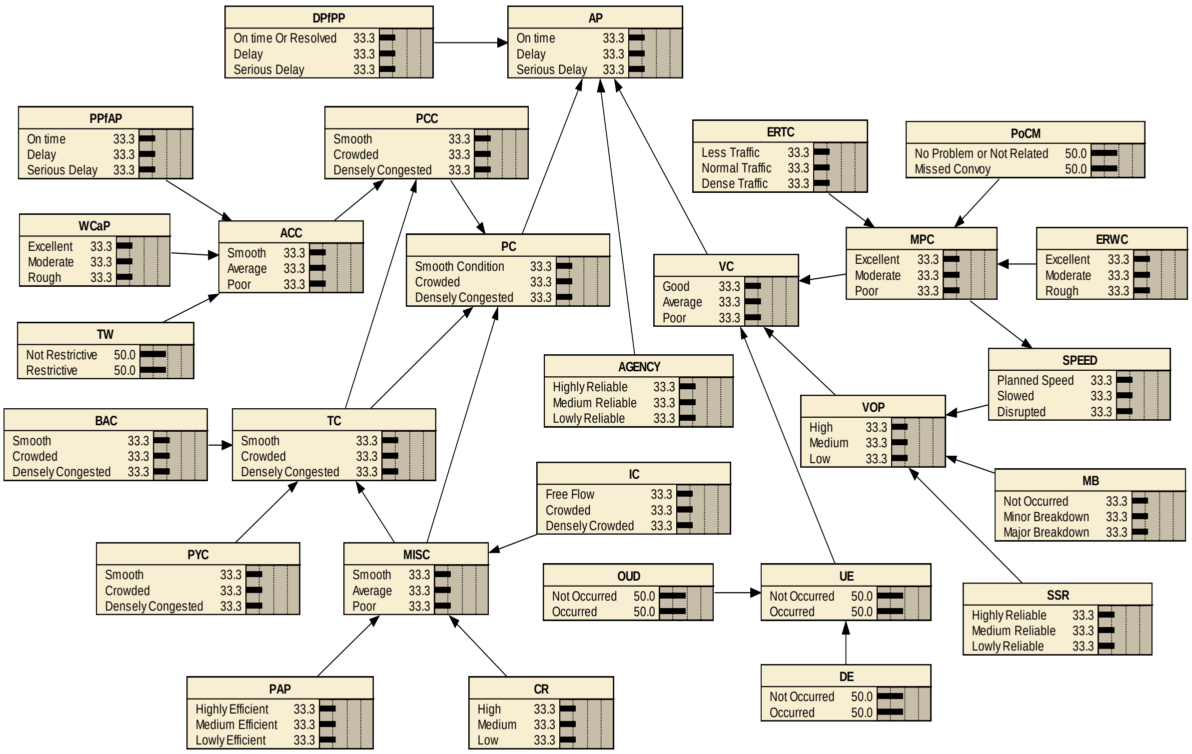

Figure 5.3: A BBN model for arrival punctuality (without data)

The abbreviations of the nodes in the arrival punctuality model are described in Table 5.3.

Table 5.3: Abbreviations of the nodes in the arrival punctuality model

Abbreviation	Description	Abbreviation	Description
AP	Arrival Punctuality	PPfAP	Punctuality of Pilotage Operation for Arrival Process
PC	Port Conditions	TW	Tidal Window
VC	Vessel Conditions	BAC	Berthing Area Condition
AGENCY	Agency	PYC	Port Yard Condition
DPfPP	Departure Punctuality from Previous Port	PAP	Port Administration Process
PCC	Port Channel Conditions	IC	Inland Corridors
TC	Terminal Conditions	CR	Country Reliability
MISC	Miscellaneous Factors	ERTC	En-Route Traffic Condition
MPC	Maritime Passage Condition	PoCM	Possibility of Canal Miss
VOP	Vessel Operational Performance	ERWC	En-Route Weather Condition
UE	Unforeseen Events	SSR	Ship Staff's Reliability
SPEED	Vessel Speed	MB	Machinery Breakdown
ACC	Access Channel Conditions	DE	Dangerous Events
WCaP	Weather Condition at Port	OUD	Other Unexpected Delays

5.3.4 Determination of Conditional Probabilities (*Step 4*)

The aforementioned CPT in Sub-section 4.4.4 is a set of distributions to represent the dependency of a child node to its parent node(s). In this chapter, a CPT for all child nodes in the arrival punctuality model is determined by using an FRB approach. To conduct conditional probability distributions using the FRB approach, four experts with 15 and more years of experience in container liner operations are selected (Mokhtari *et al*., 2012). The details of the four experts are listed as follows:

1. A ship manager/planner of an international liner shipping company in Malaysia who has been involved in the industrial operations for more than 18 years.
2. A senior ship manager of an international liner shipping company in Malaysia who has been involved in the industrial operations for more than 15 years.
3. A senior lecturer who has been involved in the maritime industry for more than 20 years.
4. An operations executive of an international liner shipping company in Malaysia who has been involved in liner shipping operations for more than 15 years.

As an example, based on the equations developed in Sub-section 5.2.5, a CPT for "ACC" is demonstrated as follows:

The node "ACC" has three states: 1) smooth 2) average and 3) poor. In the arrival model, there are three nodes influencing the node "ACC", which are: 1) "WCaP"; 2) "PPfAP" and 3) "TW". Questionnaires are sent to four selected experts for their judgements. In these questionnaires, a range of preference numbers between 1 and 5 (i.e. between "Very Poor" and "Smooth") as shown in Table 5.4, have been used.

Table 5.4: The preference numbers for the node "ACC"

Preference Numbers	Preference Terms for "ACC"
5	Smooth
4	Fairly Smooth
3	Average
2	Poor
1	Very Poor

Based on Table 5.5, rule 2, *IF* "WCaP" is excellent, "PPfAP" is on-time but "TW" is restricted, *THEN* the experts one (E1) and three (E3) judged the access channel conditions as poor (i.e. 2), expert two (E2) judged it as average (i.e. 3) and expert four (E4) judged it as very poor (i.e. 1). By using the geometric mean (Equation 3.17), the average output value of rule 2 is computed as follows:

$$GM = [E_1 \cdot E_2 \cdot E_3 \cdots E_k]^{\frac{1}{k}} = (2 \times 3 \times 2 \times 1)^{\frac{1}{4}} = 1.8612$$

where k is the number of experts and E_k stands for the k^{th} expert judgement for the FRB condition. The average output of rule 2 is known to be 1.8612. By using the same technique, average output values of all rules for "ACC" are computed as shown in Table 5.5.

Table 5.5: The evaluation of the node "ACC" by the experts

Rules	Attributes (Parent Nodes)			ACC (Child Nodes)				Average
	WCaP	PPfAP	TW	E1	E2	E3	E4	
1.	Excellent	On-time	Not Restrictive	5	5	5	5	5.0000
2.	Excellent	On-time	Restrictive	2	3	2	1	1.8612
3.	Excellent	Delay	Not Restrictive	5	5	4	3	4.1618
…	…	…	…	…	…	…	…	…
17.	Rough	Serious Delay	Not Restrictive	1	1	1	1	1.0000
18.	Rough	Serious Delay	Restrictive	1	1	1	1	1.0000

The average output value of each rule is then transformed into membership functions in order to obtain the degrees of memberships for that node, "ACC". If the average output is within the core of a particular state or linguistic term, then the degree of membership of that state is known to be 1. If there is any average output (e.g.h_i) plotted in the range of $h_{n+1,i}$ (with a grade H_{n+1}) and $h_{n,i}$ (with a grade H_n) which is in between the cores of two states, the degrees of membership can be evaluated by using Equation 3.18.

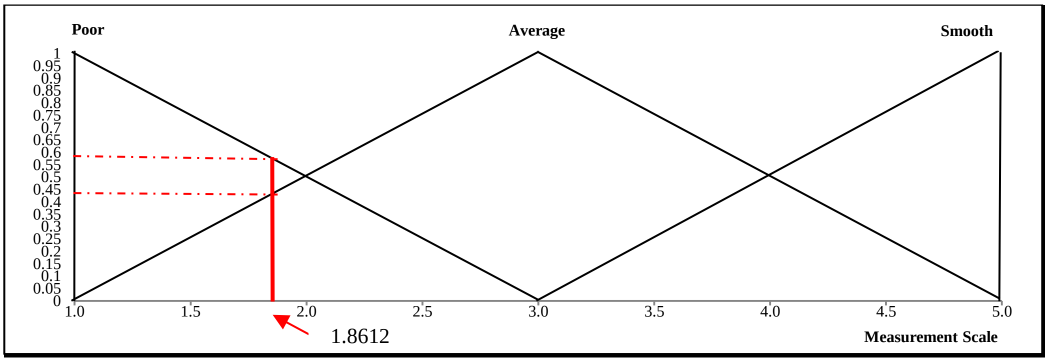

Figure 5.4: Membership functions for the "ACC" for rule 2

Based on Figure 5.4, the membership functions for the node "ACC" are developed based on three states: 1) Poor (i.e. preference number 1), 2) Average (i.e. preference number 3) and 3) Smooth (i.e. preference number 5). Preference numbers (i.e. 1 to 5) are uniformly distributed in the form of triangular membership functions. As shown in Figure 5.4, the set of "ACC" for rule 2 is evaluated as follows:

$$ACC_2 = \{(\text{Smooth}, 0), (\text{Average}, 0.4306), (\text{Poor}, 0.5694)\}$$

By using the same technique, the sets or linguistic variables of all rules, as shown in Table 5.5, are evaluated. Accordingly, these values are transformed into the CPT of the concerned node "ACC" (i.e. Table 5.6).

Table 5.6: The CPT for the node "ACC"

WCaP	PPfAP	TW	ACC		
			Smooth	Average	Poor
Excellent	On-time	Not Restrictive	1	0	0
Excellent	On-time	Restrictive	0	0.4306	0.5694
Excellent	Delay	Not Restrictive	0.5809	0.4191	0
…	…	…	…	…	…
Rough	Serious Delay	Not Restrictive	0	0	1
Rough	Serious Delay	Restrictive	0	0	1

The same process as demonstrated above is applied to all child nodes in the arrival punctuality model (i.e. "ACC", "PCC", "TC", "MISC", "MPC", "VOP", "UE", "PC", "VC", "SPEED" and "AP"). The determination of the CPT for all child nodes can be found in Sub-section 5.4.3.

5.3.5 Determination of Unconditional Probabilities (*Step 5*)

The methodology for determination of unconditional probabilities has been discussed in Sub-section 4.3.5. In this chapter, for assessing the unconditional probabilities of the root nodes in the arrival punctuality model, firstly, a particular vessel (e.g. $VESSEL_A$) needs to be chosen. The required data about vessel conditions will be obtained from the LSO and agency (i.e. historical data, experts' judgements and vessel records). Secondly, a port of arrival (e.g. $PORT_A$) for $VESSEL_A$ will be selected. The required data about the port conditions can be obtained from several reliable sources (i.e. historical data, expert judgements and port statistics) for assessing the unconditional probabilities of root nodes under consideration. For assessing the unconditional probabilities of the root nodes, membership functions need to be constructed.

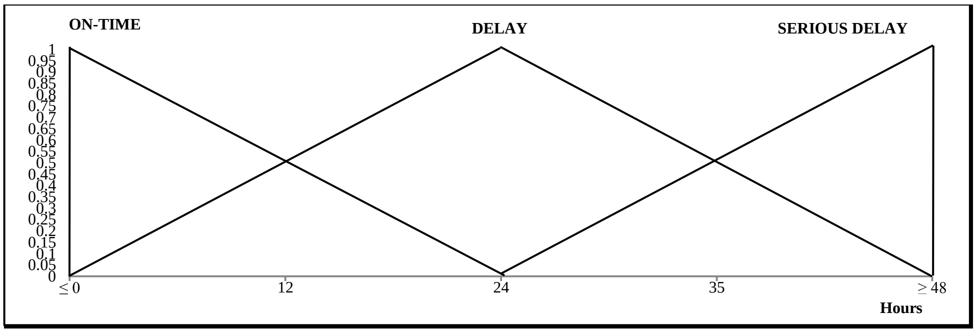

Figure 5.5: Membership functions for the node "DPfAP"

If a vessel departs from her previous port of call on or before her ETD, then the vessel is considered to be on-time. If a vessel departs from a port 24 hours after her ETD, then the vessel is considered as delay (Drewry Shipping Consultants, 2012). If a vessel departs from a port 48 hours and more after her ETD, then the vessel is considered as serious delay. As a result, the membership functions for departure punctuality from the previous port are shown in Figure 5.5.

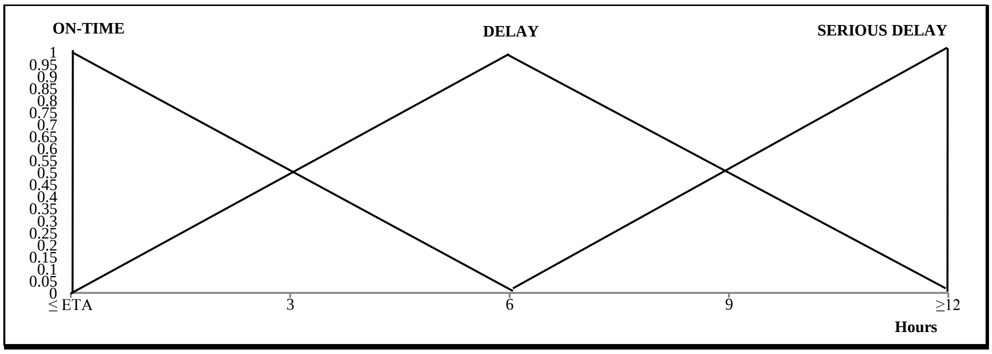

Figure 5.6: Membership functions for the node "PPfAP"

For assessing the punctuality of the pilotage operation for the arrival process, based on experts' opinion (i.e. two senior ship managers of an LSO in Malaysia who have been involved in the industrial operations for more than 15 years), as shown in Figure 5.6, if a pilotage operation is initiated exactly on or before the ETA, the punctuality of the pilot operation is considered to be on-time. If a pilotage operation is initiated 6 hours after the ETA, the punctuality of the pilotage operation is considered as delay. If a pilotage operation is initiated 12 hours or more after the ETA, the punctuality of the pilotage operation is considered as serious delay.

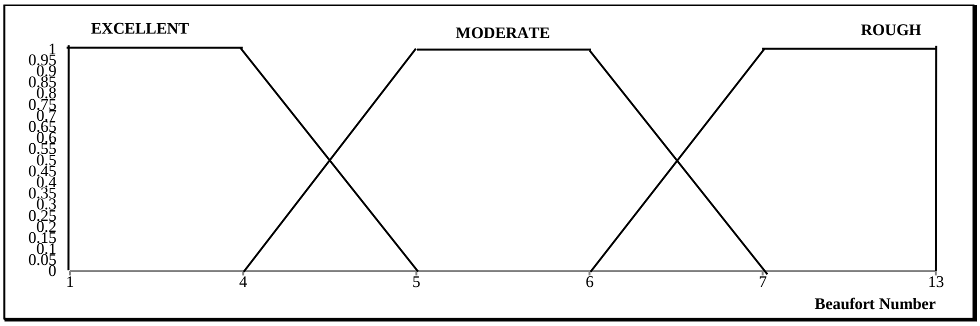

Figure 5.7: Membership functions for the node "WCaP" (arrival)

Based on Riahi *et al.* (2012a), weather conditions at a port of call can be measured by using Beaufort numbers ranging from 0-13, as shown in Figure 5.7; if the Beaufort number is between 0 and 4, the weather condition can be considered as an excellent condition and between 5 and 6 it can be considered as moderate condition. If the Beaufort number is between 7 and 13, this signifies rough weather.

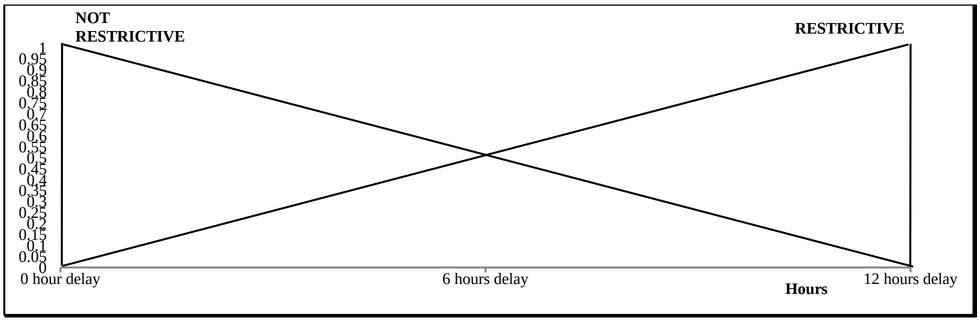

Figure 5.8: Membership functions for the node "TW" (arrival)

Based on experts' opinion (i.e. two senior ship managers of an LSO in Malaysia who have been involved in the industrial operations for more than 15 years), if there is no delay due to a tidal window, then the tidal window is considered not to be restrictive. If there is a delay of up to 12 hours due to a tidal window, then it is considered to be a restrictive condition. As a result, the membership functions for the tidal window are shown in Figure 5.8.

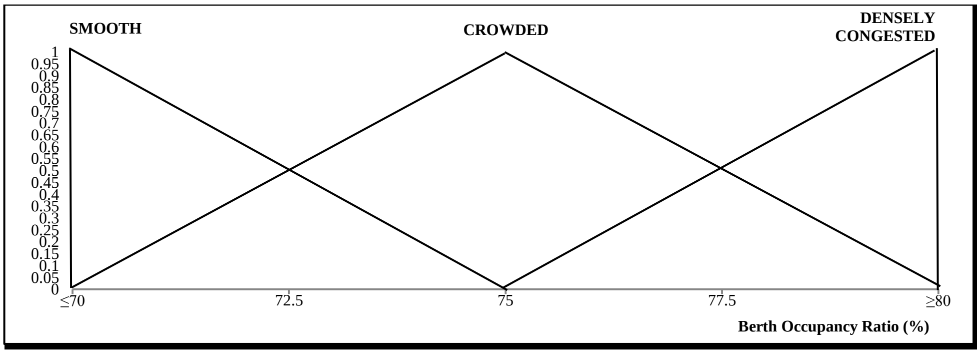

Figure 5.9: Membership functions for the node “BAC” (arrival)

Based on Mwasenga (2012) and further consultation with the port experts, berth occupancy ratio (BOR) can be assigned for evaluation of congestion at berthing areas. A high BOR can indicate congestion at berth areas while a low BOR signifies underutilisation of resources. Based on Mwasenga (2012) and the port experts’ opinion, if BOR is 70% or less, it can be considered to be a smooth condition (Figure 5.9). If BOR is 75%, 80% or more, respectively, it can be considered to be crowded and densely congested (Figure 5.9).

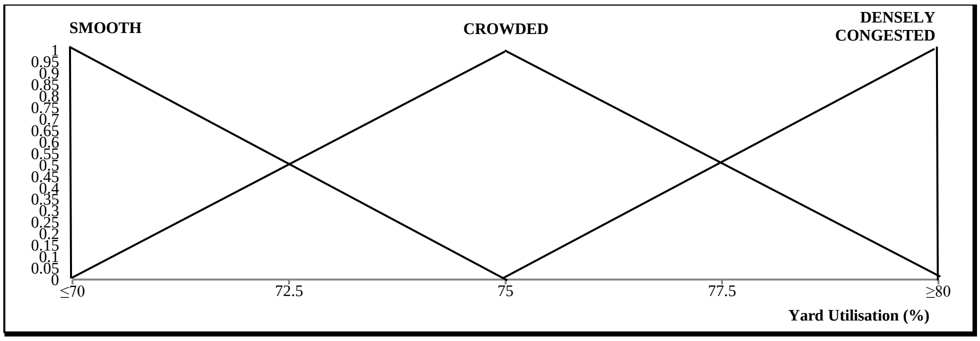

Figure 5.10: Membership functions for the node “PYC” (arrival)

Based on Mwasenga (2012) and further consultation with port experts, yard utilisation can be used as an indication of congestion at a port yard. Yard utilisation is the ratio of the number of storage slots (i.e. number of containers on hand) to the number of available slots (i.e. yard capacity). As shown in Figure 5.10, based on Mwasenga (2012) and the port experts’ opinion, if yard utilisation is 70% or less, it can be considered as a smooth condition. If yard utilisation is 75%, 80% or more, respectively, it can be considered as crowded and densely congested.

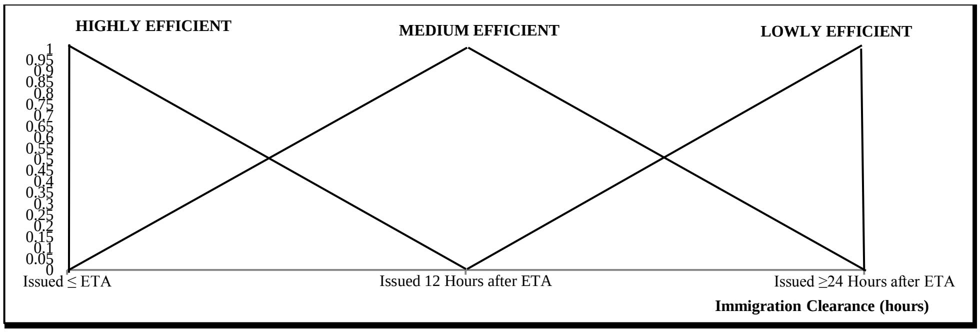

Figure 5.11: Membership functions for the node "PAP" (arrival)

Vessels arriving from foreign ports are required to obtain immigration clearance before commencing loading/unloading operations. Based on Gurning (2011) and further discussion with the experts (i.e. two senior ship managers of an LSO in Malaysia who have been involved in the industrial operations for more than 15 years), the process of immigration clearance can be assessed to determine the port administration efficiency during the arrival process. As shown in Figure 5.11, if the immigration clearance is issued before ETA for the arrival process, the port administration can be considered as high efficiency. If the immigration clearance is issued within 12 hours after ETA, the port administration can be considered as medium efficiency. If the immigration clearance is issued after 24 hours after the ETA, the port administration can be considered as low efficiency.

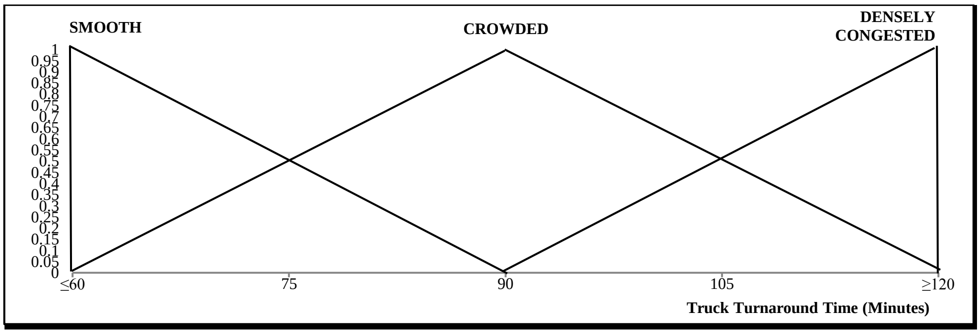

Figure 5.12: Membership functions for the node "IC" (arrival)

Based on Mwasenga (2012) and further discussion with the port experts, truck turnaround time (TTT) can be assessed for determining the condition of inland corridors. A TTT is the time between the vehicle's arrival at the terminal entrance gate and its departure from the terminal exit gate. TTT can be used as an indication of inland flow conditions. A long TTT signifies congestion at the port's corridors while a short of TTT signifies a free flow of the port's corridors. As shown in Figure 5.12, based on Mwasenga (2012) and the port experts' opinion, if a TTT is 60 minutes or less, it can be considered as free flow condition. If a

TTT is 90, 120 minutes or more, respectively, it can be considered as crowded and densely congested.

The membership functions shown in Figure 5.7 can be used for assessing the root node "ERWC".

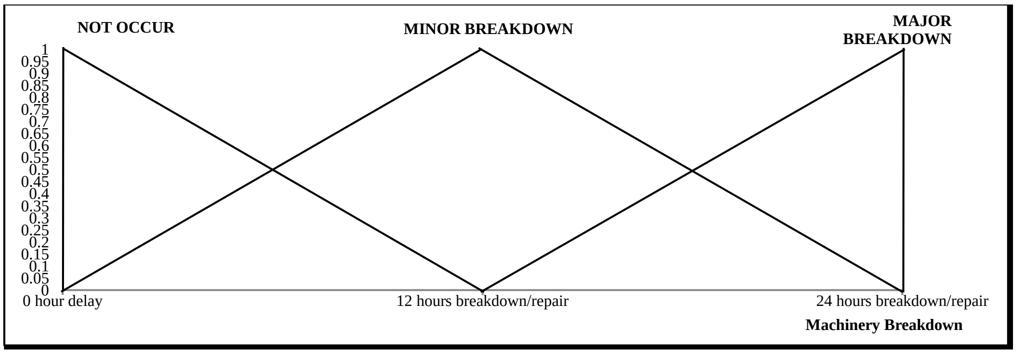

Figure 5.13: Membership functions for the node "MB" (arrival)

Based on experts' opinion (i.e. two senior ship managers of an LSO in Malaysia who have been involved in the industrial operations for more than 15 years), as shown in Figure 5.13, the machinery breakdown of a vessel can be assessed. If no machinery breakdown occurs, then no delay is expected. If a machinery breakdown occurs and is repaired within 12 hours, then it can be considered to be a minor breakdown. If a machinery breakdown occurs and is fixed within 24 hours or more, then it can be considered to be a major breakdown.

For assessing qualitative criteria (i.e. en-route traffic condition (ERTC) and ship staff's reliability (SSR)), an assessment can be conducted subjectively by the nominated evaluators (e.g. a ship captain, operation manager and ship manager) using subjective judgements. Then, assessments from different evaluators are aggregated by using an ER algorithm.

For assessing the occurrence probability of missing a convoy at a canal, dangerous events and other unexpected delays, an assessment can be conducted by the nominated evaluator (i.e. the ship captain). The assessment can be conducted by ticking the "not occur" condition or "occur" condition.

For assessing the reliability value of a country, the assessment model that has been developed in Chapter 3 will be used. For assessing the reliability and capability value of an agency, the assessment model that has been developed in Chapter 4 will be used.

After all the CPTs of child nodes and unconditional probabilities of root nodes are determined, the marginal probabilities of the child node(s) can be calculated with the help of Bayes' chain rules and as shown in Sub-section 4.3.5. In this chapter, the *Netica* software tool is employed to calculate the marginal probability for the arrival punctuality.

5.3.6 Validation of the Proposed Model (*Step 6*)

In this chapter, sensitivity analysis (SA) and prediction error are used to validate the arrival model. SA has been demonstrated in Sub-sections 3.4.8 and 4.4.5. In order to ensure that the arrival punctuality model is functional, the SA must at least meet the following two Axioms:

Axiom 1: A slight increase or decrease in the degree of membership associated with any states of an input node will certainly result in a relative increase or decrease in the degree of membership of the highest-preference state of the model output.

Axiom 2: If the degree of membership associated with the highest-preference state of an input node is decreased by l and m (simultaneously the degree of membership associated with its lowest-preference state is increased by l and m ($1 > m > l$)), and the values of the model output are evaluated as U_l and U_m respectively, then U_l should be greater than U_m.

In addition, for further validation of the arrival punctuality model, a prediction error (Δ Predicted Arrival Time - Δ Real Arrival Time) is used. If the difference between outcome of the model and real arrival time is ≤10% or ±2.4 hours, then it will be considered to be reasonable.

5.4 Test Case: The Analysis of Arrival Punctuality of $Vessel_A$

In order to demonstrate the applicability of the proposed model, the arrival punctuality of $Vessel_A$ at $Port_A$ will be analysed in this chapter. The backgrounds of $Vessel_A$ and $Port_A$ are listed in Tables 5.7 and 5.8 respectively.

Table 5.7: Details of $Vessel_A$

Details	$Vessel_A$ (Renamed due to confidentiality)
Vessel Type	Container Ship
Gross Tonnage	17068
Deadweight	21206 tonne
Length x Breadth	186 m x 25 m
Year Built	2009

Draught	9.5 m
Distance	554 nm
Transit Time from Previous Port	36 hours (Sailing Time) 24 hours (Buffer Time)
Planned Speed	16 knot

Table 5.8: Details of $Port_A$

Details	$\boldsymbol{Port_A}$ (Renamed due to confidentiality)
Berths Capacity	12 Berths forming 4.3km of linear wharf
Yard Capacity	200,000 TEUs
Annual Handling Capacity	8,400,000
Quay Crane Capacity	44 Quay-side cranes
Berth Occupancy Ratio (December)	57.45%
Yard Utilisation (December)	54.79%
Average Truck Turnaround Time (December)	24.20 minutes

5.4.1 Nodes and their States in the Arrival Punctuality Model (*Steps 1 and 2*)

In this test case, the nodes and their states for assessing the arrival punctuality of $Vessel_A$ at $Port_A$ are presented in Table 5.2.

5.4.2 The Arrival Punctuality Modelling for $\boldsymbol{Vessel_A}$ at $\boldsymbol{Port_A}$ (*Step 3*)

The developed BBN model for assessing the arrival punctuality, as shown in Figure 5.3, is used in this test case.

5.4.3 Conditional Probability Table (CPT) (*Step 4*)

Based on Sub-section 5.3.4, to conduct conditional probability distributions using the FRB approach, a questionnaire for obtaining judgements from the aforementioned experts is designed. For example, based on Table 5.9, to establish a rule for the child node “AP” under the combination of the conditions of its parent nodes (i.e. “DPfPP”, “PC”, “VC” and “AGENCY”), a preference number ranging from 1 to 5 can be selected. These preference numbers are then aggregated by using the geometric mean (Equation 3.17) and shown in Table 5.10. The tables of consequents for other child nodes can be found in Appendix C-1. The aggregated preference numbers for each rule, as listed in Table 5.10, are then transformed into a CPT using membership functions, as demonstrated in Figure 5.4, and by using Equation 3.18. As a result, the CPT for the child node “Arrival Punctuality” is shown in Table 5.11.

Table 5.9: Preference numbers for the child node "Arrival Punctuality"

Arrival Punctuality States	**On-time** (Exactly arrive on or before ETA)	**Slight Delay** (Up to 12 hours after ETA)	**Delay** (Up to 24 hours after ETA)	**Serious Delay** (Up to 36 hours after ETA)	**Very Serious Delay** (48 hours and more after ETA)
Preference Number	**5**	**4**	**3**	**2**	**1**

Table 5.10: Consequents for the child node "Arrival Punctuality"

Rules	*IF*				*THEN*				
					Arrival Punctuality				
	Departure Punctuality from Previous Port	Vessel Conditions	Port Conditions	Agency	Expert 1 (E1)	Expert 2 (E2)	Expert 3 (E3)	Expert 4 (E4)	Aggregation
1	On-time	Good	Smooth	Highly Reliable	5	5	5	5	5.0000
2	On-time	Good	Smooth	Medium Reliable	5	5	5	5	5.0000
3	On-time	Good	Smooth	Lowly Reliable	4	5	4	5	4.4721
4	On-time	Good	Crowded	Highly Reliable	4	5	4	5	4.4721
5	On-time	Good	Crowded	Medium Reliable	4	5	4	4	4.2295
6	On-time	Good	Crowded	Lowly Reliable	5	5	1	3	2.9428
7	On-time	Good	Densely Congested	Highly Reliable	1	5	2	3	2.3403
8	On-time	Good	Densely Congested	Medium Reliable	1	4	2	3	2.2134
9	On-time	Good	Densely Congested	Lowly Reliable	1	4	1	2	1.6818
10	On-time	Average	Smooth	Highly Reliable	4	5	4	3	3.9360
11	On-time	Average	Smooth	Medium Reliable	4	5	3	2	3.3098
12	On-time	Average	Smooth	Lowly Reliable	4	5	2	1	2.5149
13	On-time	Average	Crowded	Highly Reliable	4	4	2	3	3.1302
14	On-time	Average	Crowded	Medium Reliable	4	5	2	2	2.9907
15	On-time	Average	Crowded	Lowly Reliable	4	5	1	1	2.1147
16	On-time	Average	Densely Congested	Highly Reliable	1	4	2	1	1.6818
17	On-time	Average	Densely Congested	Medium Reliable	1	4	2	1	1.6818
18	On-time	Average	Densely Congested	Lowly Reliable	1	3	1	1	1.3161
19	On-time	Poor	Smooth	Highly Reliable	1	5	4	1	2.1147
20	On-time	Poor	Smooth	Medium Reliable	1	5	3	1	1.9680
21	On-time	Poor	Smooth	Lowly Reliable	1	5	2	1	1.7783
22	On-time	Poor	Crowded	Highly Reliable	1	5	3	1	1.9680

23	On-time	Poor	Crowded	Medium Reliable	1	5	2	1	1.7783
24	On-time	Poor	Crowded	Lowly Reliable	1	5	1	1	1.4953
25	On-time	Poor	Densely Congested	Highly Reliable	1	3	2	1	1.5651
26	On-time	Poor	Densely Congested	Medium Reliable	1	3	2	1	1.5651
27	On-time	Poor	Densely Congested	Lowly Reliable	1	4	1	1	1.4142
28	Delay	Good	Smooth	Highly Reliable	5	5	4	3	4.1618
29	Delay	Good	Smooth	Medium Reliable	5	5	3	3	3.8730
30	Delay	Good	Smooth	Lowly Reliable	5	5	2	1	2.6591
31	Delay	Good	Crowded	Highly Reliable	4	5	4	2	3.5566
32	Delay	Good	Crowded	Medium Reliable	4	5	3	3	3.6628
33	Delay	Good	Crowded	Lowly Reliable	4	4	2	1	2.3784
34	Delay	Good	Densely Congested	Highly Reliable	1	3	2	1	1.5651
35	Delay	Good	Densely Congested	Medium Reliable	1	3	2	1	1.5651
36	Delay	Good	Densely Congested	Lowly Reliable	1	3	1	1	1.3161
37	Delay	Average	Smooth	Highly Reliable	4	4	3	3	3.4641
38	Delay	Average	Smooth	Medium Reliable	3	4	2	2	2.6321
39	Delay	Average	Smooth	Lowly Reliable	2	4	1	1	1.6818
40	Delay	Average	Crowded	Highly Reliable	3	4	3	3	3.2237
41	Delay	Average	Crowded	Medium Reliable	3	4	2	2	2.6321
42	Delay	Average	Crowded	Lowly Reliable	2	4	1	1	1.6818
43	Delay	Average	Densely Congested	Highly Reliable	1	3	2	1	1.5651
44	Delay	Average	Densely Congested	Medium Reliable	1	3	2	1	1.5651
45	Delay	Average	Densely Congested	Lowly Reliable	1	3	1	1	1.3161
46	Delay	Poor	Smooth	Highly Reliable	1	4	2	1	1.6818
47	Delay	Poor	Smooth	Medium Reliable	1	4	1	1	1.4142
48	Delay	Poor	Smooth	Lowly Reliable	1	4	1	1	1.4142
49	Delay	Poor	Crowded	Highly Reliable	1	4	2	1	1.6818
50	Delay	Poor	Crowded	Medium Reliable	1	4	2	1	1.6818
51	Delay	Poor	Crowded	Lowly Reliable	1	4	1	1	1.4142
52	Delay	Poor	Densely Congested	Highly Reliable	1	2	1	1	1.1892
53	Delay	Poor	Densely Congested	Medium Reliable	1	2	1	1	1.1892
54	Delay	Poor	Densely Congested	Lowly Reliable	1	2	1	1	1.1892
55	Serious Delay	Good	Smooth	Highly Reliable	1	4	2	1	1.6818
56	Serious Delay	Good	Smooth	Medium Reliable	1	4	2	1	1.6818
57	Serious Delay	Good	Smooth	Lowly Reliable	1	4	1	1	1.4142

58	Serious Delay	Good	Crowded	Highly Reliable	1	4	2	1	1.6818
59	Serious Delay	Good	Crowded	Medium Reliable	1	4	2	1	1.6818
60	Serious Delay	Good	Crowded	Lowly Reliable	1	4	1	1	1.4142
61	Serious Delay	Good	Densely Congested	Highly Reliable	1	3	2	1	1.5651
62	Serious Delay	Good	Densely Congested	Medium Reliable	1	3	2	1	1.5651
63	Serious Delay	Good	Densely Congested	Lowly Reliable	1	3	1	1	1.3161
64	Serious Delay	Average	Smooth	Highly Reliable	1	3	2	1	1.5651
65	Serious Delay	Average	Smooth	Medium Reliable	1	3	2	1	1.5651
66	Serious Delay	Average	Smooth	Lowly Reliable	1	3	1	1	1.3161
67	Serious Delay	Average	Crowded	Highly Reliable	1	3	1	1	1.3161
68	Serious Delay	Average	Crowded	Medium Reliable	1	3	1	1	1.3161
69	Serious Delay	Average	Crowded	Lowly Reliable	1	3	1	1	1.3161
70	Serious Delay	Average	Densely Congested	Highly Reliable	1	2	1	1	1.1892
71	Serious Delay	Average	Densely Congested	Medium Reliable	1	2	1	1	1.1892
72	Serious Delay	Average	Densely Congested	Lowly Reliable	1	2	1	1	1.1892
73	Serious Delay	Poor	Smooth	Highly Reliable	1	2	1	1	1.1892
74	Serious Delay	Poor	Smooth	Medium Reliable	1	2	1	1	1.1892
75	Serious Delay	Poor	Smooth	Lowly Reliable	1	2	1	1	1.1892
76	Serious Delay	Poor	Crowded	Highly Reliable	1	2	1	1	1.1892
77	Serious Delay	Poor	Crowded	Medium Reliable	1	2	1	1	1.1892
78	Serious Delay	Poor	Crowded	Lowly Reliable	1	2	1	1	1.1892
79	Serious Delay	Poor	Densely Congested	Highly Reliable	1	2	1	1	1.1892
80	Serious Delay	Poor	Densely Congested	Medium Reliable	1	2	1	1	1.1892
81	Serious Delay	Poor	Densely Congested	Lowly Reliable	1	1	1	1	1.0000

Table 5.11: CPTs for the child node of "Arrival Punctuality"

Rules	*IF*				*THEN*			
					Arrival Punctuality			
	Departure Punctuality from Previous Port	**Vessel Conditions**	**Current Port Conditions**	**Agency**	**Aggregated Preferences Number (Average Output)**	**CPT**		
						On-time	**Delay**	**Serious Delay**
1	On-time	Good	Smooth	Highly Reliable	5.0000	1	0	0
2	On-time	Good	Smooth	Medium Reliable	5.0000	1	0	0
3	On-time	Good	Smooth	Lowly Reliable	4.4721	0.7360	0.2640	0
4	On-time	Good	Crowded	Highly Reliable	4.4721	0.7360	0.2640	0
5	On-time	Good	Crowded	Medium Reliable	4.2295	0.6148	0.3852	0
6	On-time	Good	Crowded	Lowly Reliable	2.9428	0	0.9714	0.0286
7	On-time	Good	Densely Congested	Highly Reliable	2.3403	0	0.6701	0.3299
8	On-time	Good	Densely Congested	Medium Reliable	2.2134	0	0.6067	0.3933
9	On-time	Good	Densely Congested	Lowly Reliable	1.6818	0	0.3408	0.6592
10	On-time	Average	Smooth	Highly Reliable	3.9360	0.4680	0.5320	0
11	On-time	Average	Smooth	Medium Reliable	3.3098	0.1549	0.8451	0
12	On-time	Average	Smooth	Lowly Reliable	2.5149	0	0.7574	0.2426
13	On-time	Average	Crowded	Highly Reliable	3.1302	0.0651	0.9349	0
14	On-time	Average	Crowded	Medium Reliable	2.9907	0	0.9954	0.0047
15	On-time	Average	Crowded	Lowly Reliable	2.1147	0	0.5573	0.4427
16	On-time	Average	Densely Congested	Highly Reliable	1.6818	0	0.3409	0.6591
17	On-time	Average	Densely Congested	Medium Reliable	1.6818	0	0.3409	0.6591
18	On-time	Average	Densely Congested	Lowly Reliable	1.3161	0	0.1580	0.8420
19	On-time	Poor	Smooth	Highly Reliable	2.1147	0	0.5573	0.4427
20	On-time	Poor	Smooth	Medium Reliable	1.9680	0	0.4840	0.5160
21	On-time	Poor	Smooth	Lowly Reliable	1.7783	0	0.3891	0.6109
22	On-time	Poor	Crowded	Highly Reliable	1.9680	0	0.484	0.516
23	On-time	Poor	Crowded	Medium Reliable	1.7783	0	0.3891	0.6109
24	On-time	Poor	Crowded	Lowly Reliable	1.4953	0	0.2476	0.7524
25	On-time	Poor	Densely Congested	Highly Reliable	1.5651	0	0.2825	0.7175
26	On-time	Poor	Densely Congested	Medium Reliable	1.5651	0	0.2825	0.7175
27	On-time	Poor	Densely Congested	Lowly Reliable	1.4142	0	0.2071	0.7929

28	Delay	Good	Smooth	Highly Reliable	4.1618	0.5809	0.4191	0
29	Delay	Good	Smooth	Medium Reliable	3.8730	0.4365	0.5635	0
30	Delay	Good	Smooth	Lowly Reliable	2.6591	0	0.8296	0.1705
31	Delay	Good	Crowded	Highly Reliable	3.5566	0.2783	0.7217	0
32	Delay	Good	Crowded	Medium Reliable	3.6628	0.3314	0.6686	0
33	Delay	Good	Crowded	Lowly Reliable	2.3784	0	0.6892	0.3108
34	Delay	Good	Densely Congested	Highly Reliable	1.5651	0	0.2825	0.7175
35	Delay	Good	Densely Congested	Medium Reliable	1.5651	0	0.2825	0.7175
36	Delay	Good	Densely Congested	Lowly Reliable	1.3161	0	0.1580	0.8420
37	Delay	Average	Smooth	Highly Reliable	3.4641	0.232	0.7680	0
38	Delay	Average	Smooth	Medium Reliable	2.6321	0	0.618	0.382
39	Delay	Average	Smooth	Lowly Reliable	1.6818	0	0.3409	0.6591
40	Delay	Average	Crowded	Highly Reliable	3.2237	0.1118	0.8882	0
41	Delay	Average	Crowded	Medium Reliable	2.6321	0	0.618	0.382
42	Delay	Average	Crowded	Lowly Reliable	1.6818	0	0.3409	0.6591
43	Delay	Average	Densely Congested	Highly Reliable	1.5651	0	0.2825	0.7175
44	Delay	Average	Densely Congested	Medium Reliable	1.5651	0	0.2825	0.7175
45	Delay	Average	Densely Congested	Lowly Reliable	1.3161	0	0.1580	0.8420
46	Delay	Poor	Smooth	Highly Reliable	1.6818	0	0.3409	0.6591
47	Delay	Poor	Smooth	Medium Reliable	1.4142	0	0.2071	0.7929
48	Delay	Poor	Smooth	Lowly Reliable	1.4142	0	0.2071	0.7929
49	Delay	Poor	Crowded	Highly Reliable	1.6818	0	0.3409	0.6591
50	Delay	Poor	Crowded	Medium Reliable	1.6818	0	0.3409	0.6591
51	Delay	Poor	Crowded	Lowly Reliable	1.4142	0	0.2071	0.7929
52	Delay	Poor	Densely Congested	Highly Reliable	1.1892	0	0.0946	0.9054
53	Delay	Poor	Densely Congested	Medium Reliable	1.1892	0	0.0946	0.9054
54	Delay	Poor	Densely Congested	Lowly Reliable	1.1892	0	0.0946	0.9054
55	Serious Delay	Good	Smooth	Highly Reliable	1.6818	0	0.3409	0.6591
56	Serious Delay	Good	Smooth	Medium Reliable	1.6818	0	0.3409	0.6591
57	Serious Delay	Good	Smooth	Lowly Reliable	1.4142	0	0.2071	0.7929
58	Serious Delay	Good	Crowded	Highly Reliable	1.6818	0	0.3409	0.6591
59	Serious Delay	Good	Crowded	Medium Reliable	1.6818	0	0.3409	0.6591
60	Serious Delay	Good	Crowded	Lowly Reliable	1.4142	0	0.2071	0.7929
61	Serious Delay	Good	Densely Congested	Highly Reliable	1.5651	0	0.2825	0.7175
62	Serious Delay	Good	Densely Congested	Medium Reliable	1.5651	0	0.2825	0.7175

63	Serious Delay	Good	Densely Congested	Lowly Reliable	1.3161	0	0.2825	0.7175
64	Serious Delay	Average	Smooth	Highly Reliable	1.5651	0	0.2825	0.7175
65	Serious Delay	Average	Smooth	Medium Reliable	1.5651	0	0.2825	0.7175
66	Serious Delay	Average	Smooth	Lowly Reliable	1.3161	0	0.1580	0.8420
67	Serious Delay	Average	Crowded	Highly Reliable	1.3161	0	0.1580	0.8420
68	Serious Delay	Average	Crowded	Medium Reliable	1.3161	0	0.1580	0.8420
69	Serious Delay	Average	Crowded	Lowly Reliable	1.3161	0	0.1580	0.8420
70	Serious Delay	Average	Densely Congested	Highly Reliable	1.1892	0	0.0946	0.9054
71	Serious Delay	Average	Densely Congested	Medium Reliable	1.1892	0	0.0946	0.9054
72	Serious Delay	Average	Densely Congested	Lowly Reliable	1.1892	0	0.0946	0.9054
73	Serious Delay	Poor	Smooth	Highly Reliable	1.1892	0	0.0946	0.9054
74	Serious Delay	Poor	Smooth	Medium Reliable	1.1892	0	0.0946	0.9054
75	Serious Delay	Poor	Smooth	Lowly Reliable	1.1892	0	0.0946	0.9054
76	Serious Delay	Poor	Crowded	Highly Reliable	1.1892	0	0.0946	0.9054
77	Serious Delay	Poor	Crowded	Medium Reliable	1.1892	0	0.0946	0.9054
78	Serious Delay	Poor	Crowded	Lowly Reliable	1.1892	0	0.0946	0.9054
79	Serious Delay	Poor	Densely Congested	Highly Reliable	1.1892	0	0.0946	0.9054
80	Serious Delay	Poor	Densely Congested	Medium Reliable	1.1892	0	0.0946	0.9054
81	Serious Delay	Poor	Densely Congested	Lowly Reliable	1.0000	0	0	1

The same process is applied to all the child nodes in the arrival punctuality model (i.e. "ACC", "PCC", "TC", "MISC", "MPC", "VC", "UE", "PC", "VOP" and "SPEED"). The number of pieces of data that needs to be transformed and inserted into the arrival punctuality model is 259 per expert. The CPTs for all other child nodes in the arrival punctuality model can be found in Appendix C-2.

5.4.4 Assessing the Unconditional Probability Distributions (*Step 5*)

Based on the given data and membership functions that have been demonstrated in Sub-section 5.3.5, the unconditional probabilities of the root nodes can be assessed as follows:

5.4.4.1 Test Case 1

The details of the real arrival time of $Vessel_A$ at $Port_A$ for test 1 (i.e. 28/12/13) are shown in Table 5.12 and the datasets for test 1 are shown in Table 5.13.

Table 5.12: Real arrival time of $Vessel_A$ at $Port_A$ for test case 1

Real Arrival Time at $Port_A$	Date	Time	Strategy Implementation
ETA at Berth	28/12/13	1900	NIL
ATA at Berth	28/12/13	1954	

Table 5.13: Datasets for arrival punctuality for test case 1

<table>
<tr><th>No.</th><th>Root Nodes</th><th>Measurement</th><th colspan="4">Data</th></tr>
<tr><td>1</td><td>DPfPP</td><td>ΔDeparture = ATD – ETD</td><td colspan="4">-3 hours and 12 minutes (Before ETD)</td></tr>
<tr><td>2</td><td>WCaP</td><td>Beaufort Number</td><td colspan="4">3</td></tr>
<tr><td>3</td><td>PPfAP</td><td>Initiated Time</td><td colspan="4">Before ETA</td></tr>
<tr><td>4</td><td>TW</td><td>Hours Delay</td><td colspan="4">No Delay</td></tr>
<tr><td>5</td><td>BAC</td><td>Berth Occupancy Ratio (%)</td><td colspan="4">57.45%</td></tr>
<tr><td>6</td><td>BAC</td><td>Yard Utilisation (%)</td><td colspan="4">54.79%</td></tr>
<tr><td>7</td><td>PAP</td><td>Immigration Clearance Issuance</td><td colspan="4">Before ETA</td></tr>
<tr><td>8</td><td>IC</td><td>Truck Turnaround Time</td><td colspan="4">24.20 minutes</td></tr>
<tr><td rowspan="4">9</td><td rowspan="4">ERTC</td><td rowspan="4">En-Route Traffic Condition (Qualitative)</td><td>States / Evaluator</td><td>Less Traffic</td><td>Normal Traffic</td><td>Dense Traffic</td></tr>
<tr><td>Evaluator 1</td><td>100%</td><td>0%</td><td>0%</td></tr>
<tr><td>Evaluator 2</td><td>100%</td><td>0%</td><td>0%</td></tr>
<tr><td>Evaluator 3</td><td>90%</td><td>10%</td><td>0%</td></tr>
<tr><td>10</td><td>PoCM</td><td>Occurrence</td><td colspan="4">Not Involved</td></tr>
<tr><td>11</td><td>ERWC</td><td>Beaufort Number</td><td colspan="4">3</td></tr>
<tr><td>12</td><td>MB</td><td>Occurrence and delayed time</td><td colspan="4">Not Breakdown</td></tr>
<tr><td rowspan="4">13</td><td rowspan="4">SSR</td><td rowspan="4">Reliability (Qualitative)</td><td>States / Evaluator</td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td>Evaluator 1</td><td>90%</td><td>10%</td><td>0%</td></tr>
<tr><td>Evaluator 2</td><td>80%</td><td>20%</td><td>0%</td></tr>
<tr><td>Evaluator 3</td><td>70%</td><td>30%</td><td>0%</td></tr>
<tr><td>14</td><td>DE</td><td>Occurrence</td><td colspan="4">Not Occur</td></tr>
<tr><td>15</td><td>OUD</td><td>Occurrence</td><td colspan="4">Not Occur</td></tr>
<tr><td rowspan="3">16</td><td rowspan="3">CR</td><td rowspan="3">Chapter 3</td><td>High</td><td colspan="3">0.3429</td></tr>
<tr><td>Medium</td><td colspan="3">0.5788</td></tr>
<tr><td>Low</td><td colspan="3">0.0783</td></tr>
</table>

17	AGENCY	Chapter 4	High	0.7700
			Medium	0.2092
			Low	0.0208

Based on Sub-section 5.3.5 and the datasets given in Table 5.13, the unconditional probabilities of all root nodes for test case 1 are assessed as follows:

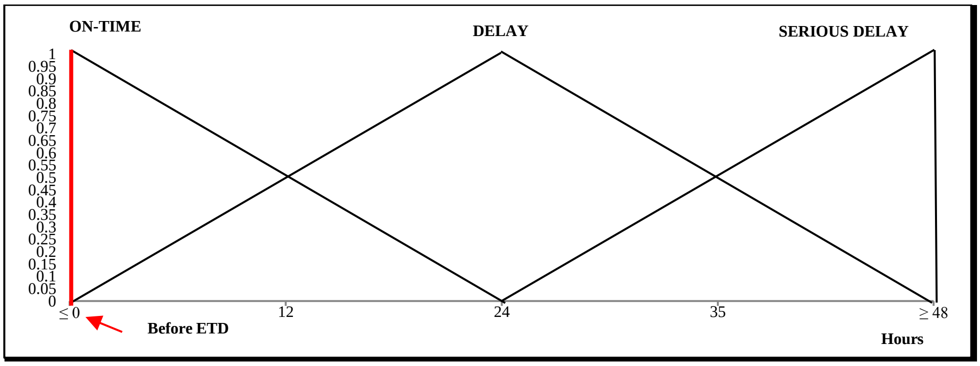

Figure 5.14: Membership functions for the node "DPfPP" (arrival test case 1)

Based on Figure 5.14, the set for the departure punctuality from the previous port is evaluated as:

1. H_n is On-time
2. H_{n+1} is Delay
3. h_i = 0, $h_{n,i}$ = 0 and $h_{n+1,i}$ = 24
4. $\beta_{n,i}$ = (24-0) / (24-0) = 1 with On-time and $\beta_{n+1,i}$ = 1-1 = 0 with Delay

$$DPfPP = \{(\text{On-time}, 1), (\text{Delay}, 0), (\text{Serious Delay}, 0)\}$$

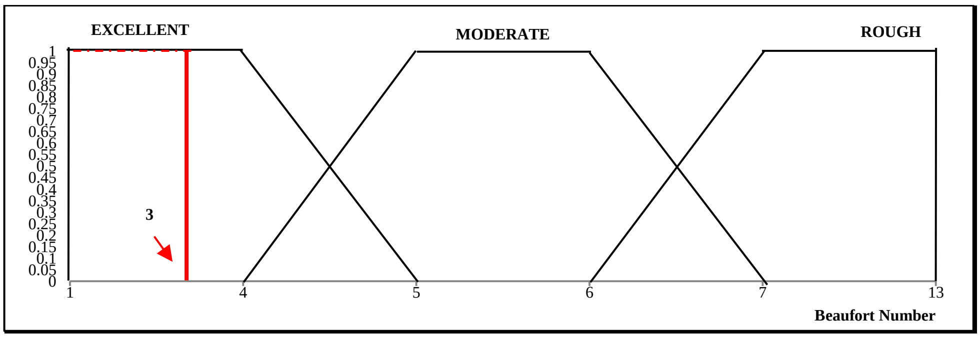

Figure 5.15: Membership functions for the node "WCaP" (arrival test case 1)

Based on Figure 5.15, the set for weather condition at port is evaluated as:

$$WCaP = \{(\text{Excellent}, 1), (\text{Moderate}, 0), (\text{Rough}, 0)\}$$

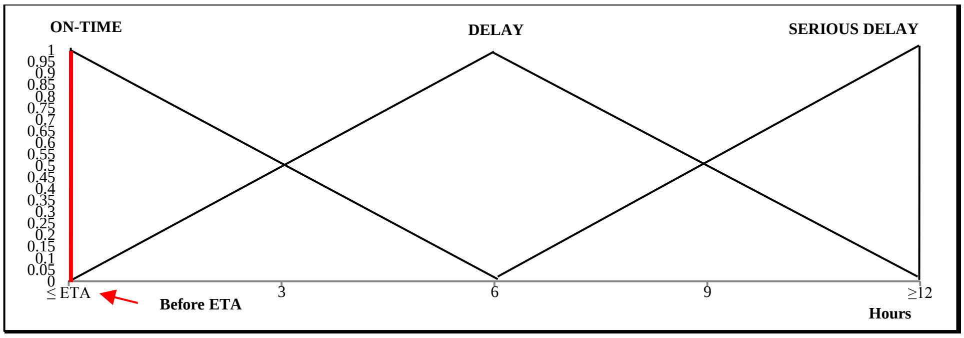

Figure 5.16: Membership functions for the node "PPfAP" (arrival test case 1)

Based on Figure 5.16, the set for the punctuality of pilotage operation for the arrival process is evaluated as:

$$PPfAP = \{(\text{On-time}, 1), (\text{Delay}, 0), (\text{Serious Delay}, 0)\}$$

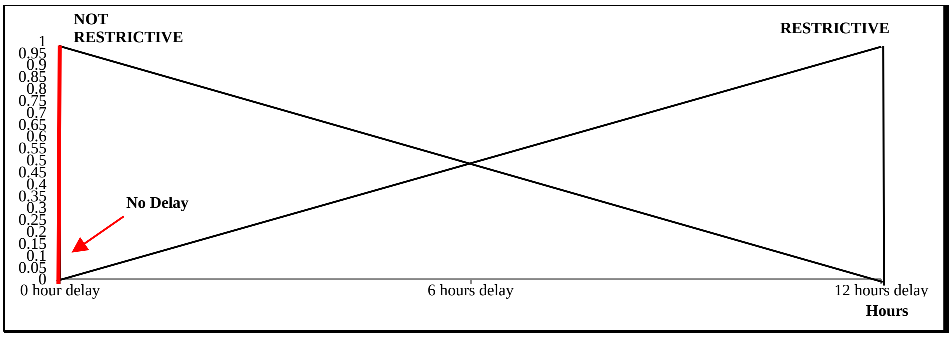

Figure 5.17: Membership functions for the node "TW" (arrival test case 1)

Based on Figure 5.17, the set for the tidal window is evaluated as:

$$TW = \{(\text{Not Restrictive}, 1), (\text{Restrictive}, 0)\}$$

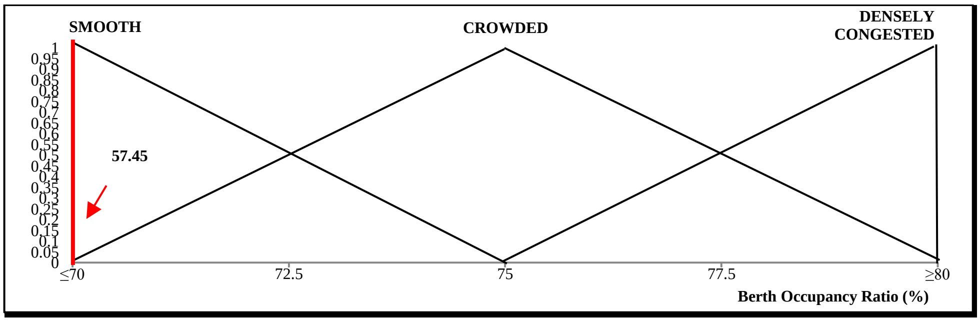

Figure 5.18: Membership functions for the node "BAC" (arrival test case 1)

Based on Figure 5.18, the set for the berthing area condition is evaluated as:

$$BAC = \{(\text{Smooth}, 1), (\text{Crowded } 0), (\text{Densely Congested}, 0)\}$$

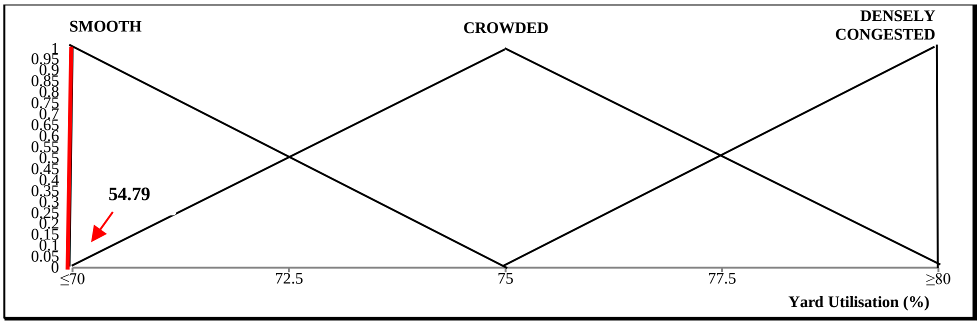

Figure 5.19: Membership functions for the node "PYC" (arrival test case 1)

Based on Figure 5.19, the set for the port yard condition is evaluated as:

PYC = {(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}

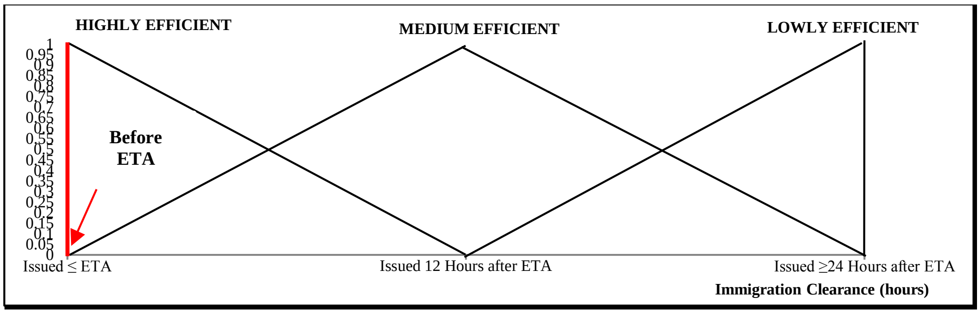

Figure 5.20: Membership functions for the node "PAP" (arrival test case 1)

Based on Figure 5.20, the set for the port administration process is evaluated as:

PAP = {(Highly Efficient, 1), (Medium Efficient, 0), (Lowly Efficient, 0)}

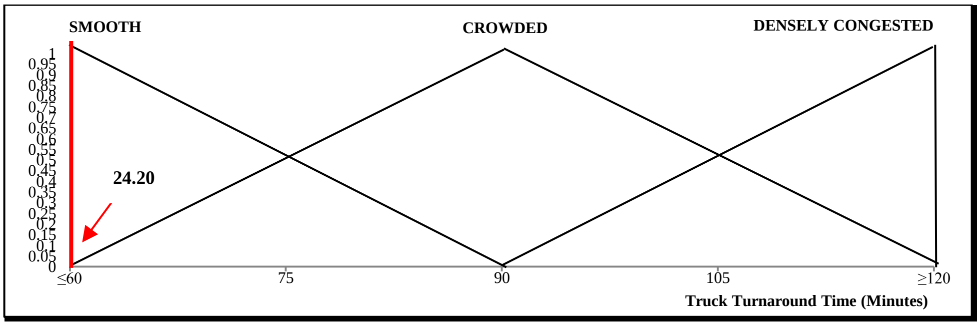

Figure 5.21: Membership functions for the node "IC" (arrival test case 1)

Based on Figure 5.21, the set for the inland corridors is evaluated as:

IC = {(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}

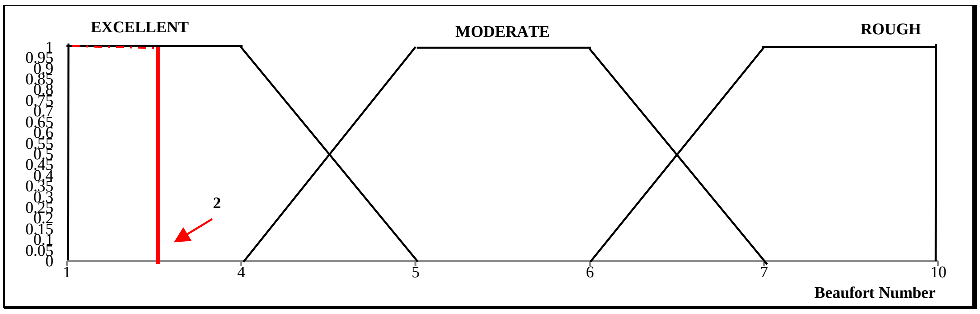

Figure 5.22: Membership functions for the node "ERWC" (arrival test case 1)

Based on Figure 5.22, the set for the en-route weather condition is evaluated as:

$$ERWC = \{(\text{Excellent}, 1), (\text{Moderate}, 0), (\text{Rough}, 0)\}$$

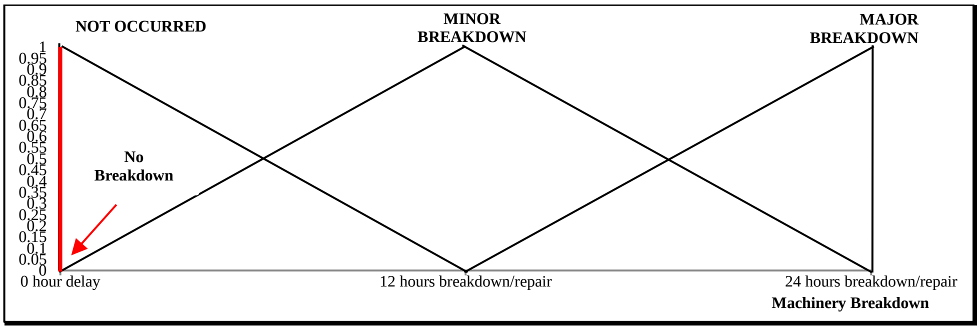

Figure 5.23: Membership functions for the node "MB" (arrival test case 1)

Based on Figure 5.23, the set for the vessel's machinery breakdown is evaluated as:

$$MB = \{(\text{Not Occurred}, 1), (\text{Minor Breakdown}, 0), (\text{Major Breakdown}, 0)\}$$

For assessing the occurrence probabilities of the nodes "PoCM", "DE" and "OUD" in the arrival model, assessments are made by the ship captain of $Vessel_A$ as shown in Table 5.14.

Table 5.14: Occurrence probability of the nodes "PoCM", "DE" and "OUD" (arrival test case 1)

Qualitative Criteria	Assessment Grades		
	Source	Not Occur	Occur
CM	Ship Captain	1	0
DE	Ship Captain	1	0
OUD	Ship Captain	1	0

For assessing qualitative criteria in the arrival model, assessments are made by three evaluators (i.e. ship captain (Evaluator 1), operation manager (Evaluator 2) and ship manager (Evaluator 3)) under fuzzy environments. Then, the assessments from these evaluators are aggregated by using an ER algorithm (i.e. Tables 5.15 and 5.16).

Table 5.15: Assessment of the node "ERTC" (arrival test case 1)

Qualitative Criteria	Assessment Grades			
	Source	Less Traffic	Normal Traffic	Dense Traffic
ERTC	Evaluator 1	1	0	0
	Evaluator 2	1	0	0
	Evaluator 3	0.9	0.1	0
	Aggregation (ER)	0.9784	0.0216	0.000

Table 5.16: Assessment of the node "SSR" (arrival test case 1)

Qualitative Criteria	Assessment Grades			
	Source	Highly Reliable	Medium Reliable	Lowly Reliable
SSR	Evaluator 1	0.9	0.1	0
	Evaluator 2	0.8	0.2	0
	Evaluator 3	0.7	0.3	0
	Aggregation (ER)	0.8413	0.1587	0

For assessing the reliability value of the host country (CR), the assessment model that has been developed in Chapter 3 is used. For assessing the reliability value of the agency (AGENCY), the assessment model that has been developed in Chapters 4 is used. The results are shown in Table 5.17.

Table 5.17: Reliability values of the country and agency (arrival test case 1)

Qualitative Criteria	Assessment Grades		
	Highly Reliable	Medium Reliable	Lowly Reliable
CR	0.3429	0.5788	0.0783
AGENCY	0.7700	0.2092	0.0208

The sets for all root nodes are obtained and shown in Table 5.18. These sets are used for evaluation of the unconditional probabilities distributions of the root nodes.

Table 5.18: The belief degrees of all root nodes (arrival test case 1)

Root Nodes	Sets
DPfPP	{(On-time, 1), (Delay, 0), (Serious Delay, 0)}
WCaP	{(Excellent, 1), (Moderate, 0), (Rough, 0)}
PPfAP	{(On-time, 1), (Delay, 0), (Serious Delay, 0)}
TW	{(Not Restrictive, 1), (Restrictive, 0)}
BAC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
BAC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
PAP	{(Highly Efficient, 1), (Medium Efficient, 0), (Lowly Efficient, 0)}
IC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
ERTC	{(Less Traffic, 0.9784), (Normal Traffic, 0.0216),

	(Dense Traffic, 0)}
PoCM	{(No Problem or Not Related, 1), (Miss Convoy, 0)}
ERWC	{(Excellent, 1), (Moderate, 0), (Rough, 0)}
MB	{(No Breakdown, 1), (Minor Breakdown, 0), (Major Breakdown, 0)}
SSR	{(Highly Reliable, 0.8413), (Medium Reliable, 0.1587), (Lowly Reliable, 0)}
DE	{(Not Occurred, 1), (Occurred, 0)}
OUD	{(Not Occurred, 1), (Occurred, 0)}
CR	{(Highly Reliable, 0.3429), (Medium Reliable, 0.5788), (Lowly Reliable, 0.0783)}
AGENCY	{(Highly Reliable, 0.7700), (Medium Reliable, 0.2092), (Lowly Reliable, 0.0208)}

The *Netica* software tool is employed to calculate the marginal probabilities for arrival punctuality. After all the CPTs for child nodes and unconditional probabilities of root nodes are determined and inserted into the software, the marginal probabilities of the child node(s) can be calculated. Based on Figure 5.24, the marginal probability of $Vessel_A$ to arrive at $Port_A$ on-time is 92.1% (i.e. test case 1).

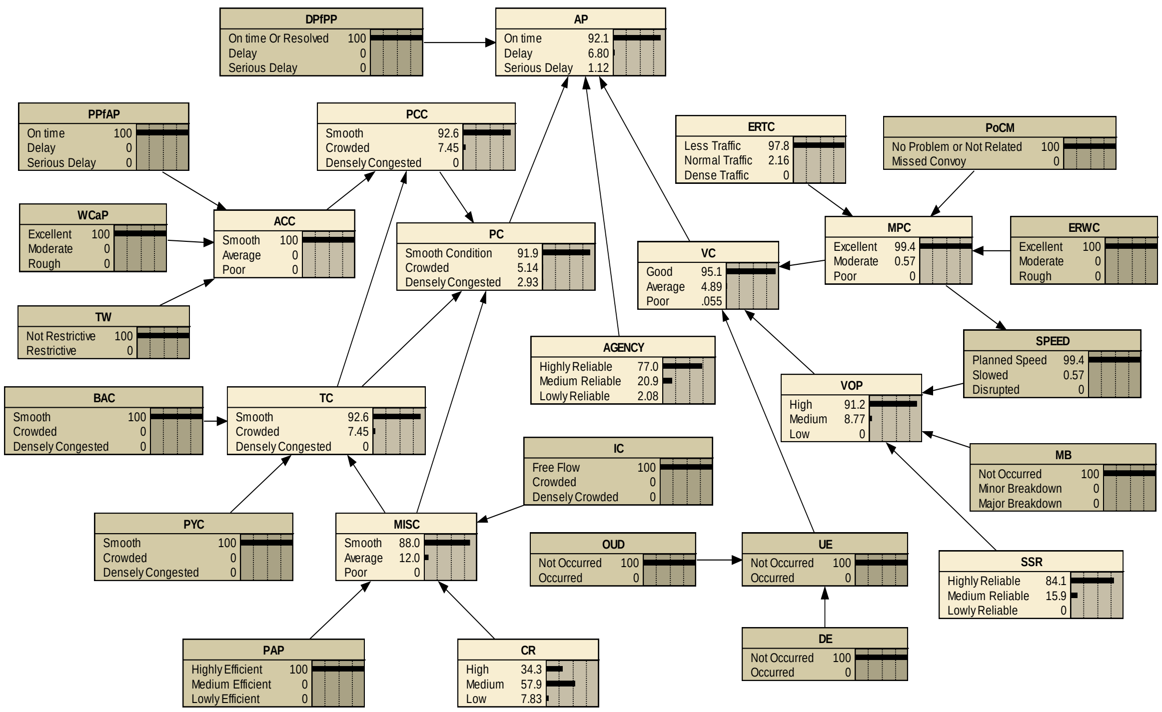

Figure 5.24: The probability set for the arrival punctuality in test case 1

5.4.4.2 Test Case 2

In test case 2, the same vessel is arriving at the same port on 18/12/13. The details of the real arrival time of $Vessel_A$ at $Port_A$ for test case 2 (i.e. 18/12/13) are shown in Table 5.19 and the datasets for test case 2 are shown in Table 5.20.

Table 5.19: Real arrival time of $Vessel_A$ at $Port_A$ for test case 2

Real Arrival Time at $Port_A$	Date	Time	Strategy Implementation
ETA at Berth	18/12/13	0100	NIL
ATA at Berth	18/12/13	1530	

Table 5.20: Datasets for arrival punctuality for test case 2

No.	Root Nodes	Measurement	Data			
1	DPfPP	ΔDeparture = ATD– ETD	+54 minutes			
2	WCaP	Beaufort Number	4			
3	PPfAP	Initiated Time	+6 hours after ETA			
4	TW	Hours Delay	+12 hours Delay			
5	BAC	Berth Occupancy Ratio (%)	57.45%			
6	BAC	Yard Utilisation (%)	54.79%			
7	PAP	Immigration Clearance Issuance Time	Before ETA			
8	IC	Truck Turnaround Time (Minutes)	24.20 minutes			
9	ERTC	En-Route Traffic Condition (Qualitative)	States / Evaluators	Less Traffic	Normal Traffic	Dense Traffic
			Evaluator 1	20%	40%	40%
			Evaluator 2	30%	50%	20%
			Evaluator 3	30%	40%	30%
10	PoCM	Occurrence	Not Involved			
11	ERWC	Beaufort Number	4			
12	MB	Delayed Time	Not Breakdown			
13	SSR	Reliability (Qualitative)	States / Evaluators	High	Medium	Low
			Evaluator 1	80%	15%	5%
			Evaluator 2	80%	20%	0
			Evaluator 3	70%	20%	10%
14	DE	Occurrence	Not Occur			
15	OUD	Occurrence	Not Occur			
16	CR	Chapter 3	High	0.3429		
			Medium	0.5788		
			Low	0.0783		
17	AGENCY	Chapter 4	High	0.7700		
			Medium	0.2092		
			Low	0.0208		

By using the same technique as shown in test case 1, the unconditional probabilities of all root nodes for test case 2 are assessed (Appendix C-3). The sets for all the root nodes are obtained and shown in Table 5.21. These sets will be used for evaluation of the unconditional probabilities distributions for the root nodes for test case 2.

Table 5.21: The belief degrees of all root nodes (arrival test case 2)

Root Nodes	Sets
DPfPP	{(On-time, 0.9625), (Delay, 0.0375), (Serious Delay, 0)}
WCaP	{(Excellent, 1), (Moderate, 0), (Rough, 0)}
PPfAP	{(On-time, 0), (Delay, 1), (Serious Delay, 0)}
TW	{(Not Restrictive, 0), (Restrictive, 1)}
BAC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
BAC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}

PAP	{(Highly Efficient, 1), (Medium Efficient, 0), (Lowly Efficient, 0)}
IC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
ERTC	{(Less Traffic, 0.2565), (Normal Traffic, 0.4513), (Dense Traffic, 0.2922)}
PoCM	{(No Problem, 1), (Miss Convoy, 0)}
ERWC	{(Excellent, 1), (Moderate, 0), (Rough, 0)}
MB	{(No Breakdown, 1), (Minor Breakdown, 0), (Major Breakdown, 0)}
SSR	{(Highly Reliable, 0.8136), (Medium Reliable, 0.1487), (Lowly Reliable, 0.0377)}
DE	{(Not Occurred, 1), (Occurred, 0)}
OUD	{(Not Occurred, 1), (Occurred, 0)}
CR	{(Highly Reliable, 0.3429), (Medium Reliable, 0.5788), (Lowly Reliable, 0.0783)}
AGENCY	{(Highly Reliable, 0.7700), (Medium Reliable, 0.2092), (Lowly Reliable, 0.0208)}

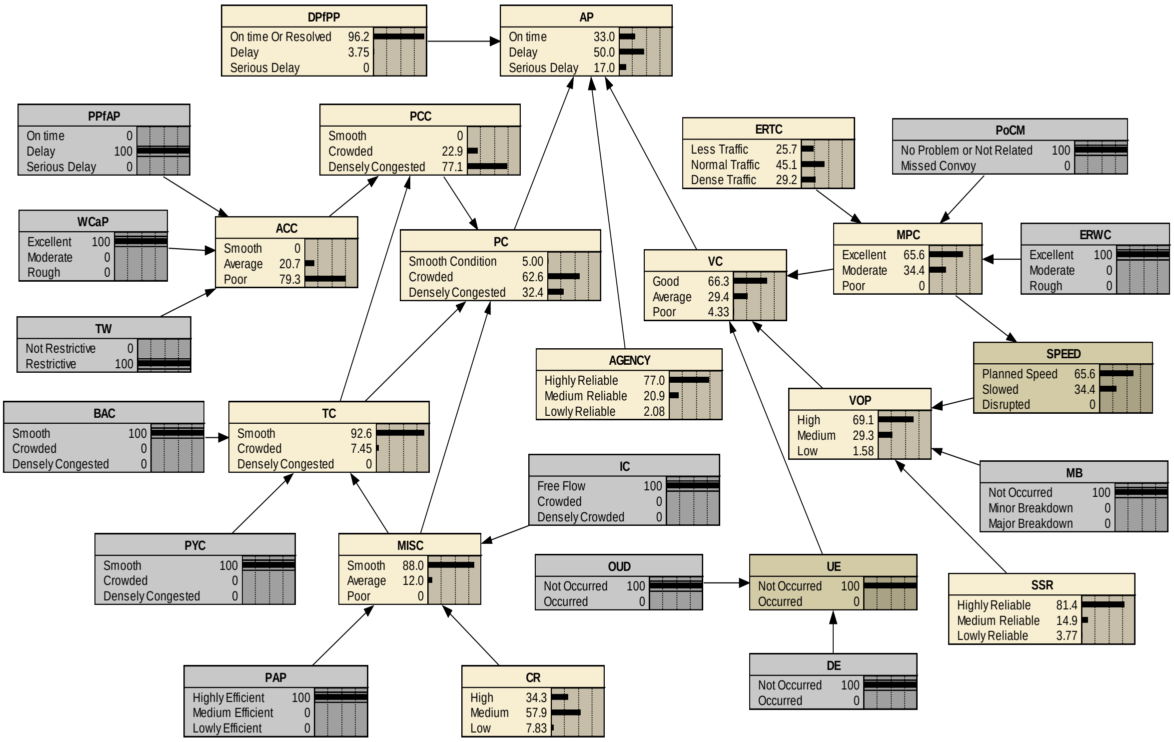

Figure 5.25: The probability set for the arrival punctuality in test case 2

As a result, based on Figure 5.25, the probability of $Vessel_A$ to arrive at $Port_A$ on-time is only 33% (i.e. test case 2).

5.4.4.3 Test Case 3: Operation with the Speeding Strategy

In test case 3, the same vessel is arriving at the same port on 5/12/13. The details of the real arrival time of $Vessel_A$ at $Port_A$ for test case 3 (i.e. 5/12/13) are shown in Table 5.22 and the datasets for test case 3 are shown in Table 5.23.

Table 5.22: Real arrival time of $Vessel_A$ at $Port_A$ for test case 3

Real Arrival Time at $Port_A$	Date	Time	Strategy Implementation
ETA at Berth	5/12/13	0300	Speeding
ATA at Berth	5/12/13	0242	

Table 5.23: Datasets for arrival punctuality for test case 3

No.	Root Nodes	Measurement	Data			
1	DPfPP	ΔDeparture = ATD– ETD	+3 hours and 12 minutes.			
2	WCaP	Beaufort Number	2			
3	PPfAP	Initiated Time	Before ETA			
4	TW	Hours Delay	No Delay			
5	BAC	Berth Occupancy Ratio (%)	57.45%			
6	BAC	Yard Utilisation (%)	54.79%			
7	PAP	Immigration Clearance Issuance Time	Before ETA			
8	IC	Truck Turnaround Time (Minutes)	24.20 minutes			
9	ERTC	En-Route Traffic Condition (Qualitative)	States / Evaluators	Less Traffic	Normal Traffic	Dense Traffic
			Evaluator 1	100%	0	0
			Evaluator 2	100%	0	0
			Evaluator 3	100%	0	0
10	PoCM	Occurrence	Not Involved			
11	ERWC	Beaufort Number	2			
12	MB	Delayed Time	Not Breakdown			
13	SSR	Reliability (Qualitative)	States / Evaluators	High	Medium	Low
			Evaluator 1	70%	25%	5%
			Evaluator 2	80%	20%	0
			Evaluator 3	70%	30%	0
14	DE	Occurrence	Not Occur			
15	OUD	Occurrence	Not Occur			
16	CR	Chapter 3	High	0.3429		
			Medium	0.5788		
			Low	0.0783		
17	AGENCY	Chapter 4	High	0.7700		
			Medium	0.2092		
			Low	0.0208		

By using the same technique as shown in test case 1, the unconditional probabilities of all root nodes for test case 3 are assessed (Appendix C-4). The sets for all the root nodes are obtained and shown in Table 5.24. These sets will be used for evaluation of the unconditional probabilities distributions for the root nodes for test case 3.

Table 5.24: The belief degrees of all root nodes (arrival test case 3)

Root Nodes	Sets
DPfPP	{(On-time, 0.8667), (Delay, 0.1333), (Serious Delay, 0)}
WCaP	{(Excellent, 1), (Moderate, 0), (Rough, 0)}
PPfAP	{(On-time, 1), (Delay, 0), (Serious Delay, 0)}
TW	{(Not Restrictive, 1), (Restrictive, 0)}
BAC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
BAC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
PAP	{(Highly Efficient, 1), (Medium Efficient, 0), (Lowly Efficient, 0)}

IC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
ERTC	{(Less Traffic, 1), (Normal Traffic, 0), (Dense Traffic, 0)}
PoCM	{(No Problem, 1), (Miss Convoy, 0)}
ERWC	{(Excellent, 1), (Moderate, 0), (Rough, 0)}
MB	{(No Breakdown, 1), (Minor Breakdown, 0), (Major Breakdown, 0)}
SSR	{(Highly Reliable, 0.7759), (Medium Reliable, 0.2116), (Lowly Reliable, 0.0125)}
DE	{(Not Occurred, 1), (Occurred, 0)}
OUD	{(Not Occurred, 1), (Occurred, 0)}
CR	{(Highly Reliable, 0.3429), (Medium Reliable, 0.5788), (Lowly Reliable, 0.0783)}
AGENCY	{(Highly Reliable, 0.7700), (Medium Reliable, 0.2092), (Lowly Reliable, 0.0208)}

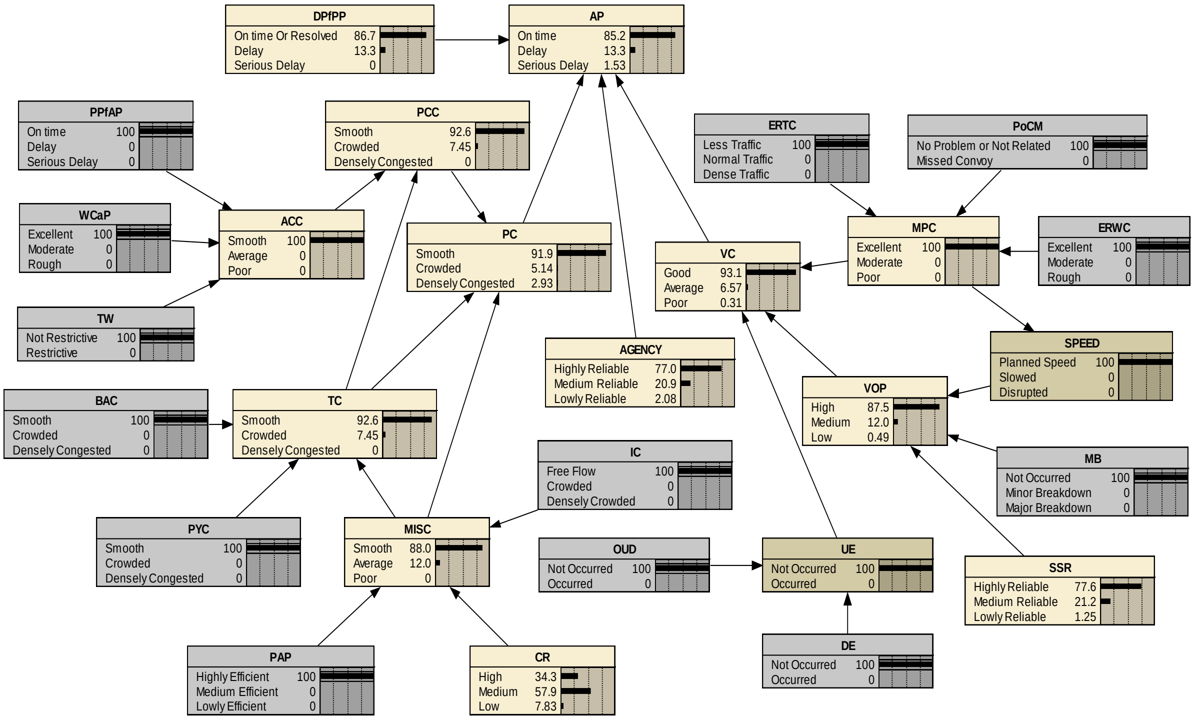

Figure 5.26: The probability set for the arrival punctuality in test case 3

As a result, based on Figure 5.26, the probability of $Vessel_A$ arriving at $Port_A$ on-time is 85.2% (i.e. test case 3).

5.4.5 Model and Result Validations (*Final Step*)

For the validation through SA, test case 1 is chosen and the two Axioms as described in Sub- section 5.3.6 are used. The degree of membership for the highest preference state of an input node is decreased by 0.1 and simultaneously the degree of membership for the lowest preference state is increased by 0.1, as shown in Table 5.25, and the "on-time" values are assessed by the model in Figure 5.24. Since the assessed "on-time" values are smaller than the actual one (i.e. 0.921 "on-time"), the results are aligned with Axiom 1.

Table 5.25: Decrement of values of the root node by 0.1 (arrival punctuality model)

Input Node	Degree of membership for the highest preference state of an input node is decreased by 0.1.	"On-time" value
DPfPP	{(On-time, 0.9), (Delay, 0), (Serious Delay, 0.1)}	0.829
WCaP	{(Excellent, 0.9), (Moderate, 0), (Rough, 0.1)}	0.877
PPfAP	{(On-time, 0.9), (Delay, 0), (Serious Delay, 0.1)}	0.875
TW	{(Not Restrictive, 0.9), (Restrictive, 0.1)}	0.876
BAC	{(Smooth, 0.9), (Crowded, 0), (Densely Congested, 0.1)}	0.847
PYC	{(Smooth, 0.9), (Crowded, 0), (Densely Congested, 0.1)}	0.862
PAP	{(Highly Efficient, 0.9), (Medium Efficient, 0), (Lowly Efficient, 0.1)}	0.858
IC	{(Smooth, 0.9), (Crowded, 0), (Densely Congested, 0.1)}	0.889
ERTC	{(Less Traffic, 0.8784), (Normal Traffic, 0.0216), (Dense Traffic, 0.1)}	0.882
PoCM	{(No Problem, 0.9), (Miss Convoy, 0.1)}	0.880
ERWC	{(Excellent, 0.9), (Moderate, 0), (Rough, 0.1)}	0.860
MB	{(No Breakdown, 0.9), (Minor Breakdown, 0), (Major Breakdown, 0.1)}	0.849
SSR	{(Highly Reliable, 0.7413), (Medium Reliable, 0.1587), (Lowly Reliable, 0.1)}	0.870
DE	{(Not Occurred, 0.9), (Occurred, 0.1)}	0.829
OUD	{(Not Occurred, 0.9), (Occurred, 0.1)}	0.829
CR	{(Highly Reliable, 0.2429), (Medium Reliable, 0.5788), (Lowly Reliable, 0.1783)}	0.901
AGENCY	{(Highly Reliable, 0.6700), (Medium Reliable, 0.2092), (Lowly Reliable, 0.1208)}	0.892

In Axiom 2, the degree of membership for the highest preference state of an input node is decreased by 0.1, 0.2 and 0.3 respectively and simultaneously the degree of membership for the lowest preference state is increased by 0.1, 0.2 and 0.3 respectively. The "on-time" values are assessed by the model in Figure 5.24 and the results are tabulated in Table 5.26 and shown in Figure 5.47. The obtained results are in harmony with Axiom 2.

Table 5.26: The "on-time" values due to the variation of belief degrees of the 17 input nodes (arrival punctuality model)

Root Nodes	On-time values due to decreasing the degree of membership for the highest preference state of an input node by 0.1, 0.2 and 0.3.		
	0.1 (Alteration k)	**0.2 (Alteration l)**	**0.3 (Alteration m)**
DPfPP	0.829	0.737	0.645
WCaP	0.877	0.833	0.789
PPfAP	0.875	0.829	0.784
TW	0.876	0.832	0.787
BAC	0.847	0.773	0.699
PYC	0.862	0.804	0.746
PAP	0.858	0.795	0.733
IC	0.889	0.856	0.824

ERTC	0.882	0.844	0.805
PoCM	0.880	0.838	0.797
ERWC	0.860	0.799	0.738
MB	0.849	0.777	0.705
SSR	0.870	0.819	0.768
DE	0.829	0.737	0.645
OUD	0.829	0.737	0.645
CR	0.901	0.882	0.863
AGENCY	0.892	0.863	0.834

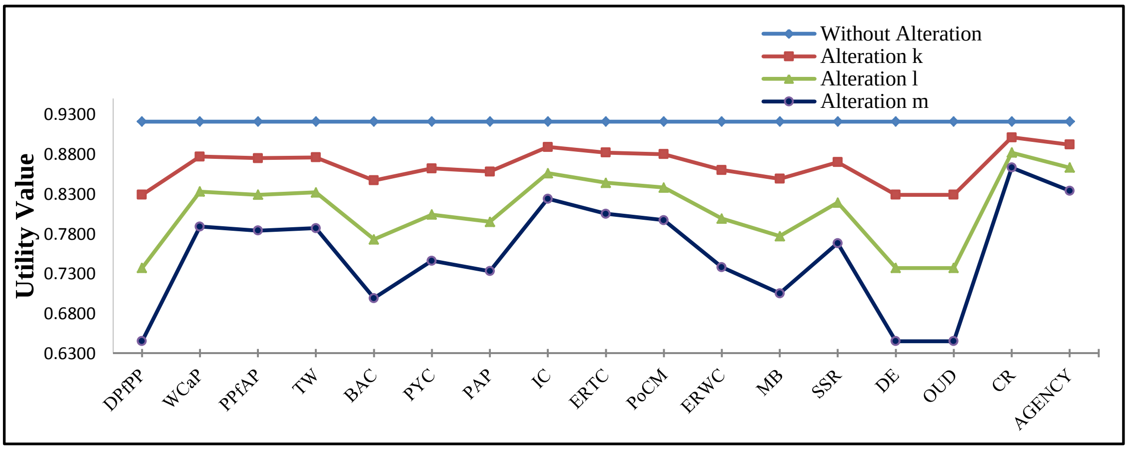

Figure 5.27: Representation of Axioms 1 and 2 (arrival punctuality model)

In order to test the accuracy of the model, the model is validated by using prediction error. Based on Figure 5.24 (i.e. test case 1), the outcome of the model (i.e. the marginal probability of $Vessel_A$ to depart from $Port_A$ on-time) was evaluated as 92.1%. Based on the real record obtained from the ship manager of $Vessel_A$ (i.e. Table 5.12), the Δ Arrival of $Vessel_A$ at $Port_A$ is +54 minutes and can be considered as 96.3% on-time ((24 hours – 0.9 hours) / (24 hours – 0 hours) × 100%). The prediction error is calculated as 4.2% (i.e. 96.3% - 92.1%). As a result, the outcome of test case 1 is considered as reasonable (i.e. less than 10%) and it can be concluded that the developed result in this chapter is reasonable. The summary of prediction errors for test cases 1, 2 and 3 is presented in Table 5.27.

Table 5.27: Prediction errors for test cases 1, 2 and 3 (arrival punctuality model)

Test	Model Result	Real Arrival Time	Difference	Reasonable
Test case 1	92.1%	96.3%	4.2%	Yes
Test case 2	33%	39.6%	6.6%	Yes
Test case 3	85.2%	100%	14.8%	No. (The speeding strategy has been implemented to solve the departure delay from previous port.) It will be discussed in detail in Sub-sub-section 5.5.1.1.

5.5 Results and Discussion

Within this chapter, a model for assessing the departure punctuality of a vessel by using an FBBN model is developed. In this model, the arrival punctuality depends upon many criteria which are port conditions, vessel conditions, process management efficiency by agency and departure punctuality from the previous port of call. It is noteworthy to mention that this developed model is highly sensitive. Any alteration of criteria values will also alter the arrival punctuality's value. In test case 1, based on the given datasets in Table 5.13, the arrival punctuality value of $Vessel_A$ at $Port_A$ is evaluated as 92.1%. This arrival punctuality value is not fixed and by alterations of a criterion's value it will change. To justify these statements, the deviation of arrival punctuality of $Vessel_A$ at $Port_A$ due to alteration of each criterion as shown in Table 5.28 is evaluated.

Table 5.28: Arrival punctuality value of $Vessel_A$ at different situations

No.	Description of Event (Change of Event)	On-time	Rank
1	Departure from previous port is 100% serious delay	0%	1
2	Weather condition at port is 100% rough	48.2%	10
3	Punctuality of pilotage operation is 100% serious delay	46.4%	8
4	Tidal window is 100% restrictive	47.6%	9
5	Berthing area condition is 100% densely congested	18.3%	2
6	Port yard condition is 100% densely congested	33.6%	6
7	Port administration process is 100% low efficiency	29.4%	4
8	Inland corridor is 100% densely congested	59.8%	13
9	En-route traffic condition is 100% dense traffic	53.8%	12
10	Missing a convoy at a canal occurs	50.9%	11
11	En-route weather condition is 100% rough	31.3%	5
12	Machinery breakdown is 100% major	20.2%	3
13	Ship's staff are 100% low reliability	43.8%	7
14	Dangerous event occurs	0%	1
15	Other unexpected delays occur	0%	1
16	Country reliability is 100% low reliability	77.1%	15
17	Agency is 100% low reliability	64.3%	14

As shown in Table 5.28, the model output is more sensitive to the departure punctuality from the previous port, dangerous events and other unexpected delays, respectively. The condition of the berthing area is ranked 2^{nd} and vessel machinery breakdown is ranked 3^{rd}. Consequently, the ship manager should pay more attention to these criteria for further planning, monitoring and prevention measures.

5.5.1 Control Options

5.5.1.1 Departure Delay from the Previous Port

Based on Tables 5.25, 5.26 and 5.28, the importance of departure punctuality of $Vessel_A$ from the previous port of call was proven. If the departure punctuality from the previous port is assessed as 100% serious delay, the probability of $Vessel_A$ to arrive at $Port_A$ on-time is 0%. As a result, ship managers should ensure that the vessel always departs on-time from the previous port of call in order to ensure on-time arrival at the next port of call. This objective can be achieved by having an efficient process management (i.e. agency) and excellent coordination between a vessel and a port.

During the validation process by using a prediction error, all prediction results for test cases 1, 2, and 3 have been compared with the real arrival time records. Results of test cases 1 and 2 are found to be reasonable since both prediction errors are less than 10% (i.e. 4.2% and 6.6% respectively). However, the prediction error for test case 3 is evaluated as 14.8% due to the implementation of the speeding strategy to solve the departure delay from the previous port of call.

5.5.1.2 Unforeseen Events (Dangerous Events and Other Unexpected Events)

Dangerous and other unexpected events such as pirate attacks, armed robbery, looting and ship hijacking, war, detention by port state control, ship captain or crew deaths and embargoes adversely disrupt the operation of a vessel. Based on Table 5.28, there is no chance for $Vessel_A$ to arrive at $Port_A$ on-time if unforeseen events occur during the voyage. In general, to avoid dangerous and other unexpected events, the following are suggested:

- Compliance with all necessary safety regulations such as the International Convention for the Safety of Life at Sea (SOLAS), 1974 and the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) 1978, and practice safety routine tasks as recommended by the Conventions.
- Compliance with all necessary requirements (e.g. required certificates) for arrival and departure processes to avoid detention by the port authority.
- Increase safety measures when entering High Risk Areas by providing additional lookouts by crew, adequate equipment and facilities such as binoculars and alarms, considering the use of night-vision optics and carefully monitoring radar watch.

- Allocate extra buffer time in schedule planning for voyages involving High Risk Areas.
- Develop a contingency procedure for replacing crew and the captain in case of injury or casualty in order to avoid any serious delay.

5.5.1.3 Berthing Area Condition

The most registered cause of vessel delays is port congestion due to low efficiency at berth operational areas (Notteboom, 2006). Based on Table 5.28, berth area condition has become the second most significant factor in determining arrival punctuality, with only an 18.3% chance for $Vessel_A$ to achieve on-time arrival at $Port_A$ if berthing area at $Port_A$ is densely congested. This result supports the previous literature which claimed that congestion at ports is one of the main sources of schedule unreliability (Notteboom, 2006; Gurning, 2011; Ducruet and Notteboom, 2012; Vernimmen *et al*., 2012). To deal with the congestion at berth, LSOs approach this issue in different ways; one of the strategies is strategic investment at major ports of call. Within this strategy, shipping lines have entered the market via the development of dedicated terminals at major load centres (Notteboom, 2006). LSOs seek control over berths at liner terminals so they can control the loading/unloading process for their own vessels. However, many of these liner terminals offer port services to other LSOs' vessels as well, thus creating some hybrid form in between pure dedicated facilities and independently operated multi-user facilities (Notteboom, 2006).

5.5.1.4 Machinery Breakdown

Although machinery breakdown is found to be an infrequent event leading to vessel delay, once it happens, it can completely disrupt a vessel's operation depending on its seriousness (Notteboom, 2006). In this chapter, based on Table 5.28, once $Vessel_A$ experiences a major breakdown during the voyage, the chance to arrive at $Port_A$ on-time is only 20.2%. As a result, the maintenance unit should regularly check and monitor machinery and engine performance in order to avoid machinery breakdown.

Maintenance should keep machinery up-to-date and running smoothly. Each machine or engine requires maintenance, which has to be carried out at regular intervals of time. In the last decade, the number of crew members and engineers on board a vessel was large so that maintenance was carried out quickly and easily. However, in the current scenario, the number of crew members and engineers on board a vessel has reduced drastically. As a result, the required manpower and time may not always be available as the number of crew members has decreased. For this reason, it is important to plan the maintenance of the machinery in advance so that it can be repaired and maintained properly. There are three types of maintenance procedures, which can be implemented as follows (Marine Insight, 2010):

- **Preventive or Scheduled Maintenance System.** It is famously known as the Planned Maintenance System (PMS). In this type of system, the maintenance is carried out as per the running hours – like 4000 hours, 8000 hours, *etc*. – or by calendar intervals, like six months and two months. The maintenance is carried out irrespective of the condition of the machinery. The parts have to be replaced if they are written in the schedule, even if they can still be used.
- **Corrective or Breakdown Maintenance**. In this system, the maintenance is carried out at the machinery breakdown. It is known as breakdown maintenance. This is not a suitable or good method as situations may occur wherein the machinery is required in an emergency. The only advantage of this system is that the machinery is used to its full life or until it breaks. This system might become costly as during breakdown several other parts may also be damaged.
- **Condition Maintenance System**. In this system, the machinery parts are checked regularly. With the help of sensors *etc*. the condition of the machinery is assessed regularly and the maintenance is performed accordingly. This system requires experience and training as wrong interpretation may damage the machinery and lead to costly repairs, which may not be acceptable by the LSO.

5.6 Conclusion

Within the previous chapter, an FBBN model was developed for evaluating the ORC of an LSO. The output of the newly developed model (i.e. ORC) is used within this chapter to evaluate the reliability and capability of the agency responsible for ensuring the arrival process of a vessel at port of call is well managed.

Within this chapter, the new mathematical model for analysing and predicting the arrival punctuality of a vessel to a port of call under dynamic environments by using a hybrid technique (i.e. FBBN method), is developed. For the analysis of arrival punctuality, firstly, the critical factors for analysing and predicting the arrival punctuality have been identified through literature and cause and effect analysis. Secondly, the states of each node were defined by using literature and consultation with experts. Thirdly, a model for analysing and predicting the arrival punctuality was constructed using an FBBN method. Fourthly, the strength of direct dependence of each child node to its associated parents was quantified by assigning each child node a CPT using an FRB approach. Fifthly, unconditional probabilities were determined by assigning assessment grades to all the root nodes in the arrival punctuality model. Those assessment grades could be either quantitative or qualitative. Finally, the developed model and results were validated by using SA and prediction error. Based on the proposed model, LSOs will be able to forecast their vessels' arrival punctuality and, further, tactical strategies can be implemented if a vessel is expected to be delayed. In addition, the punctuality model is capable of helping academic researchers and industrial practitioners to comprehend the influence of uncertain environments on service punctuality.

Based on the SA, one of three most significant factors in the developed model for analysing the arrival punctuality is found to be the departure punctuality of a vessel from the previous port of call. As a result, an FBBN model will again be developed in the next chapter (i.e. Chapter 6) for analysing and predicting the critical factors in determining the departure punctuality of a liner vessel from a particular port of call.

CHAPTER SIX

Adopting a Fuzzy Rule Base in the Fuzzy Bayesian Belief Network Model for Analysing and Predicting Vessel Punctuality in Liner Operations: Departure Punctuality

Summary

Within the previous chapter, the model for the arrival punctuality of a vessel has been modelled and analysed. Based on the sensitivity analysis, departure punctuality has become an initial factor for ensuing on-time arrival of a vessel at the next port of call. Within this chapter, a second aspect of analysis which is departure punctuality will be modelled and analysed. This study makes full use of the FBBN incorporated with an FRB under high uncertainties. This model is capable of helping researchers and practitioners to understand the influence of dynamic environments on the departure punctuality of a vessel. A feasibility test case is demonstrated in this chapter.

6.1 Introduction

One of the most significant factors in the developed model for analysing the arrival punctuality is found to be the departure punctuality of a vessel. Based on the previous chapter (i.e. Chapter 5), the sensitivity analysis (SA) has shown that, if a vessel has a serious departure delay (i.e. more than 48 hours) from her previous port of call, the probability of a vessel to arrive at the next port of call on-time is 0%. Therefore, the aim of this chapter is to exploit an FBBN incorporated with an FRB method for analysing critical influential factors and predicting the departure punctuality of a vessel under uncertain environments. The literature emphasising the determinants of the departure punctuality of a vessel has been discussed in Section 5.2.

This chapter is formulated in the following sequence. A methodology for analysing and predicting the departure punctuality is demonstrated in Section 6.2. A test case is represented in Section 6.3. Results and discussions are provided in Section 6.4 and, finally, this chapter is completed with a conclusion in Section 6.5.

6.2 Methodology

The aim of the study is to analyse the departure punctuality of a vessel from a port of call under uncertain environments by using a hybrid technique, which is the FBBN method. For developing the model for analysing and predicting the departure punctuality of a vessel, as shown in Figure 6.1, six main steps are followed.

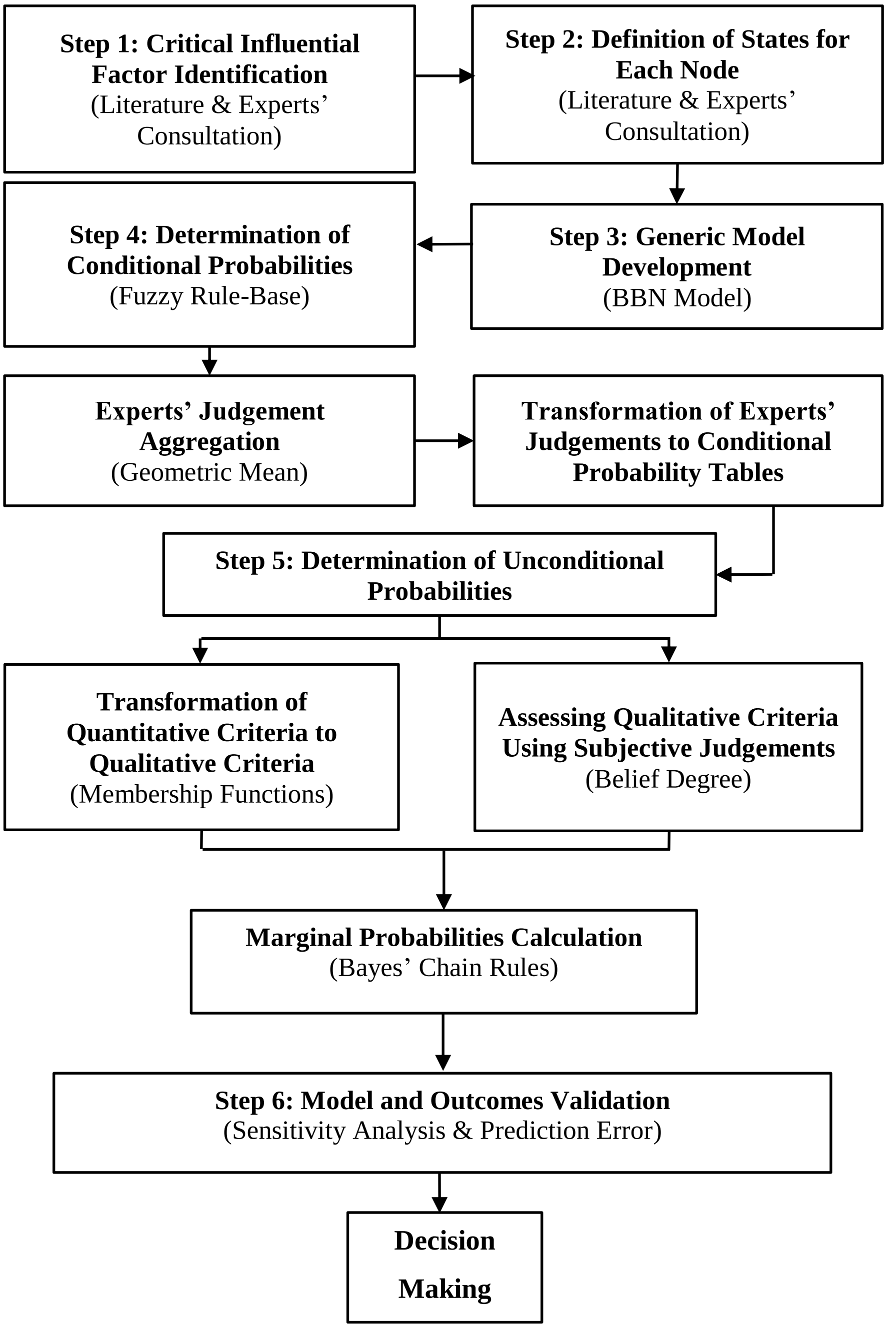

Figure 6.1: The procedure for analysing departure punctuality

Step 1: The critical influential factors for analysing and predicting departure punctuality are identified through literature review and experts' consultation.

Step 2: States of each node are defined by reviewing the literature as well as consulting with experts.

Step 3: The model for analysing and predicting the departure punctuality is constructed using a BBN model.

Step 4: The strength of direct dependence of each child node to its associated parents is quantified by assigning each child node a CPT by using an FRB approach.

Step 5: The unconditional probabilities are determined by collection of data and assigning assessment grades to them. Those assessment grades could be either quantitative or qualitative.

Final step (Step 6): The departure punctuality model and its outcomes are validated by using sensitivity analysis and prediction errors.

6.2.1 The Critical Influential Factor Identification for Analysing Departure Punctuality (*Step1*)

Extensive literature review and consultations with experts are used to identify the critical factors that influenced the departure punctuality of a vessel. Based on the literature review in Section 5.2, the critical influential factors for departure punctuality of a vessel have been identified, as listed in Table 6.1.

Table 6.1: Summary of factors identified for analysing departure punctuality

Departure Model			
Main Criteria	**Sub-criteria**	**Sub-sub-criteria**	**References**
Port Conditions	Channel Conditions during Departure Process	Punctuality of Pilotage Operation	Jason *et al*., (2002), Sawhney and Sumukadas (2005), Lewis *et al.* (2006), Merrick and Dorp (2006), Notteboom (2006), Woodburn (2007), Bosch (2008), and Gurning (2011).
		Weather Condition at Port	
		Tidal Window	
	Terminal Conditions	Berthing Area Condition	
		Port Yard Condition	
		Miscellaneous Factors	
	Miscellaneous Factors	Port Administration Process	
		Inland Corridors	
		Country Reliability (Chapter 3)	
Vessel Conditions	Vessel Operational Performance	Machinery Breakdown	Williams and Treadaway (1992), Shrivastava (1993), Notterboom (2006), Gaonkar *et al.* (2011), Rodrigue and Notteboom (2013).
		Ship Staff's Reliability	
	Unforeseen Events	Dangerous Events	
		Other Unexpected Delays	
Arrival Punctuality at the Same Port			Vernimmen *et al*. (2007).
Agency			Refer to Chapter 4

6.2.2 Definition of Node States (*Step 2*)

The process of establishing states for different nodes has been explained in Sub-section 4.3.2 (i.e. Chapter 4). By reviewing the literature and consulting with the domain experts in the CLSI, the states of each node in the departure model are illustrated in Table 6.2.

Table 6.2: The list of nodes and states for the departure model

Departure Model		
No	**Nodes**	**States**
1.	Departure Punctuality	On-time, Delay, Serious Delay
2.	Port Conditions	Smooth, Crowded, Densely Congested
3.	Vessel Conditions	Good, Average, Poor
4.	Agency	Highly Reliable, Medium Reliable, Lowly Reliable
5.	Arrival Punctuality at the Same Port	On-time or Resolved, Delay, Serious Delay
6.	Channel Conditions during Departure Process	Smooth, Average, Poor
7.	Terminal Conditions	Smooth, Crowded, Densely Congested
8.	Miscellaneous Factors	Smooth, Average, Poor
9.	Vessel Operational Performance	High, Medium, Low
10.	Unforeseen Events	Not Occurred, Occurred
11.	Weather Condition at Port	Excellent, Moderate, Rough
12.	Punctuality of Pilotage Operation for Departure Process	On-time, Delay, Serious Delay
13.	Tidal Window	Not Restrictive, Restrictive
14.	Berthing Area Condition	Smooth, Crowded, Densely Congested
15.	Port Yard Condition	Smooth, Crowded, Densely Congested
16.	Port Administration Process	Highly Efficient, Medium Efficient, Lowly Efficient
17.	Inland Corridors	Freely Flow, Crowded, Densely Congested
18.	Country Reliability	High, Medium, Low
19.	Ship Staff's Reliability	Highly Reliable, Medium Reliable, Lowly Reliable
20.	Machinery Breakdown	Not Occurred, Minor Breakdown, Major Breakdown
21.	Dangerous Events	Not Occurred, Occurred
22.	Other Unexpected Delays	Not Occurred, Occurred

6.2.3 Development of a Model for Departure Punctuality (*Step 3*)

In this chapter, a departure punctuality model is developed by using a BBN model. Based on the identified factors and their states as discussed in Sub-sections 6.2.1 and 6.2.2, the BBN model for the departure punctuality is shown in Figure 6.2. As shown in Figure 6.2, the node "departure punctuality (DP)" has four parent nodes, namely "arrival punctuality at the same port (APSP)", "port conditions (PC)", "vessel conditions (VC)" and "agency (AGENCY)". The parent nodes that influence the node "PC" consist of "channel conditions during departure process (CCdDP)", "terminal conditions (TC)" and "miscellaneous factors (MISC)". The parent nodes that influence the node "CCdDP" consist of "punctuality of pilotage operation for departure process (PPfDP)", "tidal window (TW)" and "weather condition at port (WCaP)". The node "TC" has two parent nodes, namely "berth area condition (BAC)" and "port yard condition (PYC)"; whereas the node "MISC" has three parent nodes, namely "port administration process (PAP)", "inland corridors (IC)" and "country reliability (CR)". The node "vessel conditions" has two parent nodes, namely "vessel operational performance (VOP)" and "unforeseen events (UE)". "Machinery breakdown (MB)" and "ship staff's reliability (SSR)" are the two parent nodes of the node "VOP". Finally, "dangerous events (DE)" and "other unexpected delays (OUD)" are the two parent nodes that influence the node "UE".

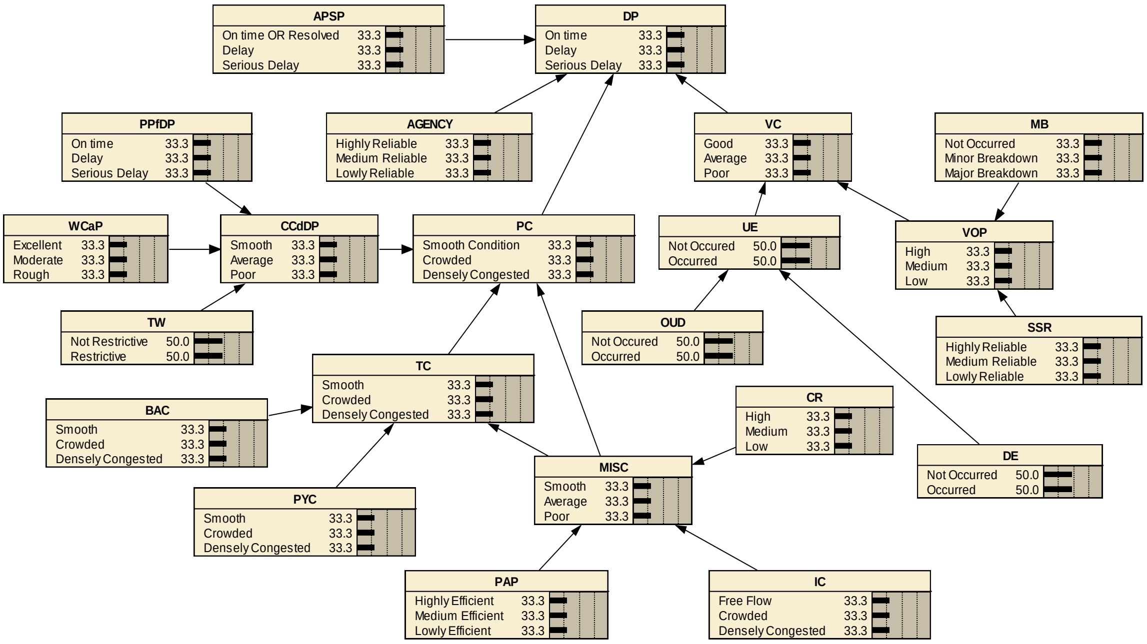

Figure 6.2: A BBN model for departure punctuality (without data)

The abbreviations for the nodes in the departure punctuality model are described in Table 6.3.

Table 6.3: Abbreviations for the nodes in the departure punctuality model

Abbreviation	Description
DP	Departure Punctuality
PC	Port Conditions
VC	Vessel Conditions
AGENCY	Agency
APSP	Arrival Punctuality at the Same Port
CCdDP	Channel Conditions during Departing Process
TC	Terminal Conditions
MISC	Miscellaneous Factors

VOP	Vessel Operational Performance
UE	Unforeseen Events
WCaP	Weather Condition at Port
PPfDP	Punctuality of Pilotage Operation for Departure Process
TW	Tidal Window
BAC	Berthing Area Condition
PYC	Port Yard Condition
PAP	Port Administration Process
IC	Inland Corridors
CR	Country Reliability
SSR	Ship Staff's Reliability
MB	Machinery Breakdown
DE	Dangerous Events
OUD	Other Unexpected Delays

6.2.4 Determination of Conditional Probabilities (*Step 4*)

For determining the conditional probability distributions for the child nodes (i.e. "CCdDP", "TC", "MISC", "VOP", "UE", "PC", "VC" and "DP") in the departure punctuality model, as demonstrated in Sub-section 5.3.4, an FRB approach will be used. To assign conditional probability distributions using an FRB approach, four domain experts with more than 15 years of experience in the liner shipping operations are selected. The details of the four experts are listed as follows:

1. A ship manager/planner of an international liner shipping company in Malaysia who has been involved in the industrial operations for more than 18 years.
2. A senior ship manager of an international liner shipping company in Malaysia who has been involved in the industrial operations for more than 15 years.
3. A senior lecturer who has been involved in the maritime industry for more than 20 years.
4. An operations executive of an international liner shipping company in Malaysia who has been involved in the liner shipping operations for more than 15 years.

6.2.5 Determination of Unconditional Probabilities (*Step 5*)

The methodology for the determination of unconditional probabilities has been described in Sub-sections 4.3.5 and 5.3.5. In this chapter, for assessing the unconditional probabilities of the root nodes in the departure model, firstly, a particular vessel (e.g. $VESSEL_A$) needs to be chosen. The required data about vessel conditions will be obtained from the LSO and agency (i.e. historical data, experts' judgements and vessel records). Secondly, a port of departure (e.g. $PORT_A$) for $VESSEL_A$ will be selected. The required data about the port conditions are obtained from several reliable sources (i.e.

historical data, expert judgements and port statistics) for assessing the unconditional probabilities of root nodes under consideration. For assessing the unconditional probabilities of the root nodes, membership functions need to be constructed.

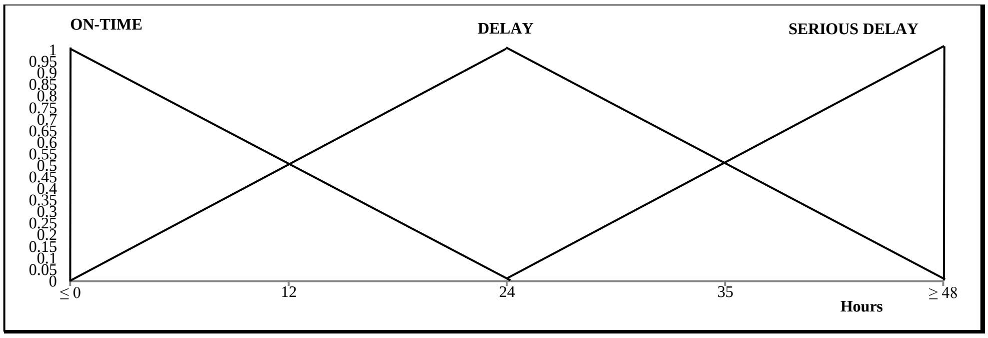

Figure 6.3: Membership functions for the node "APSP"

If a vessel arrives at a port of call on her ETA, then the vessel is considered as on-time. If a vessel arrives at a port 24 hours after her ETA, then the vessel is considered as delay. If a vessel arrives at a port 48 hours or more after her ETA, then the vessel considered as serious delay. As a result, the membership functions for arrival punctuality at the same port are shown in Figure 6.3.

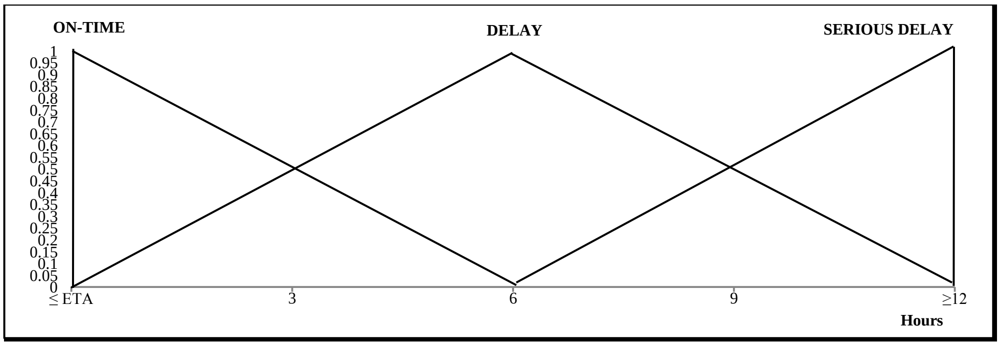

Figure 6.4: Membership functions for the node "PPfDP"

Based on experts' opinion (i.e. two senior ship managers of an LSO in Malaysia who have been involved in the industrial operations for more than 15 years), if a pilotage operation is initiated exactly on or before ETD, the punctuality of the pilot operation is considered to be on-time. If a pilotage operation is initiated within 6 hours after ETD, the punctuality of the pilotage operation is considered as delay. If a pilotage operation is initiated 12 hours or more after ETD, the punctuality of the pilotage operation is considered as serious delay. As a result, the membership functions for the punctuality of a pilotage operation for departure process are shown in Figure 6.4.

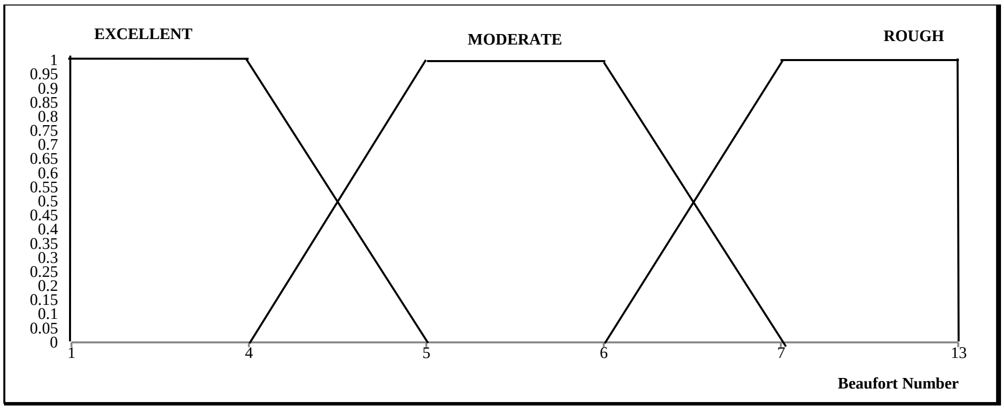

Figure 6.5: Membership functions for the node "WCaP" (departure)

Based on Riahi *et al.* (2012a), weather conditions at a port can be measured by using the Beaufort numbers ranging from 0-13, as shown in Figure 6.5. If the Beaufort number is between 0 and 4, the weather condition can be considered to be excellent and between 5 and 6 it can be considered to be moderate. If the Beaufort number is between 7 and 13, this signifies rough weather.

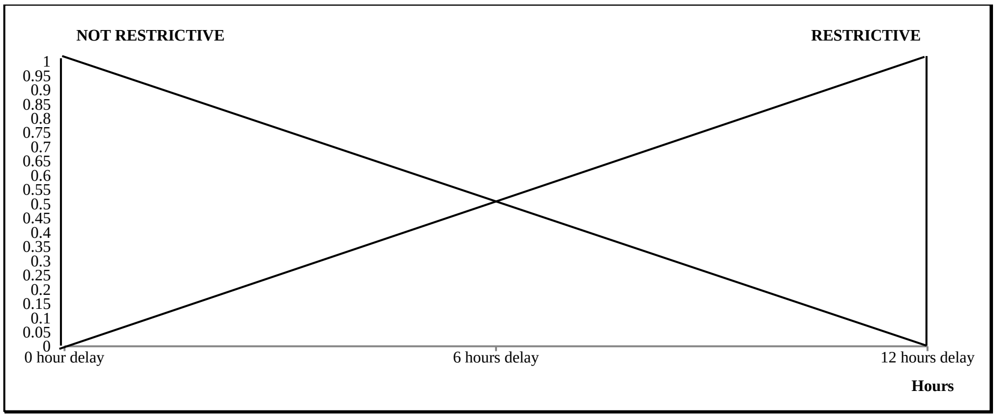

Figure 6.6: Membership functions for the node "TW" (departure)

Based on experts' opinion (i.e. two senior ship managers of an LSO in Malaysia who have been involved in the industrial operations for more than 15 years), if there is no delay due to a tidal window, then the tidal window is considered not to be restrictive. If there is a delay of up to 12 hours due to the tidal window, then it is considered to be a restrictive condition. As a result, the membership functions for the tidal window are shown in Figure 6.6.

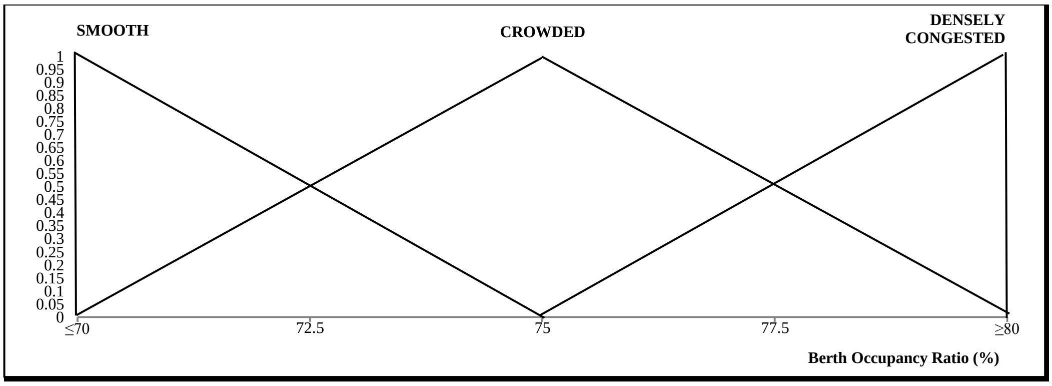

Figure 6.7: Membership functions for the node "BAC" (departure)

Based on Mwasenga (2012) and further consultation with the port experts, berth occupancy ratio (BOR) can be assigned for evaluation of the condition of a berthing area. A high BOR indicates congestion at a berthing area while a low BOR signifies underutilisation of resources. Based on Mwasenga (2012) and experts' opinion, if BOR is 70% or less, it can be considered to be a smooth condition (Figure 6.7). If BOR is 75%, 80% or more, respectively, it can be considered to be crowded and densely congested (Figure 6.7).

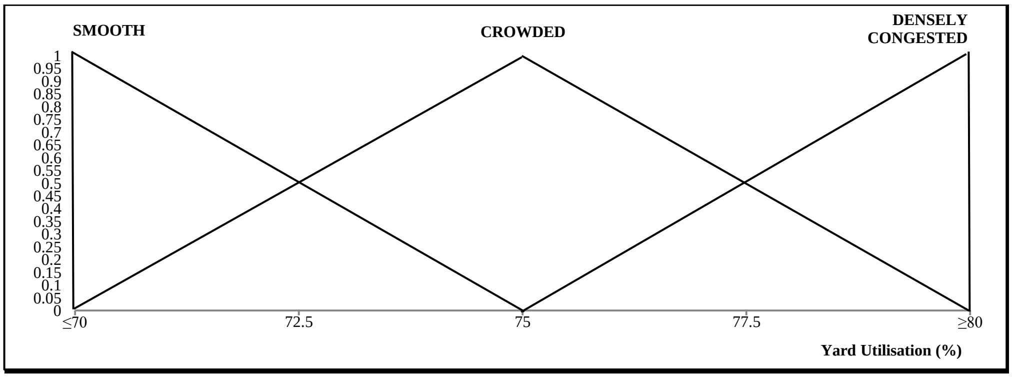

Figure 6.8: Membership functions for the node "PYC" (departure)

Based on Mwasenga (2012) and further consultation with the port experts, port yard utilisation can be used as indication of the condition of a port yard. Yard utilisation is the ratio of the number of storage slots (i.e. number of containers on hand) to the number of available slots (i.e. yard capacity). Based on Mwasenga (2012) and experts' consultations, if yard utilisation is 70% or less, it can be considered to be a smooth condition (Figure 6.8). If yard utilisations is 75%, 80% or more, respectively it can be considered to be crowded and densely congested (Figure 6.8).

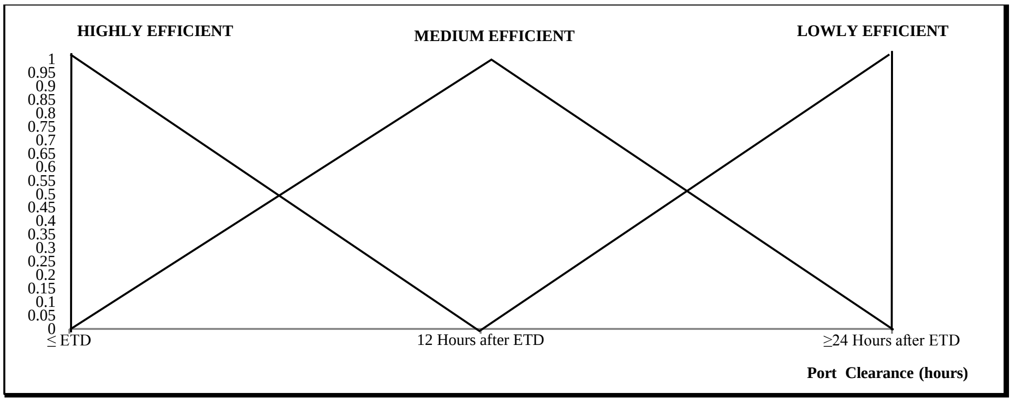

Figure 6.9: Membership functions for the node "PAP" (departure)

In any port around the world, an agent or a master of a vessel must make a declaration before departure by submitting required documents (e.g. certificate of registry, load line certificate, insurance certificate, *etc.*). A vessel leaving a port is required to obtain port clearance. Based on Gurning (2011) and experts' opinion, the process of issuing port clearance can be considered to be an indicator for assessment of port administration efficiency. As shown in Figure 6.9, if the port clearance is issued exactly on or before ETD, the efficiency of the port administration process is considered to be high. If the port clearance is issued within 12 hours after ETD, the efficiency of the port administration process is considered to be medium. If the port clearance is issued 24 hours or more after ETD, the efficiency of the port administration process is considered to be low.

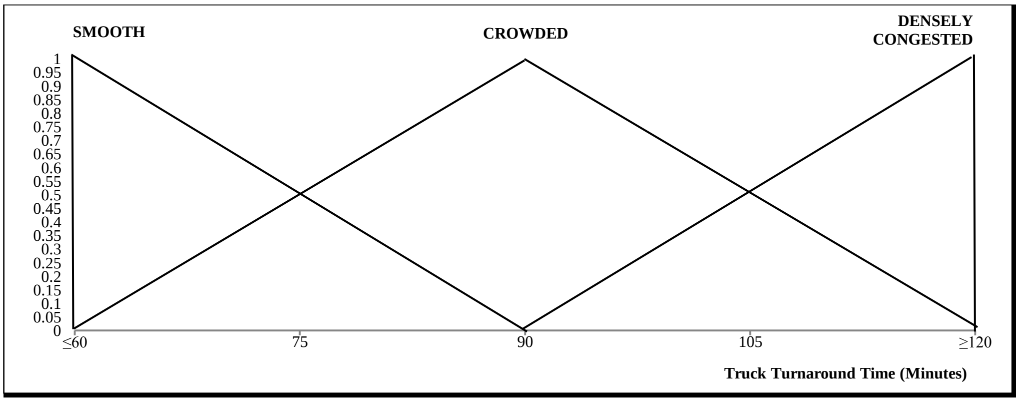

Figure 6.10: Membership functions for the node "IC" (departure)

Based on Mwasenga (2012) and further discussion with the port experts, truck turnaround time (TTT) can be assessed for determining the condition of inland corridors. A TTT is the time between the vehicle's arrival at the terminal entrance gate and its departure from the terminal exit gate. TTT will be used as an indication of inland flow condition. A long TTT indicates congestion at a port's corridor while a short TTT indicates free flow of a port's corridor. As shown in Figure 6.10, based on Mwasenga (2012), if a TTT is 60 minutes or less, it can be considered to be a free flow condition and if a TTT is 90, 120 minutes or more, respectively, it can be considered to be crowded and densely congested.

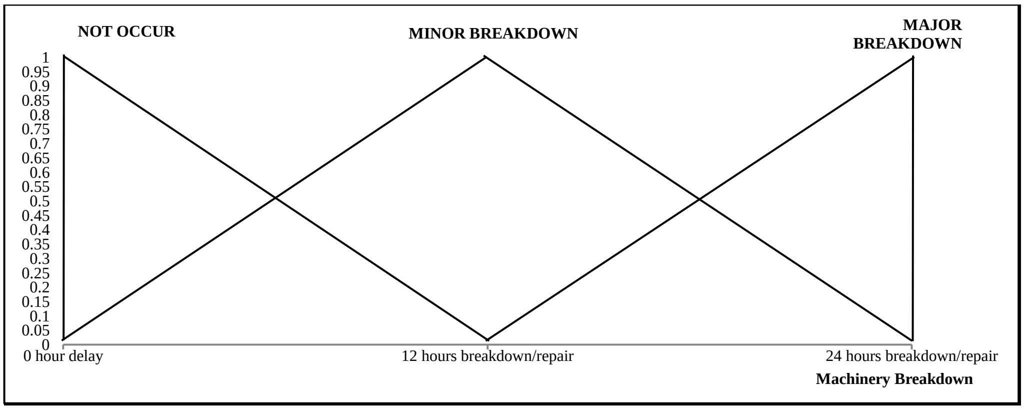

Figure 6.11: Membership functions for the node “MB” (departure)

Based on experts’ opinion (i.e. two senior ship managers of an LSO in Malaysia who have been involved in the industrial operations for more than 15 years), if a vessel does not experience machinery breakdown during her port stay, then no delay is expected. If a vessel’s machinery does break down during her port stay and is restored within 12 hours, then it can be considered to be a minor breakdown. If a vessel’s machinery breaks down during her port stay and it takes 24 hours or more to restore it, then it can be considered to be a major breakdown. As a result, membership functions for a vessel’s machinery breakdown during her port stay are shown in Figure 6.11.

For assessing ship staff’s reliability (SSR), an assessment can be conducted subjectively by the evaluators (e.g. a ship captain, operation manager and ship manager) under fuzzy environments. Then, assessments from different evaluators are aggregated by using an ER algorithm.

For assessing the occurrence probability of missing a convoy at a canal, dangerous events and other unexpected delays, assessments can be conducted by the evaluator (i.e. the ship captain). The assessments can be conducted by ticking the “not occur” condition or “occur” condition.

For assessing the reliability value of a country, the assessment model that has been developed in Chapter 3 will be used. For assessing the reliability and capability value of an agency, the assessment model that has been developed in Chapter 4 will be used.

After all the CPTs of the child nodes and unconditional probabilities of the root nodes are determined, the marginal probabilities of the child node(s) can be calculated with the help of Bayes' chain rules and shown in Sub-section 4.3.5. In this chapter, the *Netica* software tool is employed to calculate the marginal probability for departure punctuality.

6.2.6 Validation of the Proposed Model (*Step 6*)

SA and prediction error will be used for validating the outcomes of the proposed model. The two axioms as discussed in Sub-section 5.3.6 will be employed for SA. In addition, for further validation of the departure punctuality model, a prediction error (Δ Predicted Departure Time - Δ Real Departure Time), is used. If the difference between outcome of the model and real departure time is ≤10% or ±2.4 hours, then it will be considered to be reasonable.

6.3 Test Case: The Analysis of Departure Punctuality of $\boldsymbol{Vessel_A}$

In order to demonstrate the applicability of the proposed model, the departure punctuality (i.e. historical data) of $Vessel_A$ from $Port_A$ will be analysed in this chapter. The details of $Vessel_A$ and $Port_A$ are listed in Tables 6.4 and 6.5 respectively.

Table 6.4: Details of $Vessel_A$ (departure punctuality)

Details	$\boldsymbol{Vessel_A}$ (Renamed due to confidential)
Vessel Type	Container Ship
Gross Tonnage	17068
Deadweight	21206 tonne
Length x Breadth	186 m x 25 m
Year Built	2009
Draught	9.5 m
Port of Departure	$\boldsymbol{Port_A}$
Port Stay at $\boldsymbol{Port_A}$	22 hours

Table 6.5: Details of $Port_A$ (departure punctuality)

Details	$\boldsymbol{Port_A}$ (Renamed due to confidential)
Berths Capacity	12 Berths forming 4.3km of linear wharf
Yard Capacity	200,000 TEUs
Annual Handling Capacity	8,400,000
Quay Crane Capacity	44 Quay-side cranes
Berth Occupancy Ratio (December 2013)	57.45%
Yard Utilisation (December 2013)	54.79%
Truck Turnaround Time (December 2013)	24.20 minutes

6.3.1 Nodes and their States in the Departure Punctuality Model (*Steps 1 and 2*)

In this test case, the nodes and their states for assessing the departure punctuality of $Vessel_A$ at $Port_A$ are presented in Table 6.2.

6.3.2 The Departure Punctuality Model for Test Case (*Step 3*)

The developed BBN model for assessing the departure punctuality, as shown in Figure 6.2, is used in this test case.

6.3.3 Conditional Probability Table (CPT) (*Step 4*)

Based on Sub-section 5.3.4, to conduct conditional probability distributions using the FRB approach, a questionnaire for obtaining judgements from the aforementioned experts is designed. Based on Table 6.6, to establish a rule for the child node "DP" under the combination of the conditions of its parent nodes (i.e. "APSP", "PC", "VC" and "AGENCY"), a preference number ranging from 1 to 5 can be selected. These preference numbers are then aggregated by using the geometric mean (Equation 3.17) and shown in Table 6.7. The tables of consequents for other child nodes can be found in Appendix D-1.

The aggregated preference numbers for each rule, as listed in Table 6.7, are then transformed into a CPT using membership functions, as demonstrated in Figure 5.4, and by using Equation 3.18. As a result, the CPT for the child node "Arrival Punctuality" is shown in Table 6.8.

The same process is applied to all other child nodes (i.e. "PC", "VC", "CCdDP", "TC", "MISC", "VOP", "UE",) and the CPTs for all these child nodes are shown in Appendix D-2. It is worth mentioning that the amount of data that needs to be collected is 199 per expert.

6.3.4 Assessing the Unconditional Probability Distributions (*Step 5*)

Based on the given data and membership functions that have been demonstrated in Sub-section 6.2.5, the unconditional probabilities of the root nodes can be assessed.

Table 6.6: Preference numbers for the child node "Departure Punctuality"

Departure Punctuality States	**On-time** (Exactly depart on ETD or before)	**Slight Delay** (Up to 12 hours after ETD)	**Delay** (Up to 24 hours after ETD)	**Serious Delay** (Up to 36 hours after ETD)	**Very Serious Delay** (48 hours and more after ETD)
Preference Number	**5**	**4**	**3**	**2**	**1**

Table 6.7: Consequents for the child node "Departure Punctuality"

Rules	***IF***				***THEN***				
	Arrival Punctuality at the Same Port	**Port Conditions**	**Vessel Conditions**	**Agency**	**Departure Punctuality**				
					Expert 1 (E1)	**Expert 2 (E2)**	**Expert 3 (E3)**	**Expert 4 (E4)**	**Aggregation**
1	On-time	Smooth	Good	Highly Reliable	5	5	5	5	5.0000
2	On-time	Smooth	Good	Medium Reliable	5	5	4	3	4.1618
3	On-time	Smooth	Good	Lowly Reliable	5	5	3	2	3.4996
4	On-time	Smooth	Average	Highly Reliable	5	5	4	4	4.4721
5	On-time	Smooth	Average	Medium Reliable	5	5	4	3	4.1618
6	On-time	Smooth	Average	Lowly Reliable	5	5	3	2	3.4996
7	On-time	Smooth	Poor	Highly Reliable	3	5	3	1	2.5900
8	On-time	Smooth	Poor	Medium Reliable	3	5	2	1	2.3403
9	On-time	Smooth	Poor	Lowly Reliable	3	5	1	1	1.9680
10	On-time	Crowded	Good	Highly Reliable	4	5	4	3	3.9360
11	On-time	Crowded	Good	Medium Reliable	4	5	3	2	3.3098
12	On-time	Crowded	Good	Lowly Reliable	4	5	2	1	2.5149
13	On-time	Crowded	Average	Highly Reliable	4	5	2	2	2.9907
14	On-time	Crowded	Average	Medium Reliable	3	5	2	2	2.7832
15	On-time	Crowded	Average	Lowly Reliable	3	5	1	1	1.9680
16	On-time	Crowded	Poor	Highly Reliable	3	5	2	1	2.3403
17	On-time	Crowded	Poor	Medium Reliable	3	5	2	1	2.3403
18	On-time	Crowded	Poor	Lowly Reliable	3	5	1	1	1.9680
19	On-time	Densely Congested	Good	Highly Reliable	3	5	4	3	3.6628
20	On-time	Densely Congested	Good	Medium Reliable	3	5	3	3	3.4087
21	On-time	Densely Congested	Good	Lowly Reliable	3	5	2	2	2.7832
22	On-time	Densely Congested	Average	Highly Reliable	3	5	3	3	3.4087

23	On-time	Densely Congested	Average	Medium Reliable	3	5	2	2	2.7832
24	On-time	Densely Congested	Average	Lowly Reliable	3	5	1	1	1.9680
25	On-time	Densely Congested	Poor	Highly Reliable	2	5	2	1	2.1147
26	On-time	Densely Congested	Poor	Medium Reliable	2	5	2	1	2.1147
27	On-time	Densely Congested	Poor	Lowly Reliable	2	5	1	1	1.7783
28	Delay	Smooth	Good	Highly Reliable	5	5	4	3	4.1618
29	Delay	Smooth	Good	Medium Reliable	5	5	3	3	3.8730
30	Delay	Smooth	Good	Lowly Reliable	5	5	2	1	2.6591
31	Delay	Smooth	Average	Highly Reliable	4	5	4	3	3.9360
32	Delay	Smooth	Average	Medium Reliable	4	5	3	3	3.6628
33	Delay	Smooth	Average	Lowly Reliable	4	5	2	2	2.9907
34	Delay	Smooth	Poor	Highly Reliable	4	4	2	1	2.3784
35	Delay	Smooth	Poor	Medium Reliable	4	4	2	1	2.3784
36	Delay	Smooth	Poor	Lowly Reliable	4	4	1	1	2.0000
37	Delay	Crowded	Good	Highly Reliable	4	4	3	2	3.1302
38	Delay	Crowded	Good	Medium Reliable	4	4	2	2	2.8284
39	Delay	Crowded	Good	Lowly Reliable	3	4	1	1	1.8612
40	Delay	Crowded	Average	Highly Reliable	3	4	3	2	2.9130
41	Delay	Crowded	Average	Medium Reliable	3	4	2	2	2.6321
42	Delay	Crowded	Average	Lowly Reliable	3	4	1	1	1.8612
43	Delay	Crowded	Poor	Highly Reliable	3	4	2	1	2.2134
44	Delay	Crowded	Poor	Medium Reliable	3	4	2	1	2.2134
45	Delay	Crowded	Poor	Lowly Reliable	3	4	1	1	1.8612
46	Delay	Densely Congested	Good	Highly Reliable	2	4	2	2	2.3784
47	Delay	Densely Congested	Good	Medium Reliable	2	4	1	1	1.6818
48	Delay	Densely Congested	Good	Lowly Reliable	2	4	1	1	1.6818
49	Delay	Densely Congested	Average	Highly Reliable	2	4	2	2	2.3784
50	Delay	Densely Congested	Average	Medium Reliable	2	4	2	1	2.0000
51	Delay	Densely Congested	Average	Lowly Reliable	1	4	1	1	1.4142
52	Delay	Densely Congested	Poor	Highly Reliable	1	4	1	1	1.4142
53	Delay	Densely Congested	Poor	Medium Reliable	1	4	1	1	1.4142
54	Delay	Densely Congested	Poor	Lowly Reliable	1	4	1	1	1.4142
55	Serious Delay	Smooth	Good	Highly Reliable	4	4	2	1	2.3784
56	Serious Delay	Smooth	Good	Medium Reliable	4	4	2	1	2.3784
57	Serious Delay	Smooth	Good	Lowly Reliable	4	4	1	1	2.0000

58	Serious Delay	Smooth	Average	Highly Reliable	3	4	2	1	2.2134
59	Serious Delay	Smooth	Average	Medium Reliable	3	4	2	1	2.2134
60	Serious Delay	Smooth	Average	Lowly Reliable	3	4	1	1	1.8612
61	Serious Delay	Smooth	Poor	Highly Reliable	3	3	2	1	2.0598
62	Serious Delay	Smooth	Poor	Medium Reliable	3	3	2	1	2.0598
63	Serious Delay	Smooth	Poor	Lowly Reliable	3	3	1	1	1.7321
64	Serious Delay	Crowded	Good	Highly Reliable	3	3	2	1	2.0598
65	Serious Delay	Crowded	Good	Medium Reliable	3	3	2	1	2.0598
66	Serious Delay	Crowded	Good	Lowly Reliable	2	3	1	1	1.5651
67	Serious Delay	Crowded	Average	Highly Reliable	2	3	1	1	1.5651
68	Serious Delay	Crowded	Average	Medium Reliable	2	3	1	1	1.5651
69	Serious Delay	Crowded	Average	Lowly Reliable	2	3	1	1	1.5651
70	Serious Delay	Crowded	Poor	Highly Reliable	2	3	1	1	1.5651
71	Serious Delay	Crowded	Poor	Medium Reliable	1	1	1	1	1.0000
72	Serious Delay	Crowded	Poor	Lowly Reliable	1	1	1	1	1.0000
73	Serious Delay	Densely Congested	Good	Highly Reliable	1	1	1	1	1.0000
74	Serious Delay	Densely Congested	Good	Medium Reliable	1	1	1	1	1.0000
75	Serious Delay	Densely Congested	Good	Lowly Reliable	1	1	1	1	1.0000
76	Serious Delay	Densely Congested	Average	Highly Reliable	1	1	1	1	1.0000
77	Serious Delay	Densely Congested	Average	Medium Reliable	1	1	1	1	1.0000
78	Serious Delay	Densely Congested	Average	Lowly Reliable	1	1	1	1	1.0000
79	Serious Delay	Densely Congested	Poor	Highly Reliable	1	1	1	1	1.0000
80	Serious Delay	Densely Congested	Poor	Medium Reliable	1	1	1	1	1.0000
81	Serious Delay	Densely Congested	Poor	Lowly Reliable	1	1	1	1	1.0000

Table 6.8: CPTs for the child node of "Departure Punctuality"

Rules	*IF*				*THEN*			
					Departure Punctuality			
	Arrival Punctuality	**Port Conditions**	**Vessel Conditions**	**Agency**	**Aggregated Preference Number (Average Output)**	**CPT**		
						On-time	**Delay**	**Serious Delay**
1	On-time	Smooth	Good	Highly Reliable	5.0000	1	0	0
2	On-time	Smooth	Good	Medium Reliable	4.1618	0.5809	0.4191	0
3	On-time	Smooth	Good	Lowly Reliable	3.4996	0.2498	0.7502	0
4	On-time	Smooth	Average	Highly Reliable	4.4721	0.7360	0.2640	0
5	On-time	Smooth	Average	Medium Reliable	4.1618	0.5809	0.4191	0
6	On-time	Smooth	Average	Lowly Reliable	3.4996	0.2498	0.7502	0
7	On-time	Smooth	Poor	Highly Reliable	2.5900	0	0.7950	0.2050
8	On-time	Smooth	Poor	Medium Reliable	2.3403	0	0.6702	0.3298
9	On-time	Smooth	Poor	Lowly Reliable	1.9680	0	0.484	0.516
10	On-time	Crowded	Good	Highly Reliable	3.9360	0.468	0.532	0
11	On-time	Crowded	Good	Medium Reliable	3.3098	0.1549	0.8451	0
12	On-time	Crowded	Good	Lowly Reliable	2.5149	0	0.7574	0.2426
13	On-time	Crowded	Average	Highly Reliable	2.9907	0	0.9953	0.0047
14	On-time	Crowded	Average	Medium Reliable	2.7832	0	0.8916	0.1084
15	On-time	Crowded	Average	Lowly Reliable	1.9680	0	0.484	0.516
16	On-time	Crowded	Poor	Highly Reliable	2.3403	0	0.6702	0.3298
17	On-time	Crowded	Poor	Medium Reliable	2.3403	0	0.6702	0.3298
18	On-time	Crowded	Poor	Lowly Reliable	1.9680	0	0.484	0.516
19	On-time	Densely Congested	Good	Highly Reliable	3.6628	0.3314	0.6686	0
20	On-time	Densely Congested	Good	Medium Reliable	3.4087	0.2043	0.7957	0
21	On-time	Densely Congested	Good	Lowly Reliable	2.7832	0	0.8916	0.1084
22	On-time	Densely Congested	Average	Highly Reliable	3.4087	0.2043	0.7957	0
23	On-time	Densely Congested	Average	Medium Reliable	2.7832	0	0.8916	0.1084
24	On-time	Densely Congested	Average	Lowly Reliable	1.9680	0	0.484	0.516
25	On-time	Densely Congested	Poor	Highly Reliable	2.1147	0	0.5574	0.4427
26	On-time	Densely Congested	Poor	Medium Reliable	2.1147	0	0.5574	0.4427
27	On-time	Densely Congested	Poor	Lowly Reliable	1.7783	0	0.3891	0.6109
28	Delay	Smooth	Good	Highly Reliable	4.1618	0.5809	0.4191	0

29	Delay	Smooth	Good	Medium Reliable	3.8730	0.4365	0.5635	0
30	Delay	Smooth	Good	Lowly Reliable	2.6591	0	0.8296	0.1705
31	Delay	Smooth	Average	Highly Reliable	3.9360	0.468	0.532	0
32	Delay	Smooth	Average	Medium Reliable	3.6628	0.3314	0.6686	0
33	Delay	Smooth	Average	Lowly Reliable	2.9907	0	0.9953	0.0047
34	Delay	Smooth	Poor	Highly Reliable	2.3784	0	0.6892	0.3108
35	Delay	Smooth	Poor	Medium Reliable	2.3784	0	0.6892	0.3108
36	Delay	Smooth	Poor	Lowly Reliable	2.0000	0	0.5	0.5
37	Delay	Crowded	Good	Highly Reliable	3.1302	0.0651	0.9349	0
38	Delay	Crowded	Good	Medium Reliable	2.8284	0	0.9142	0.0858
39	Delay	Crowded	Good	Lowly Reliable	1.8612	0	0.4306	0.5694
40	Delay	Crowded	Average	Highly Reliable	2.9130	0	0.9565	0.0435
41	Delay	Crowded	Average	Medium Reliable	2.6321	0	0.816	0.184
42	Delay	Crowded	Average	Lowly Reliable	1.8612	0	0.4306	0.5694
43	Delay	Crowded	Poor	Highly Reliable	2.2134	0	0.6067	0.3933
44	Delay	Crowded	Poor	Medium Reliable	2.2134	0	0.6067	0.3933
45	Delay	Crowded	Poor	Lowly Reliable	1.8612	0	0.4306	0.5694
46	Delay	Densely Congested	Good	Highly Reliable	2.3784	0	0.6892	0.3108
47	Delay	Densely Congested	Good	Medium Reliable	1.6818	0	0.3409	0.6591
48	Delay	Densely Congested	Good	Lowly Reliable	1.6818	0	0.3409	0.6591
49	Delay	Densely Congested	Average	Highly Reliable	2.3784	0	0.6892	0.3108
50	Delay	Densely Congested	Average	Medium Reliable	2.0000	0	0.5	0.5
51	Delay	Densely Congested	Average	Lowly Reliable	1.4142	0	0.2071	0.7929
52	Delay	Densely Congested	Poor	Highly Reliable	1.4142	0	0.2071	0.7929
53	Delay	Densely Congested	Poor	Medium Reliable	1.4142	0	0.2071	0.7929
54	Delay	Densely Congested	Poor	Lowly Reliable	1.4142	0	0.2071	0.7929
55	Serious Delay	Smooth	Good	Highly Reliable	2.3784	0	0.6892	0.3108
56	Serious Delay	Smooth	Good	Medium Reliable	2.3784	0	0.6892	0.3108
57	Serious Delay	Smooth	Good	Lowly Reliable	2.0000	0	0.5	0.5
58	Serious Delay	Smooth	Average	Highly Reliable	2.2134	0	0.6067	0.3933
59	Serious Delay	Smooth	Average	Medium Reliable	2.2134	0	0.6067	0.3933
60	Serious Delay	Smooth	Average	Lowly Reliable	1.8612	0	0.4306	0.5694
61	Serious Delay	Smooth	Poor	Highly Reliable	2.0598	0	0.5299	0.4701
62	Serious Delay	Smooth	Poor	Medium Reliable	2.0598	0	0.5299	0.4701
63	Serious Delay	Smooth	Poor	Lowly Reliable	1.7321	0	0.3660	0.6340

64	Serious Delay	Crowded	Good	Highly Reliable	2.0598	0	0.5299	0.4701
65	Serious Delay	Crowded	Good	Medium Reliable	2.0598	0	0.5299	0.4701
66	Serious Delay	Crowded	Good	Lowly Reliable	1.5651	0	0.2825	0.7175
67	Serious Delay	Crowded	Average	Highly Reliable	1.5651	0	0.2825	0.7175
68	Serious Delay	Crowded	Average	Medium Reliable	1.5651	0	0.2825	0.7175
69	Serious Delay	Crowded	Average	Lowly Reliable	1.5651	0	0.2825	0.7175
70	Serious Delay	Crowded	Poor	Highly Reliable	1.5651	0	0.2825	0.7175
71	Serious Delay	Crowded	Poor	Medium Reliable	1.0000	0	0	1
72	Serious Delay	Crowded	Poor	Lowly Reliable	1.0000	0	0	1
73	Serious Delay	Densely Congested	Good	Highly Reliable	1.0000	0	0	1
74	Serious Delay	Densely Congested	Good	Medium Reliable	1.0000	0	0	1
75	Serious Delay	Densely Congested	Good	Lowly Reliable	1.0000	0	0	1
76	Serious Delay	Densely Congested	Average	Highly Reliable	1.0000	0	0	1
77	Serious Delay	Densely Congested	Average	Medium Reliable	1.0000	0	0	1
78	Serious Delay	Densely Congested	Average	Lowly Reliable	1.0000	0	0	1
79	Serious Delay	Densely Congested	Poor	Highly Reliable	1.0000	0	0	1
80	Serious Delay	Densely Congested	Poor	Medium Reliable	1.0000	0	0	1
81	Serious Delay	Densely Congested	Poor	Lowly Reliable	1.0000	0	0	1

6.3.4.1 Test Case 1

The details of the real departure time of $Vessel_A$ from $Port_A$ for test case 1 (i.e. 9/12/2013) are shown in Table 6.9 and the datasets for test case 1 are shown in Table 6.10.

Table 6.9: Real departure time of $Vessel_A$ at $Port_A$ for test case 1

Real Arrival Time at $Port_A$	Date	Time	Strategy Implementation
ETD from berth	8/12/13	2200	NIL
ATD from berth	9/12/13	0642	

Table 6.10: Datasets for departure punctuality for test case 1

<table>
<tr><th>No</th><th>Root Nodes</th><th>Measurement</th><th colspan="4">Data</th></tr>
<tr><td>1</td><td>APSP</td><td>ΔArrival = ATA– ETA</td><td colspan="4">-18 minutes</td></tr>
<tr><td>2</td><td>WCaP</td><td>Beaufort Number</td><td colspan="4">2</td></tr>
<tr><td>3</td><td>PPfDP</td><td>Initiate Time</td><td colspan="4">No delay</td></tr>
<tr><td>4</td><td>TW</td><td>Hours Delay</td><td colspan="4">+8 hours delay</td></tr>
<tr><td>5</td><td>BAC</td><td>Berth Occupancy Ratio (%)</td><td colspan="4">57.45%</td></tr>
<tr><td>6</td><td>PYC</td><td>Yard Utilisation (%)</td><td colspan="4">54.79%</td></tr>
<tr><td>7</td><td>PAP</td><td>Port Clearance Issuance Time</td><td colspan="4">Before ETD</td></tr>
<tr><td>8</td><td>IC</td><td>Truck Turnaround Time (Minutes)</td><td colspan="4">24.20 minutes</td></tr>
<tr><td>9</td><td>MB</td><td>Delayed Time due to Breakdown and Repair</td><td colspan="4">Not Breakdown</td></tr>
<tr><td rowspan="4">10</td><td rowspan="4">SSR</td><td rowspan="4">Reliability (Qualitative)</td><td>States / Evaluators</td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td>Evaluator 1</td><td>100%</td><td>0%</td><td>0%</td></tr>
<tr><td>Evaluator 2</td><td>100%</td><td>0%</td><td>0%</td></tr>
<tr><td>Evaluator 3</td><td>90%</td><td>10%</td><td>0%</td></tr>
<tr><td>11</td><td>DE</td><td>Occurrence</td><td colspan="4">Not Occur</td></tr>
<tr><td>12</td><td>OUD</td><td>Occurrence</td><td colspan="4">Not Occur</td></tr>
<tr><td rowspan="3">13</td><td rowspan="3">CR</td><td rowspan="3">Chapter 3</td><td>High</td><td colspan="3">0.3429</td></tr>
<tr><td>Medium</td><td colspan="3">0.5788</td></tr>
<tr><td>Low</td><td colspan="3">0.0783</td></tr>
<tr><td rowspan="3">14</td><td rowspan="3">AGENCY</td><td rowspan="3">Chapter 4</td><td>High</td><td colspan="3">0.7700</td></tr>
<tr><td>Medium</td><td colspan="3">0.2092</td></tr>
<tr><td>Low</td><td colspan="3">0.0208</td></tr>
</table>

Based on Sub-section 6.2.5 and the datasets given in Table 6.10, the unconditional probabilities of all root nodes for test case 1 are assessed as follows:

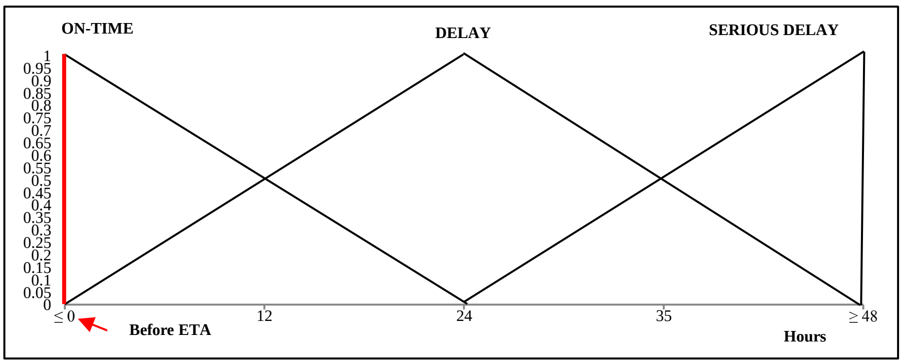

Figure 6.12: Membership functions for the node "APSP" (departure test case 1)

Based on Figure 6.12, the set for the arrival punctuality at the same port is evaluated as:

1. H_n is the On-time
2. H_{n+1} is the Delay
3. h_i = 0, $h_{n,i}$ = 0 and $h_{n+1,i}$ = 24
4. $\beta_{n,i}$ = (24-0) / (24-0) = 1 with On-time

$$APSP = \{(\text{On-time}, 1), (\text{Delay}, 0), (\text{Serious Delay}, 0)\}$$

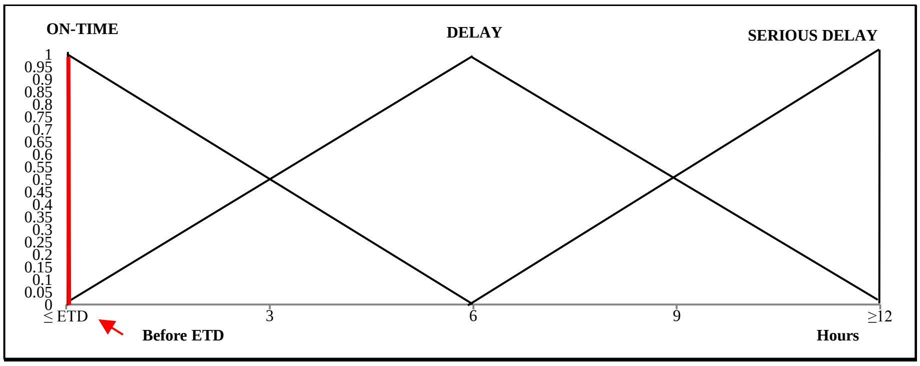

Figure 6.13: Membership functions for the node "PPfDP" (departure test case 1)

Based on Figure 6.13, the set for the punctuality of pilotage operation for the departure process is evaluated as:

$$PPfDP = \{(\text{On-time}, 1), (\text{Delay}, 0), (\text{Serious Delay}, 0)\}$$

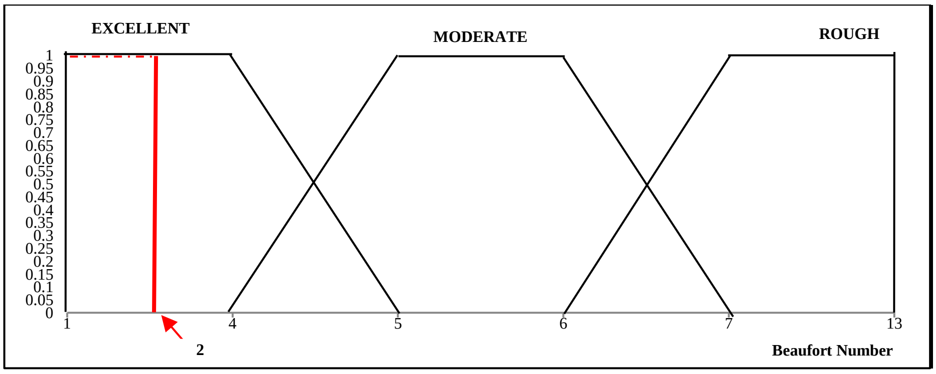

Figure 6.14: Membership functions for the node "WCaP" (departure test case 1)

Based on Figure 6.14, the set for the weather condition at the port is evaluated as:

$$WCaP = \{(\text{Excellent}, 1), (\text{Moderate}, 0), (\text{Rough}, 0)\}$$

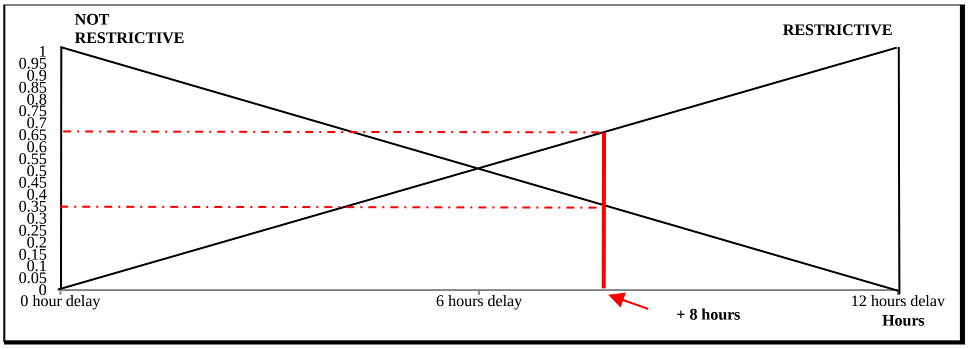

Figure 6.15: Membership functions for the node “TW” (departure test case 1)

Based on Figure 6.15, the set for tidal window during the departure process is evaluated as:

TW = {(Not Restrictive, 0.3333), (Restrictive, 0.6667)}

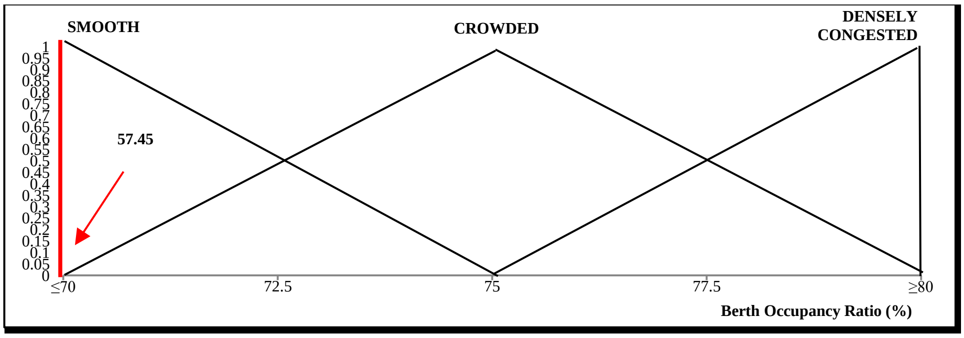

Figure 6.16: Membership functions for the node “BAC” (departure test case 1)

Based on Figure 6.16, the set for the berthing area condition is evaluated as:

BAC = {(Smooth, 1), (Crowded 0), (Densely Congested, 0)}

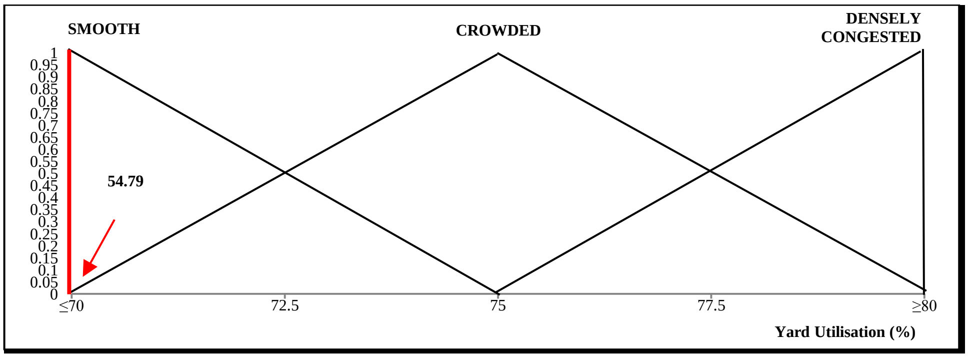

Figure 6.17: Membership functions for the node “PYC” (departure test case 1)

Based on Figure 6.17, the set for the port yard condition is evaluated as:

PYC = {(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}

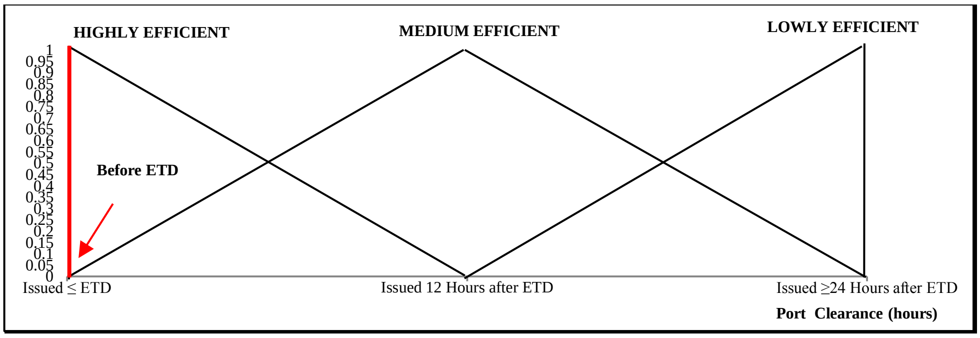

Figure 6.18: Membership functions for the node "PAP" (departure test case 1)

Based on Figure 6.18, the set for the port administration process is evaluated as:

PAP = {(Highly Efficient, 1), (Medium Efficient, 0), (Lowly Efficient, 0)}

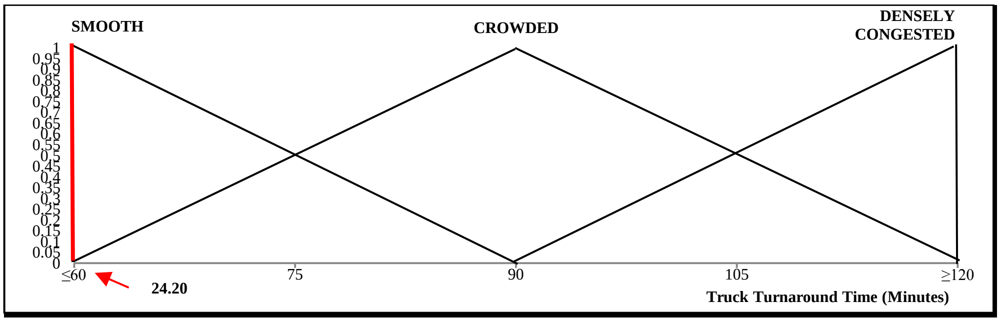

Figure 6.19: Membership functions for the node "IC" (departure test case 1)

Based on Figure 6.19, the set for the inland corridors is evaluated as:

IC = {(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}

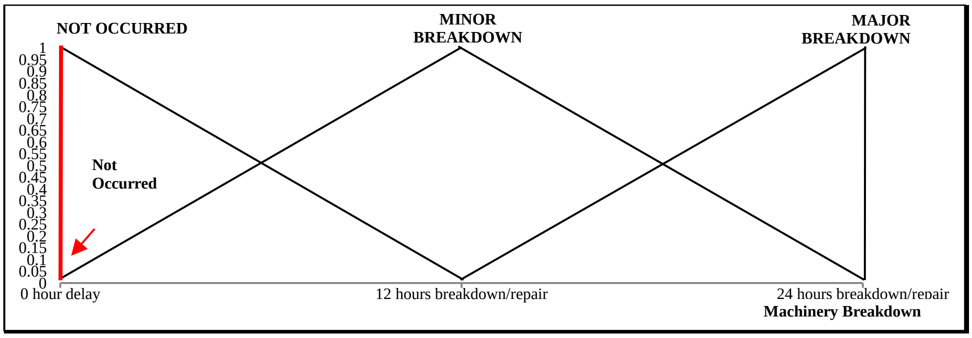

Figure 6.20: Membership functions for the node "MB" (departure test case 1)

Based on Figure 6.20, the set for the vessel's machinery breakdown during her port stays is evaluated as:

MB = {(Not Occurred, 1), (Minor Breakdown, 0), (Major Breakdown, 0)}

For assessing ship staff's reliability, assessments are made by the evaluators (i.e. ship captain (Evaluator 1), operation manager (Evaluator 2) and ship manager (Evaluator 3)) using subjective judgements. Then, the assessments from these evaluators are aggregated by using an ER algorithm (i.e. Tables 6.11).

Table 6.11: Assessment of the node "SSR" (departure test case 1)

Qualitative Criteria	Assessment Grades			
	Source	Highly Reliable	Medium Reliable	Lowly Reliable
SSR	Evaluator 1	1	0	0
	Evaluator 2	1	0	0
	Evaluator 3	0.9	0.1	0
	Aggregation (ER)	0.8413	0.1587	0

For assessing the occurrence probabilities of the nodes "DE" and "OUD" in the departure model, assessments are made by the ship captain of $Vessel_A$ as shown in Table 6.12.

Table 6.12: Occurrence probability of the nodes "DE" and "OUD" (departure test case 1)

Qualitative Criteria	Assessment Grades		
	Source	Not Occur	Occur
DE	Ship Captain	1	0
OUD	Ship Captain	1	0

For assessing the reliability value of the host country (CR), the assessment model that has been developed in Chapter 3 is used. For assessing the reliability value of the agency (AGENCY), the assessment model that has been developed in Chapter 4 is used. The results are shown in Table 6.13.

Table 6.13: Reliability values of the country and the agency (departure test case 1)

Qualitative Criteria	Assessment Grades		
	Highly Reliable	Medium Reliable	Lowly Reliable
CR	0.3429	0.5788	0.0783
AGENCY	0.7700	0.2092	0.0208

The sets for all the root nodes are obtained and shown in Table 6.14. These sets are used for evaluation of the unconditional probabilities distributions of the root nodes.

Table 6.14: The belief degrees of all root nodes (departure test case 1)

No.	Root Nodes	Sets
1	APSP	{(On-time, 1), (Delay, 0), (Serious Delay, 0)}
2	WCaP	{(Excellent, 1), (Moderate, 0), (Rough, 0)}
3	PPfDP	{(On-time, 1), (Delay, 0), (Serious Delay, 0)}
4	TW	{(Not Restrictive, 0.3333), (Restrictive, 0.6667)}
5	BAC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}

6	PYC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
7	PAP	{(Highly Efficient, 1), (Medium Efficient, 0), (Lowly Efficient, 0)}
8	IC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
9	MB	{(Not Breakdown, 1), (Minor Breakdown, 0),(Major Breakdown, 0)}
10	SSR	{(Highly Reliable, 0.8413), (Medium Reliable, 0.1587), (Lowly Reliable, 0)}
11	DE	{(Not Occurred, 1), (Occurred, 0)}
12	OUD	{(Not Occurred, 1), (Occurred, 0)}
13	CR	{(Highly Reliable, 0.3429), (Medium Reliable, 0.5788), (Lowly Reliable, 0.0783)}
14	AGENCY	{(Highly Reliable, 0.7700), (Medium Reliable, 0.2092), (Lowly Reliable, 0.0208)}

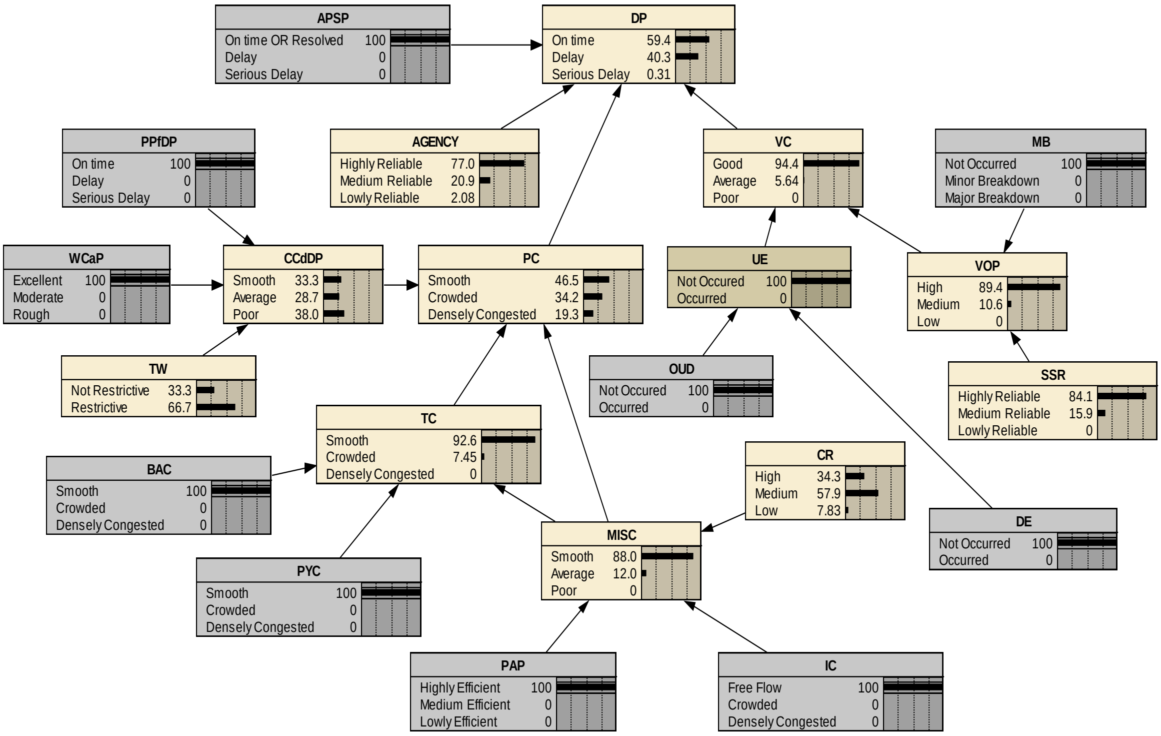

Figure 6.21: The probability set for the departure punctuality in test case 1

Based on Figure 6.21, the marginal probability of $Vessel_A$ departing from $Port_A$ on-time is 59.4% (i.e. test case 1).

6.3.4.2 Test Case 2

In test case 2, the same vessel is departing from the same port on 30/12/2013. The details of the real departure time of $Vessel_A$ from $Port_A$ for test case 2 (i.e. 30/12/2013) are shown in Table 6.15 and the datasets for test case 2 are shown in Table 6.16.

Table 6.15: Real departure time of $Vessel_A$ at $Port_A$ for test case 2

Real Arrival Time at $Port_A$	Date	Time	Strategy Implementation
ETD from berth	29/12/13	2000	NIL
ATD from berth	30/12/13	0342	

Table 6.16: The datasets for departure punctuality for test case 2

<table>
<tr><th>No.</th><th>Root Nodes</th><th>Measurement</th><th colspan="4">Data</th></tr>
<tr><td>1</td><td>APSP</td><td>ΔArrival = ATA– ETA</td><td colspan="4">+54 minutes</td></tr>
<tr><td>2</td><td>WCaP</td><td>Beaufort Number</td><td colspan="4">3</td></tr>
<tr><td>3</td><td>PPfDP</td><td>Initiated Time</td><td colspan="4">+6 hours after ETD</td></tr>
<tr><td>4</td><td>TW</td><td>Hours Delay</td><td colspan="4">No delay</td></tr>
<tr><td>5</td><td>BAC</td><td>Berth Occupancy Ratio (%)</td><td colspan="4">57.45%</td></tr>
<tr><td>6</td><td>PYC</td><td>Yard Utilisation (%)</td><td colspan="4">54.79%</td></tr>
<tr><td>7</td><td>PAP</td><td>Port Clearance Issuance Time</td><td colspan="4">Before ETD</td></tr>
<tr><td>8</td><td>IC</td><td>Truck Turnaround Time (Minutes)</td><td colspan="4">24.20 minutes</td></tr>
<tr><td>9</td><td>MB</td><td>Delayed Time due to Breakdown and Repair</td><td colspan="4">+6 hours delay</td></tr>
<tr><td rowspan="4">10</td><td rowspan="4">SSR</td><td rowspan="4">Reliability (Qualitative)</td><td>States / Evaluators</td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td>Evaluator 1</td><td>80%</td><td>15%</td><td>5%</td></tr>
<tr><td>Evaluator 2</td><td>80%</td><td>20%</td><td>0</td></tr>
<tr><td>Evaluator 3</td><td>70%</td><td>20%</td><td>10%</td></tr>
<tr><td>11</td><td>DE</td><td>Occurrence</td><td colspan="4">Not Occur</td></tr>
<tr><td>12</td><td>OUD</td><td>Occurrence</td><td colspan="4">Not Occur</td></tr>
<tr><td rowspan="3">13</td><td rowspan="3">CR</td><td rowspan="3">Chapter 3</td><td>High</td><td colspan="3">0.3429</td></tr>
<tr><td>Medium</td><td colspan="3">0.5788</td></tr>
<tr><td>Low</td><td colspan="3">0.0783</td></tr>
<tr><td rowspan="3">14</td><td rowspan="3">AGENCY</td><td rowspan="3">Chapter 4</td><td>High</td><td colspan="3">0.7700</td></tr>
<tr><td>Medium</td><td colspan="3">0.2092</td></tr>
<tr><td>Low</td><td colspan="3">0.0208</td></tr>
</table>

By using the same technique as shown in test case 1, the unconditional probabilities of all root nodes for test case 2 are assessed (Appendix D-3). The sets for all the root nodes are obtained and shown in Table 6.17. These sets will be used for evaluation of the unconditional probabilities distributions for the root nodes for test case 2.

Table 6.17: The belief degrees of all root nodes (departure test case 2)

No.	Root Nodes	Sets
1	APSP	{(On-time, 0.9625), (Delay, 0.0375), (Serious Delay, 0)}
2	WCaP	{(Excellent, 1), (Moderate, 0), (Rough, 0)}
3	PPfDP	{(On-time, 0), (Delay, 1), (Serious Delay, 0)}
4	TW	{(Not Restrictive, 1), (Restrictive, 0)}
5	BAC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
6	PYC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
7	PAP	{(Highly Efficient, 1), (Medium Efficient, 0), (Lowly Efficient, 0)}
8	IC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
9	MB	{(Not Breakdown, 0.5), (Minor Breakdown, 0.5),(Major

		Breakdown, 0)}
10	SSR	{(Highly Reliable, 0.8136), (Medium Reliable, 0.1487), (Lowly Reliable, 0.0377)}
11	DE	{(Not Occurred, 1), (Occurred, 0)}
12	OUD	{(Not Occurred, 1), (Occurred, 0)}
13	CR	{(Highly Reliable, 0.3429), (Medium Reliable, 0.5788), (Lowly Reliable, 0.0783)}
14	AGENCY	{(Highly Reliable, 0.7700), (Medium Reliable, 0.2092), (Lowly Reliable, 0.0208)}

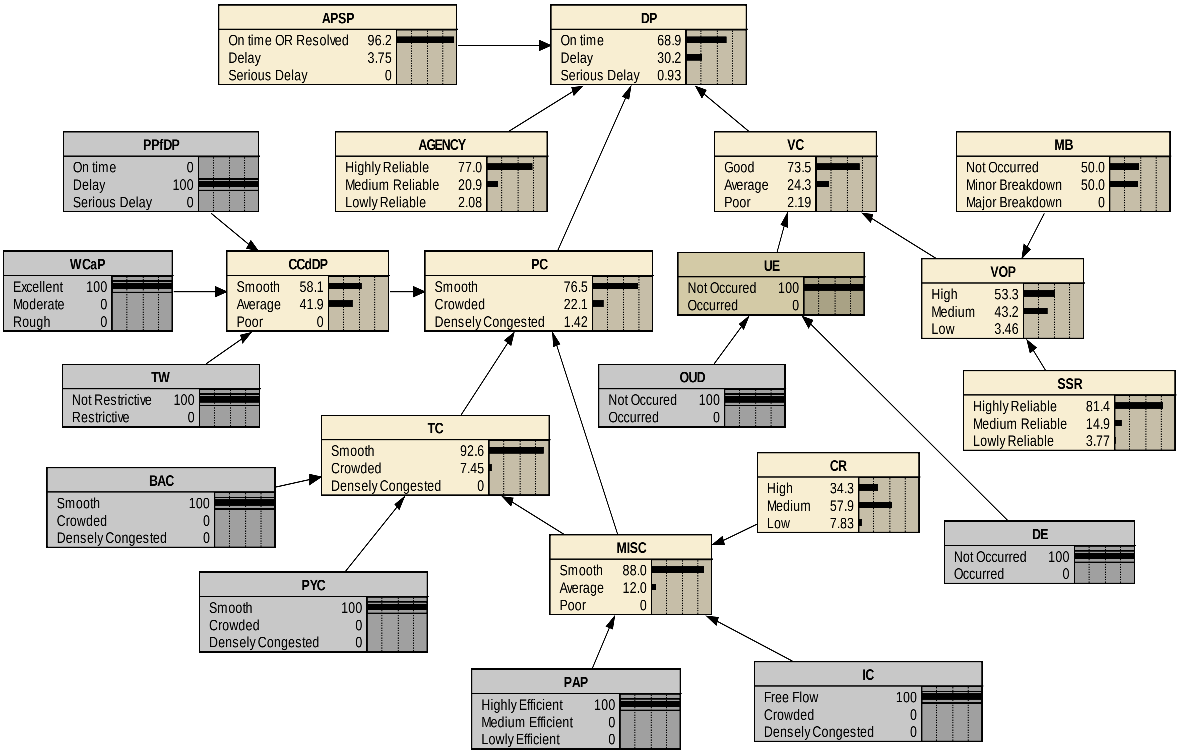

Figure 6.22: The probability set for the departure punctuality in test case 2

As a result, based on Figure 6.22, the probability of $Vessel_A$ departing from $Port_A$ on-time is 68.9% (i.e. test case 2).

6.3.4.3 Test Case 3: Operation with the Cut and Run Strategy

In test case 3, the same vessel is departing from the same port on 18/12/2013. In test case 3, the details of the real departure time of $Vessel_A$ from $Port_A$ are listed in Table 6.18 and the datasets for test case 3 are shown in Table 6.19.

Table 6.18: Real departure time of $Vessel_A$ at $Port_A$ for test case 3

Real Arrival Time at $Port_A$	Date	Time	Strategy Implementation
ETD from berth	18/12/13	2300	Cut and Run
ATD from berth	18/12/13	2254	

Table 6.19: The datasets for departure punctuality for test case 3

No	Root Nodes	Measurement	Data			
1	APSP	ΔArrival = ATA– ETA	+14 hours and 30 minutes			
2	WCaP	Beaufort Number	3			
3	PPfDP	Initiated Time	Before ETD			
4	TW	Hours Delay	No delay			
5	BAC	Berth Occupancy Ratio (%)	57.45%			
6	PYC	Yard Utilisation (%)	54.79%			
7	PAP	Port Clearance Issuance Time	Before ETD			
8	IC	Truck Turnaround Time (Minutes)	24.20 minutes			
9	MB	Delayed Time due to breakdown and repair	No Breakdown			
10	SSR	Reliability (Qualitative)	States / Evaluators	High	Medium	Low
			Evaluator 1	70%	25%	5%
			Evaluator 2	80%	20%	0%
			Evaluator 3	70%	30%	0%
11	DE	Occurrence	Not Occur			
12	CR	Chapter 3	High	0.3429		
			Medium	0.5788		
			Low	0.0783		
13	AGENCY	Chapter 4	High	0.7700		
			Medium	0.2092		
			Low	0.0208		

By using the same technique as shown in test case 1, the unconditional probabilities of all root nodes for test case 3 are assessed (Appendix D-4). The sets for all the root nodes are obtained and shown in Table 6.20. These sets will be used for evaluation of the unconditional probabilities distributions for the root nodes for test case 3.

Table 6.20: The belief degrees of all root nodes (departure test case 3)

No.	Root Nodes	Sets
1	APSP	{(On-time, 0.3958), (Delay, 0.6042), (Serious Delay, 0)}
2	WCaP	{(Excellent, 1), (Moderate, 0), (Rough, 0)}
3	PPfDP	{(On-time, 1), (Delay, 0), (Serious Delay, 0)}
4	TW	{(Not Restrictive, 1), (Restrictive, 0)}
5	BAC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
6	PYC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
7	PAP	{(Highly Efficient, 1), (Medium Efficient, 0), (Lowly Efficient, 0)}
8	IC	{(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}
9	MB	{(No Breakdown, 1), (Minor Breakdown, 0), (Major Breakdown, 0)}
10	SSR	{(Highly Reliable, 0.7759), (Medium Reliable, 0.2116), (Lowly Reliable, 0.0125)}
11	DE	{(Not Occurred, 1), (Occurred, 0)}
12	CR	{(Highly Reliable, 0.3429), (Medium Reliable, 0.5788), (Lowly Reliable, 0.0783)}
13	AGENCY	{(Highly Reliable, 0.7700), (Medium Reliable, 0.2092), (Lowly Reliable, 0.0208)}

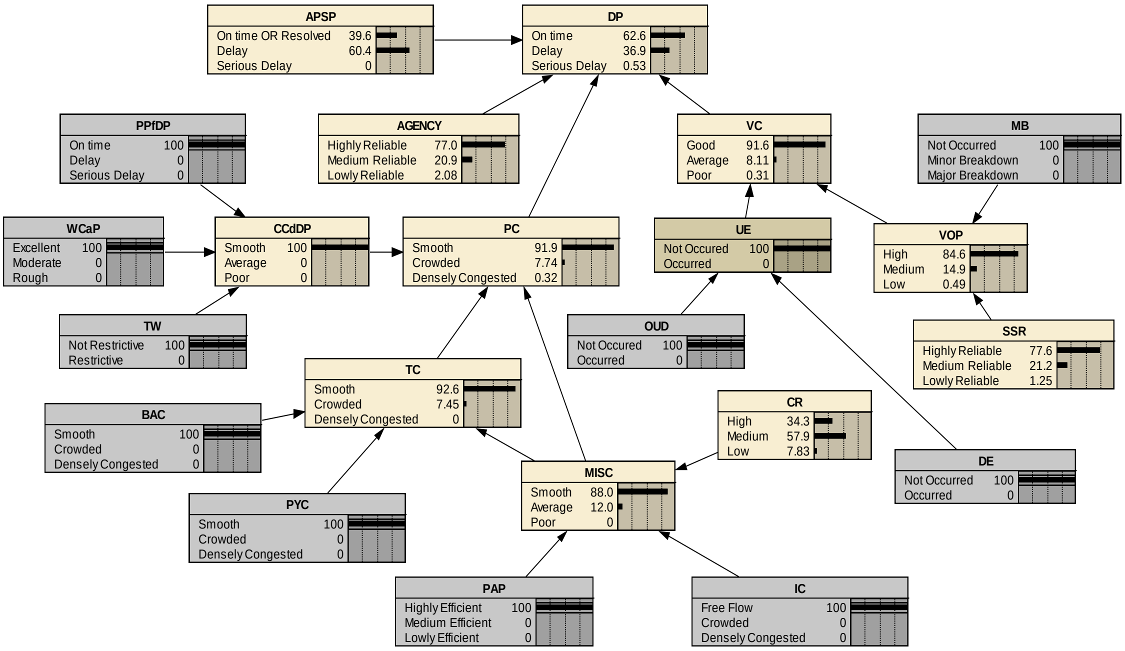

Figure 6.23: The probability set for the departure punctuality in test case 3

As a result, based on Figure 6.23, the probability of $Vessel_A$ departing from $Port_A$ on-time is 62.6% (i.e. test case 3).

6.3.5 Model and Result Validation (*Final Step*)

For the validation through SA, test case 1 is chosen and the two Axioms as described in Sub-section 5.3.6 are used. The degree of membership for the highest preference state of an input node is decreased by 0.1 and simultaneously the degree of membership for the lowest preference state is increased by 0.1, as shown in Table 6.21. The "on-time" value is assessed by the model in Figure 6.21. Since the assessed "on-time" value is smaller than the actual one (i.e. 0.594 "on-time"), the results are aligned with Axiom 1.

Table 6.21: Decrement of values of the root node by 0.1 (departure punctuality model)

Input Node	Degree of membership for the highest preference state of an input node is decreased by 0.1.	"On-time" value
APSP	{(On-time, 0.9), (Delay, 0), (Serious Delay, 0.1)}	0.535
WCaP	{(Excellent, 0.9), (Moderate, 0), (Rough, 0.1)}	0.572
PPfDP	{(On-time, 0.9), (Delay, 0), (Serious Delay, 0.1)}	0.578
TW	{(Not Restricted, 0.2333), (Restricted, 0.7667)}	0.557
BAC	{(Smooth, 0.9), (Crowded, 0), (Densely Congested, 0.1)}	0.567
PYC	{(Smooth, 0.9), (Crowded, 0), (Densely Congested, 0.1)}	0.570
PAP	{(Highly Efficient, 0.9), (Medium Efficient, 0), (Lowly Efficient, 0.1)}	0.570
IC	{(Smooth, 0.9), (Crowded, 0), (Densely Congested, 0.1)}	0.577
MB	{(No Breakdown, 0.9), (Minor Breakdown, 0), (Major Breakdown, 0.1)}	0.554

SSR	{(High Competent, 0.7413), (Medium Competent, 0.1587), (Low Competent, 0.1)}	0.567
DE	{(Less Possibility, 0.9), (More Possibility, 0.1)}	0.535
OUD	{(Less Possibility, 0.9), (More Possibility, 0.1)}	0.535
CR	{(Highly Reliable, 0.2429), (Medium Reliable, 0.5788), (Lowly Reliable, 0.1783)}	0.583
AGENCY	{(Highly Reliable, 0.6700), (Medium Reliable, 0.2092), (Lowly Reliable, 0.1208)}	0.539

In Axiom 2, the degree of membership for the highest preference state of an input node is decreased by 0.1, 0.2 and 0.3 respectively and simultaneously the degree of membership for the lowest preference state is increased by 0.1, 0.2 and 0.3 respectively. The "on-time" values are assessed by Figure 6.21 and the results are tabulated in Table 6.22 and shown in Figure 6.24. The obtained results are in harmony with Axiom 2.

Table 6.22: The "on-time" values due to the variation of belief degrees of the 14 input nodes (departure punctuality model)

Assessment Criteria	On-time values due to decreasing the degree of membership for the highest preference state of an input node by 0.1, 0.2 and 0.3.		
	0.1 (Alteration *k*)	**0.2 (Alteration *l*)**	**0.3 (Alteration *m*)**
APSP	0.535	0.475	0.416
WCaP	0.572	0.550	0.528
PPfDP	0.578	0.562	0.546
TW	0.557	0.519	0.482
BAC	0.567	0.541	0.514
PYC	0.570	0.546	0.523
PAP	0.570	0.545	0.521
IC	0.577	0.560	0.543
MB	0.554	0.514	0.474
SSR	0.567	0.540	0.513
DE	0.535	0.475	0.416
OUD	0.535	0.475	0.416
CR	0.583	0.573	0.562
AGENCY	0.539	0.483	0.428

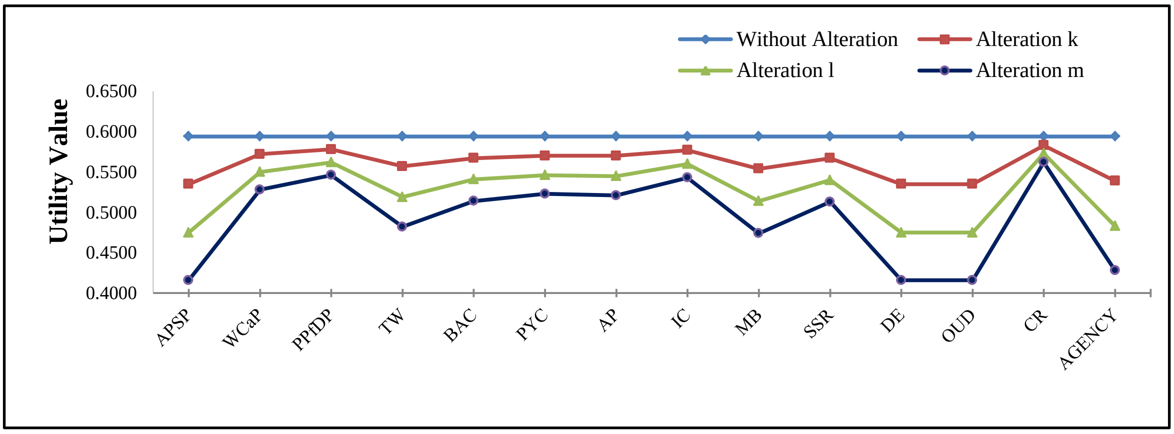

Figure 6.24: Representation of Axiom 1 and 2 (departure punctuality model)

In order to test the accuracy of the model, the model is validated by using prediction error. Based on Figure 6.21 (i.e. test case 1), the outcome of the model (i.e. the marginal probability of $Vessel_A$ departing from $Port_A$ on-time) was evaluated as 59.4%. Based on the real record obtained from the ship manager of $Vessel_A$ (i.e. Table 6.9), the Δ departure of $Vessel_A$ from $Port_A$ is +8 hours and 42 minutes and can be considered to be 63.8% on-time ((24 hours–8.7 hours) / (24 hours–0 hours) × 100%). The prediction error is calculated as 4.4% (i.e. 59.4% - 63.8%). As a result, the outcome of test case 1 is considered to be reasonable (i.e. less than 10%) and it can be concluded that the developed result in this chapter is reasonable. The summary of prediction errors for test cases 1, 2 and 3 is presented in Table 6.23.

Table 6.23: Prediction errors for test cases 1, 2 and 3 (departure punctuality model)

Test	Model Output	Real Departure Time	Difference	Reasonable
Test case 1	59.4%	63.8%	4.4%	Yes
Test case 2	68.9%	67.9%	1%	Yes
Test case 3	62.6%	100%	37.4%	No. (The "cut and run" strategy has been implemented to solve the arrival delay.) It will be discussed in detail in Section 6.4.

6.4 Results and Discussion

Within this chapter, a model for assessing the departure punctuality of a vessel by using an FBBN model is developed. Similar to the arrival punctuality model, the proposed model is highly sensitive. The departure punctuality value is not fixed and it will change with its associated criteria. In order to test the most significant events, the degree of membership for the lowest preference state of each criterion is assigned as 100%. Based on Figure 6.21, the marginal probabilities of $Vessel_A$ departing from $Port_A$ on-time are evaluated and shown in Table 6.24.

Table 6.24: Departure punctuality's Value of $Vessel_A$ at different situations

Criteria	Description of Event (Change of Event)	On-time	Rank
1	Arrival punctuality is 100% serious delay	0%	1
2	Weather condition at port is 100% rough	43.2%	10
3	Pilotage operation punctuality is 100% serious delay	37.4%	8
4	Tidal window is 100% restrictive	47%	11
5	Berthing area condition is 100% densely congested	32.6%	4
6	Port yard condition is 100% densely congested	35.5%	7
7	Administration process is 100% low efficiency	35%	6
8	Inland corridors is 100% densely congested	42.5%	9
9	Machinery breakdown is 100% major	19.4%	3

10	Ship's staff are 100% low reliability	33.7%	5
11	Dangerous events occur	0%	1
12	Other unexpected delays occur	0%	1
13	Country reliability is 100% low reliability	51.1%	12
14	Agency is 100% low reliability	11.6%	2

As shown in Table 6.24, the model output is more sensitive to the arrival punctuality, dangerous events and other unexpected delays, respectively. The reliability of agency is ranked 2nd and a vessel's machinery breakdown during her port stay is ranked 3rd. As a result, by guaranteeing the arrival punctuality, minimising the possibility of an unforeseen event, enhancing the reliability and capability of an agency, and minimising the possibility of a vessel's machinery breakdown during her port stay, the probability of $Vessel_A$ departing from $Port_A$ on-time is enhanced.

6.4.1 Control Options

6.4.1.1 Arrival Delay from the Previous Voyage

Based on Tables 6.21, 6.22 and 6.24, the influence of the arrival punctuality of $Vessel_A$ at $Port_A$ on her departure punctuality from that port was proven. If the arrival punctuality of $Vessel_A$ to $Port_A$ is assessed as 100% serious delay, the probability of $Vessel_A$ departing from $Port_A$ on-time is 0%. As a result, to enhance the departure punctuality of a vessel, a ship manager should ensure that the vessel under his/her supervision always arrives on-time to a port of call. This objective can be achieved by having efficient process management (i.e. agency) and excellent coordination between a vessel and a port.

During the validation process by using a prediction error, the results for test cases 1, 2, and 3 have been compared with the real departure time. The results of test cases 1 and 2 are found to be reasonable since both prediction errors are less than 10% or ±2.4 hours (i.e. 4.4% and 1% respectively). However, the prediction error for test case 3 is evaluated as 37.4% due to the implementation of a 'cut and run' strategy to solve the arrival delay. A 'cut and run' strategy is defined as: loading operations need to be stopped urgently so that the vessel can leave the port at once, even if there are still some containers on the stack waiting to be loaded (Notteboom, 2006). This strategy is commonly used to avoid unproductive port time caused by low tide situations or to cut time of operations due to prior arrival delays.

6.4.1.2 Unforeseen Events

Based on the analysis results obtained from arrival and departure punctuality models, it is noteworthy to mention that unforeseen events (i.e. dangerous events and other unexpected events) have a significant effect on both arrival and departure punctuality models. Based on Table 6.24, if unforeseen events occur during the port stay of $Vessel_A$, the probability of $Vessel_A$ departing from $Port_A$ on-time is nil. The unforeseen events and their measures have been explained in Sub-sub-section 5.5.1.2.

6.4.1.3 Agency

Based on Table 6.24, agency is one of the most significant criteria for assuring the departure punctuality of $Vessel_A$. The probability of $Vessel_A$ departing from $Port_A$ on-time is 11.6%, if the reliability value of the agency at $Port_A$ is 100% low. As a result, agencies play important roles in the liner operation and they have to quickly and efficiently take care of all the regular routine tasks. The importance of agency has been discussed in Sub-section 5.2.4.

6.4.1.4 Machinery Breakdown

By analysing the results that have been obtained from the arrival and departure punctuality models, a vessel's machinery breakdown is a major incident that can lead to her delay. The issue of machinery breakdown and its measures have been explained in Sub-sub-section 5.5.1.4.

6.5 Conclusion

Within the previous chapter, an FBBN model was developed for analysing and predicting the arrival punctuality of a vessel. Based on the previous analysis (i.e. Chapter 5), the significant influence of departure punctuality from a port on the arrival punctuality to the other port is revealed.

Within this chapter, a departure punctuality model is developed by using a similar technique (i.e. the FBBN method). Firstly, the critical factors for analysing and predicting departure punctuality have been identified through an extensive literature review and consultation with domain experts. Secondly, the states of each node were defined by using literature and experts' opinion. Thirdly, a model for assessing departure punctuality was constructed using an FBBN technique. Fourthly, the strength of direct dependence of each child node to its associated parents was quantified by assigning each child node a CPT using the FRB and the symmetric model. Fifthly, unconditional probabilities are determined by assigning assessment grades to all the root nodes in the FBBN model. Finally, the outcomes of the proposed model were validated by using SA and prediction error.

Based on the SA, the most significant factors in the developed model for analysing the departure punctuality of a vessel were found to be the arrival punctuality at the same port, dangerous event and other unexpected delays during port stay. In conclusion, it is noteworthy to mention that a vessel's arrival and departure punctuality are two interactive factors in the form of knock-on effect of delays.

The developed models (i.e. Chapters 5 and 6) are capable of helping LSOs to assess the punctuality of the vessels under their supervision and implement suitable tactical strategies for guaranteeing their operations.

CHAPTER SEVEN

Conclusions and Further Research

Summary

This chapter concludes the research that has been conducted in the previous chapters. In addition, research limitations and recommendations for future research that require more effort for the enhancement of the developed model are summarised.

7.1 Conclusions

As a conclusion, the integrity of container liner shipping operations is extremely reliant on the reliability of its supply chain elements. Based on the demonstrated test cases, the developed models are found to feasible. In Chapter 3, the BEBR assessment has shown that the Malaysia is a fairly low risk country. The current account to GDP is found to be the most significant criterion in the BEBR assessment model. This BEBR assessment model can provide a useful model for LSOs to assess the BEBR value in a particular country. In Chapter 4, the ORC evaluation has shown that Agency 'B' is better than Agency 'A' in the context of the ORC value and ranking order. The financial capability is found to be the strong indicator for the ORC of an LSO. In addition, the ORC model output is more sensitive to the security and safety compliances. It can be assumed that the LSO which has a high level of ORC value may perform better in the CLSI. This ORC model is capable of helping LSOs to conduct self-evaluation of the ORC for enhancing their business sustainability and competitive advantage in the CLSI. Within Chapters 5 and 6, the results have shown that the vessel's arrival and departure punctuality are two interactive factors in the form of knock-on effects of delays. Within these chapters, the arrival and departure punctuality models have achieved the accuracy target. The arrival and departure punctuality models are capable of helping LSOs to assess the punctuality of the vessels under their supervision and implement suitable tactical strategies for guaranteeing their operations. Industrial validation has revealed that the four developed models in this thesis are considerably valuable to the CLSI in assisting LSOs to assess the BEBR, the ORC and the punctuality of containerships (see Appendix E-1). The AHP, FL (i.e. FST and FRB), ER and BBN methods have been perfectly applied in the developed models. The frameworks and models that have been proposed in this research provide managerial insights for modelling and assessing complex systems dealing with both quantitative and qualitative criteria in a rational, reliable and transparent manner. In addition, these models have been developed in a generic sense so that they can be tailored for application in the

CLSI and other industrial sectors based on decision makers' preferences. Finally, these models provide researchers with an effective tool to make full use of the information generated at the lowest-level under high uncertainties.

7.2 Limitations and Recommendations for Future Research

The work presented in this thesis provides a comprehensive analysis related to risk, reliability and punctuality in container liner shipping operations. However, due to time constraints and various limitations, several important issues are not well covered and may need further investigation. Further research opportunities are identified as follows:

- In order to demonstrate the practicability of the methodological frameworks and assessment models, several real test cases were conducted. These test cases are geographically limited to one country and only focused on the Malaysian maritime industry. It does not appear to be possible to extend the findings obtained from these test cases to other geographical areas. Nevertheless, the developed methodologies and models for assessing the BEBR and the ORC of an LSO should be transferable to another area. For this reason, the application of these models could be extended across the geographical scope and cross-validation of the model could be conducted.
- Within Chapters 3 and 4, the AHP methodology was employed to assign a weight to each criterion using pair-wise comparisons. In order to conduct pair-wise comparisons, a number of domain experts with more than 15 years' experience in the CLSI (i.e. five persons in Chapter 3 and eight persons in Chapter 4) were employed. For further research the number of domain experts should be increased and they could be chosen from key positions in the CLSI (e.g. port state controls, shareholders, general managers, ship owners, ship charterers, ship's staff, maritime academia and governments). This additional judgement would contribute interesting findings and further improve the applicability of the newly developed approach.
- From the test cases, for the assessment of criteria both quantitative and qualitative data are used. Quantitative data is considered as a prime input and can be obtained from reliable databases such as the ICRG, Trading Economics, World Bank, Federal Reserve, Corruption Perception Index, Total Economy, *etc*. However, in a situation where there is a lack of existing data and imprecise information about past events, some necessary criteria are assessed by using qualitative data rather than quantitative data. For the process of qualitative data collection, subjective judgements made by domain experts (i.e. evaluators) were used. A group of three experts was selected based on their 15 to 20 years' experiences and expertise in the Malaysian liner shipping industry. Most of

the data obtained from these experts are classified as private and confidential. As a result, it has not been possible to reveal the identities of these experts within this thesis. For future research, the transparency of the experts' identities should be encouraged, and the number of assessors should be increased. These enhancements would produce better empirical results from the newly developed frameworks.

- Within Chapter 4, a methodology was developed that is capable of understanding and evaluating the current performance of the ORC of an LSO. However, it is noteworthy that different LSOs will produce different outcomes based on their performance. For this reason, it would useful if an ideal benchmark could be established based on a comprehensive analysis within individual LSOs. As a result, realistically, LSOs would able to achieve their targeted benchmark.
- The results obtained from the developed models provided useful information for developing preventive measures, improvement strategies and tactical solutions. Based on test cases, several strategies are briefly discussed in each technical chapter. For future research, a decision-making analysis could be conducted in order to choose the most preferred strategy associated with problems encountered. Several methods could be employed such as Multiple Attribute Group Decision Making (MAGDM), Technique for Order Preference by Similarity to ideal Situation (TOPSIS), and Decision-Making Trial and Evaluation Laboratory (DEMATEL). The application of these methods would improve the accuracy of a decision-making process.
- The past decade has seen the rapid development of risk and reliability managements in the maritime transportation industry. The application of decision-making methods such as AHP, FST, FRB, ER and BBN in this research has provided managerial insights for modelling and assessing complex systems dealing with both quantitative and qualitative criteria in a rational, reliable and transparent manner. However, the evaluation of criteria which are described by multiple linguistic terms and the difficulty associated with generating membership functions have been considered as drawbacks in developing fuzzy-based methodologies. Therefore, the consideration of other methods such as Artificial Neural Network (ANN), Genetic Algorithms and System Dynamic (SD) capable of resolving the problems encountered and simplifying the calculation and construction in risk assessment could be proposed.
- Within the test cases conducted in Chapters 5 and 6, the conditional probability distributions and unconditional probability distributions are constructed specifically for $Vessel_A$ at/from $Port_A$. It seems that it is not possible to apply the construction of these conditional and unconditional probability distributions to other vessel operations due to the difference of size of vessel and port specifications. Nevertheless, the developed

models and methodologies for analysing vessel punctuality can be applied to other vessel operations. For this reason, the application of these models could be extended across the operational area, and cross-validation of the model could be conducted.

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APPENDICES

APPENDIX A-1: The Aggregation Results for the Other Sub-sub-Criteria and Sub-Criteria in the BEBR Model

Table A-1.1: Aggregation result for micro political risks

Micro Political Risks	Very Low	Low	Medium	High	Very High	Weight
Customs-Related Risk	0.1208	0.2991	0.1269	0.4532	0	0.2757
Exchange Control Rules	0.0608	0.1825	0.3855	0.3712	0	0.4411
Excessive Bureaucracy in Trade	0.0586	0.1230	0.4612	0.3572	0	0.2832
Aggregation Result	**0.0674**	**0.1864**	**0.3417**	**0.4045**	**0**	**1**

Table A-1.2: Aggregation result for macroeconomic risks

Macroeconomic Risks	Very Low	Low	Medium	High	Very High	Weight
GDP per Employed Person	0	0	0.38	0.62	0	0.2584
Current Account to GDP	1	0	0	0	0	0.2342
Exchange Rate Fluctuation	0.94	0.06	0	0	0	0.1819
Inflation Rate	0.8	0.2	0	0	0	0.1480
Industrial Production	0	0.37	0.63	0	0	0.1775
Aggregation Result	**0.5570**	**0.0923**	**0.1999**	**0.1508**	**0**	**1**

Table A-1.3: Aggregation result for microeconomic risks

Microeconomic Risks	Very Low	Low	Medium	High	Very High	Weight
Labour Cost	0	0.1509	0.4096	0.4395	0	0.2667
Freight Rate Fluctuation	0	0	0.6367	0.3100	0.0533	0.3099
Bunker Price Fluctuation	0	0.1203	0.5301	0.3496	0	0.4234
Aggregation Result	**0**	**0.0785**	**0.5584**	**0.3504**	**0.0127**	**1**

Table A-1.4: Aggregation result for labour quality and availability in the market

Labour Quality and Availability in the Market	Very Low	Low	Medium	High	Very High	Weight
Labour Quality	0	0.1522	0.4934	0.3544	0	0.6538
Labour Availability	0	0.2069	0.6516	0.1415	0	0.3462
Aggregation Result	**0**	**0.1519**	**0.5665**	**0.2816**	**0**	**1**

Table A-1.5: Aggregation result for geophysical disasters

Geophysical Disasters	Very Low	Low	Medium	High	Very High	Weight
Earthquake	0.2677	0.5419	0.1904	0	0	0.4438
Tsunami	0.2690	0.5038	0.2272	0	0	0.4438
Ash from Volcanic Eruption	0.6322	0.3103	0.0575	0	0	0.1124
Aggregation Result	**0.2889**	**0.5303**	**0.1808**	**0**	**0**	**1**

Table A-1.6: Aggregation result for meteorological disasters

Meteorological Disasters	Very Low	Low	Medium	High	Very High	Weight
Severe Storms	0	0.1764	0.5075	0.2573	0.0588	0.6137
Tornadoes	0.4692	0.4428	0.0880	0	0	0.3863
Aggregation Result	**0.1262**	**0.2722**	**0.3872**	**0.1746**	**0.0398**	**1**

Table A-1.7: Aggregation result for hydrological disasters

Hydrological Disasters	**Very Low**	**Low**	**Medium**	**High**	**Very High**	**Weight**
Sea Surges	0.3863	0.5285	0.0852	0	0	0.5000
Coastal Flood	0.1829	0.3415	0.4146	0.0610	0	0.5000
Aggregation Result	**0.2799**	**0.4594**	**0.2340**	**0.0267**	**0**	**1**

Table A-1.8: Aggregation result for climatological disasters

Geophysical Disasters	**Very Low**	**Low**	**Medium**	**High**	**Very High**	**Weight**
Extreme Temperatures	0.1786	0.5833	0.1786	0.0595	0	0.3684
Climate Change	0.1178	0.6171	0.1767	0.0884	0	0.3858
Haze	0.1747	0.5428	0.2825	0	0	0.2458
Aggregation Result	**0.1352**	**0.6343**	**0.1813**	**0.0492**	**0**	**1**

Table A-1.9: Aggregation result for biological disasters

Biological Disasters	**Very Low**	**Low**	**Medium**	**High**	**Very High**	**Weight**
Insect Infestation	0.2651	0.6171	0.1178	0	0	0.3462
Epidemics/Pandemics Diseases	0.6320	0.3133	0.0547	0	0	0.6538
Aggregation Result	**0.5391**	**0.3992**	**0.0617**	**0**	**0**	**1**

Table A-1.10: Aggregation result for economic risks

Economic Risks	**Very Low**	**Low**	**Medium**	**High**	**Very High**	**Weight**
Macroeconomic Risks	0.5570	0.0923	0.1999	0.1508	0	0.6260
Microeconomic Risks	0	0.0785	0.5584	0.3504	0.0127	0.3740
Aggregation Result	**0.3817**	**0.0854**	**0.3192**	**0.2106**	**0.0031**	**1**

Table A-1.11: Aggregation result for social risks

Social Risks	**Very Low**	**Low**	**Medium**	**High**	**Very High**	**Weight**
Labour Quality and Availability in the Market	0	0.1519	0.5665	0.2816	0	0.3862
Working Cultures	0	0.1471	0.6141	0.2388	0	0.2022
Reputational Risk	0	0.2756	0.6114	0.0854	0.0276	0.2097
Religion and Ethnic Tension	0	0.67	0.33	0	0	0.2019
Aggregation Result	**0**	**0.2531**	**0.5783**	**0.1643**	**0.0043**	**1**

Table A-1.12: Aggregation result for natural hazards

Natural Hazards	**Very Low**	**Low**	**Medium**	**High**	**Very High**	**Weight**
Geophysical Disasters	0.2889	0.5303	0.1808	0	0	0.3336
Meteorological Disasters	0.1262	0.2722	0.3872	0.1746	0.0398	0.1985
Hydrological Disasters	0.2799	0.4594	0.2340	0.0267	0	0.1286
Climatological Disasters	0.1352	0.6343	0.1813	0.0492	0	0.1990
Biological Disasters	0.5391	0.3992	0.0617	0	0	0.1403
Aggregation Result	**0.2489**	**0.5069**	**0.1986**	**0.0392**	**0.0064**	**1**

APPENDIX B-1: The Construction of the Membership Functions and *If-Then* Rules for Evaluating Quantitative Criteria in the ORC Model

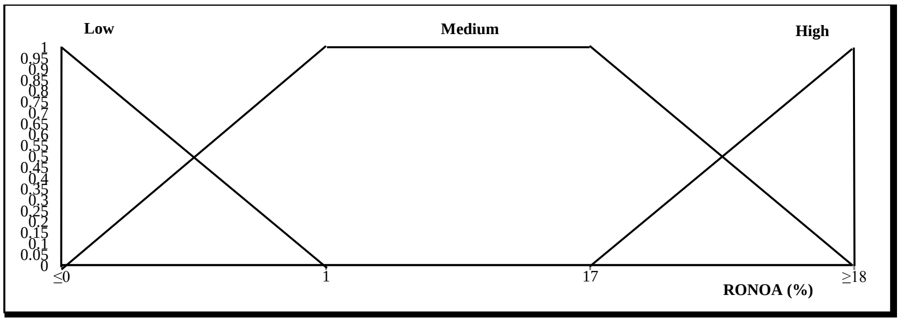

Figure B-1.1: Membership functions for the node "PROFIT"

Profitability ratio: For assessing the profitability ratio of an LSO, the Return on Net Operating Assets (RONOA) can be measured (PWC, 2012). RONOA can be calculated as follows:

$$RONOA = \frac{Earning\ Before\ Interest\ and\ Tax\ (EBIT)}{Net\ of\ Operating\ Asset}$$

As shown in Figure B-1.1, based on PWC (2012), the best performing RONOA by the global CLSI is 18% and above. Consequently, the reliability grade for the RONOA with value of 18% and above can be considered as highly reliable, between 1% and 17% as medium reliable and 0% and less as lowly reliable.

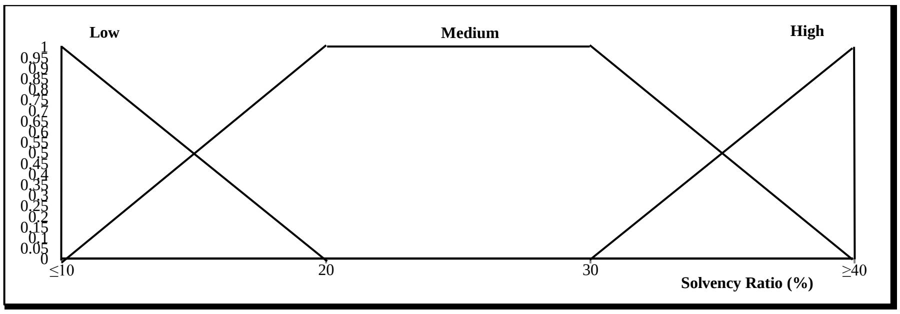

Figure B-1.2: Membership functions for the node "FS"

Finance structure ratio: For assessing the finance structure ratio, a solvency ratio can be estimated by dividing shareholder's equity by total assets (PWC, 2012). Solvency ratio can be calculated as follows:

$$Solvency\ Ratio = \frac{Shareholders'Equity}{Total\ Assets}$$

As shown in Figure B-1.2, based on PWC (2012), the solvency ratio performed by LSOs of 40% and above is considered as stable. Consequently, the reliability grade for solvency ratio with a value of 40% and above can be considered as highly reliable, between 20% and 30% as medium reliable and 10% and below as lowly reliable.

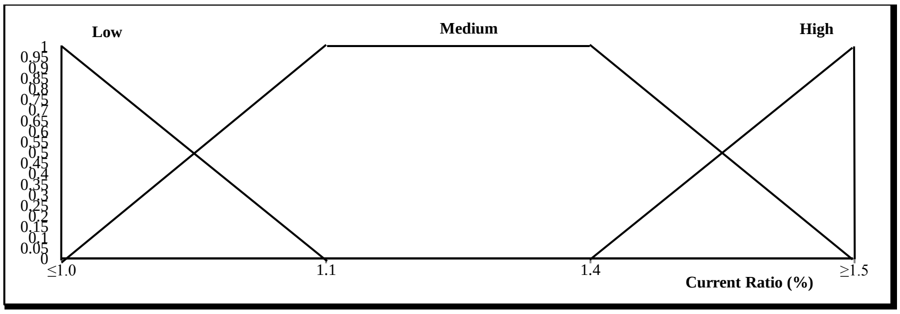

Figure B-1.3: Membership functions for the node “LIQUIDITY”

Liquidity ratio: For assessing the liquidity ratio of an LSO, the current ratio can be estimated as follows (PWC, 2012):

$$Current\ Ratio = \frac{Current\ Assets}{Current\ Liabilities}$$

As shown in Figure B-1.3, based on PWC (2012), the current ratio performed by LSOs with value of 1.5 and above is considered as healthy and 1 and less as unhealthy. Consequently, the reliability grade for current ratio of 1.5 and more can be considered as highly reliable, between 1.1 and 1.4 as medium reliable and 1 and below as lowly reliable.

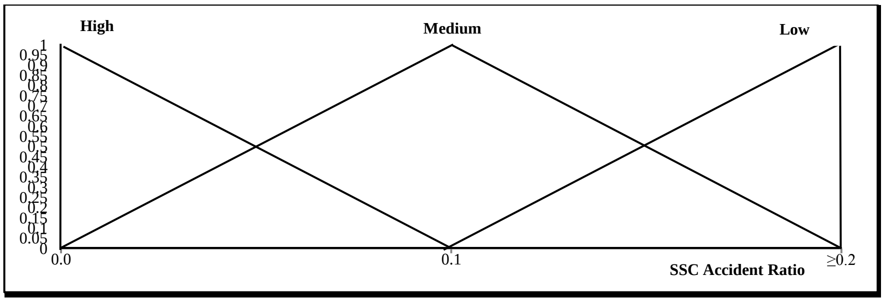

Figure B-1.4: Membership functions for the node “SSC”

Security and safety compliances (SSC): Based on domain experts’ opinion in the CLSI, the effectiveness of the LSO in complying with the security and safety regulations can be measured by accident ratio as follows:

$$SSC\ Accident\ Ratio = \frac{number\ of\ accident\ events}{total\ number\ of\ vessels}$$

As shown in Figure B-1.4 and based on domain experts' opinion in the CLSI, if the accident ratio related to security or safety events is 0 (e.g. for six previous months), the reliability of SSC can be assessed as high. In addition, within the same period, if the accident ratio related to security or safety events is 0.1 and 0.2 respectively, the reliability of SSC can be assessed as medium and low.

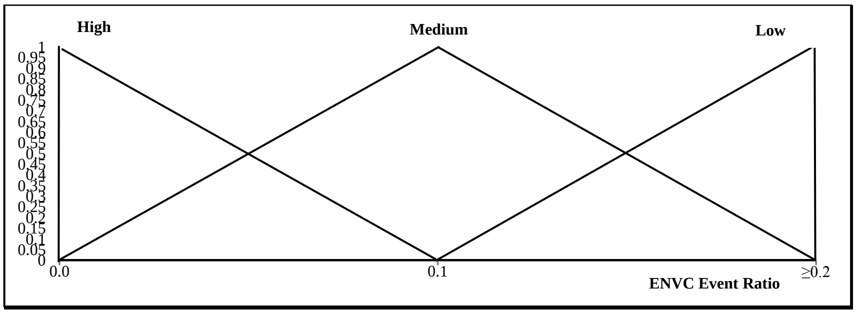

Figure B-1.5: Membership functions for the node "ENVC"

Environmental compliances (ENVC): Based on domain experts' opinion in the CLSI, the effectiveness of the LSO in complying with MARPOL regulations can be measured by event ratio as follows:

$$ENVC\ Event\ Ratio = \frac{number\ of\ pollution\ events}{total\ number\ of\ vessels}$$

As shown in Figure B-1.5 and based on domain experts' opinion in the CLSI, if the event ratio related to environmental compliances is 0 (e.g. for six previous months), the reliability of ENVC can be assessed as high. In addition, within the same period, if the event ratio related to environmental compliances is 0.1 and 0.2 respectively, the reliability of ENVC can be assessed as medium and low.

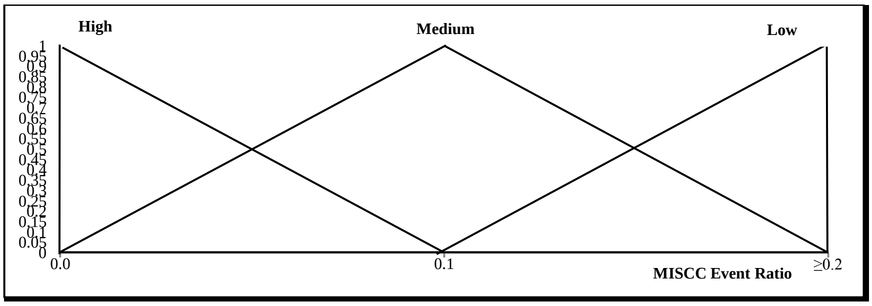

Figure B-1.6: Membership functions for the node "MISCC"

Miscellaneous compliances (MISCC): Based on domain experts' opinion in the CLSI, the effectiveness of the LSO in complying with miscellaneous compliances (i.e. compliances not related to security, safety and environmental regulations) can be measured by the event ratio as follows:

$$MISCC\ event\ Ratio = \frac{number\ of\ \ events}{total\ number\ of\ vessels}$$

As shown in Figure B-1.6 and based on domain experts' opinion in the CLSI, if the MISCC event ratio is 0 (e.g. for six previous months), the reliability of MISCC can be assessed as high. Within the same period, if the MISCC event ratio is 0.1 and 0.2 respectively, the reliability of MISCC can be assessed as medium and low.

In the ORC assessment model, *If-Then* rules are used to assess 9 quantitative criteria which are age of vessel, container management, schedule reliability, port reliability, communication with customers, response to customer enquiry, customer requirement understanding, claim responsiveness and documentation issuance. The measurement of each quantitative criterion is described as follows.

Age of vessel: The year in which a vessel has been built would indicate its performance, as a younger vessel would perform better at sea than older ones (Gaonkar *et al*., 2011). Age of vessel can be measured by using *If-Then* rules as follows:

If a vessel is 10 (or less) years old, *then* the reliability is high.
If a vessel is between 11-20 years old, *then* the reliability is medium.
If a vessel is 21 (or more) years old, *then* the reliability is low.
For n vessels, if k of them are 10 (or less) years old, l of them are between 11-20 years old and m of them are 21 (or more) years old
Then, $\frac{k}{n}$ = with high, $\frac{l}{n}$ = with medium, and $\frac{m}{n}$ = with low.

Container management: This criterion can be measured by calculating the percentage of difference between the vessel's estimated time arrival (ETA) at a local port stated in the original booking confirmation and the actual time arrival (ATA) (Drewry Shipping Consultants, 2013). Container management can be measured by using *If-Then* rules as follows:

If the difference between a vessel's ETA and ATA is within 1 day, *then* the reliability is high.
If the difference between a vessel's ETA and ATA is more than 1 and up to 2 days, *then* the reliability is medium.

If the difference between a vessel's ETA and ATA is more than 2 days, *then* the reliability is low.

For n vessels, if k of them are within 1 (or less) day, l of them are more than 1 and up to 2 days and m of them are more than 2 days

Then, $\frac{k}{n}$ = with high, $\frac{l}{n}$ = with medium, and $\frac{m}{n}$ = with low.

Schedule reliability: This criterion can be measured by calculating the difference between advertised vessel arrival (AVA) at a destination port against ATA (Drewry Shipping Consultants, 2013). Schedule reliability can be measured by using *If-Then* rules as follows:

If the difference between a vessel's AVA and ATA is within 1 day, *then* the reliability is high.

If the difference between a vessel's AVA and ATA is more than 1 and up to 2 days, *then* the reliability is medium.

If the difference between a vessel's AVA and ATA is more than 2 days, *then* the reliability is low.

For n vessels, if k of them are within 1 (or less) day, l of them are more than 1 and up to 2 days and m of them are more than 2 days

Then, $\frac{k}{n}$ = with high, $\frac{l}{n}$ = with medium, and $\frac{m}{n}$ = with low.

Port reliability: This criterion can be assessed by evaluating container dwell times. Container dwell time is the amount of time a container remains stacked at a local port while awaiting shipment for export or onward transportation (Merckx, 2006). Container dwell time can be measured by using *If-Then* rules as follows:

If the container dwell time is within 4 days, *then* the reliability is high.

If the container dwell time is more than 4 and up to 7 days, *then* the reliability is medium.

If the container dwell time is more 7 days, *then* the reliability is low.

For n containers, if k of them are within 4 (or less) days, l of them are more than 4 and up to 7 days and m of them are more 7 days

Then, $\frac{k}{n}$ = with high, $\frac{l}{n}$ = with medium, and $\frac{m}{n}$ = with low.

Communication with customers: This criterion can be assessed by evaluating the activeness of customer relationship management (CRM) department communications with customers such as phone calls and personal visits. Communication with customers can be measured by using *If-Then* rules as follows:

If the communication session is done every week, *then* the reliability is high.
If the communication session is done every month, *then* the reliability is medium.
If the communication session is done less than once a month, *then* the reliability is low.
For n communication efforts, if k of them are done every week, l of them are done every month and m of them are done less than once a month
Then, $\frac{k}{n}$ = with high, $\frac{l}{n}$ = with medium, and $\frac{m}{n}$ = with low.

Responses to customer enquiry: This criterion can be assessed by evaluating the promptness of the CRM department to respond to customers' problems, suggestions and complaints. This criterion can be measured by using *If-Then* rules as follows:

If the response is done within 1 day, *then* the reliability is high.
If the response is done after more than 1 day and up to 2 days, *then* the reliability is medium.
If the response is done after more than 2 days, *then* the reliability is low.
For n responses, if k of them are done within 1 day, l of them are done after more than 1 day and up to 2 days and m of them are done after more than 2 days
Then, $\frac{k}{n}$ = with high, $\frac{l}{n}$ = with medium, and $\frac{m}{n}$ = with low.

Customer requirement understanding: This criterion can be assessed by evaluating the activeness of the CRM department in understanding customer service requirements and expectations such as through survey and meeting. This criterion can be measured by using *If-Then* rules as follows:

If the session is done every 3 months, *then* the reliability is high.
If the session is done only once every 3-6 months, *then* the reliability is medium.
If the session is done only once every 6-12 months, *then* the reliability is low.
For n sessions, if k of them are done every three months, l of them are done within 3 - 6 months and m of them are done within 6-12 months
Then, $\frac{k}{n}$ = with high, $\frac{l}{n}$ = with medium, and $\frac{m}{n}$ = with low.

Claim responsiveness: This criterion can be assessed by measuring the difference between submissions of a claim by a customer and settlement date of the claim. This criterion can be measured by using *If-Then* rules as follows:

If the claim is settled within 3 months, *then* the reliability is high.

If the claim is settled after more than 3 months and up to 6 months, *then* the reliability is medium.

If the claim is settled after more than 6 months, *then* the reliability is low.

For n claims, if k of them are settled within 3 months, l of them are settled after more than 3 months and up to 6 months and m of them are settled after more than 6 months

Then, $\frac{k}{n}$ = with high, $\frac{l}{n}$ = with medium, and $\frac{m}{n}$ = with low.

Documentation issuances: Based on Drewry Shipping Consultants (2013), BL issuance's performance can be assessed by measuring the difference between submissions of SI and receiving date of confirmed BL. This criterion can be measured by using *If-Then* rules as follows:

If the BL is issued within 3 days, *then* the reliability is high.

If the BL is issued after more than 3 days and up to 5 days, *then* the reliability is medium.

If the BL is issued after more than 5 days, *then* the reliability is low.

For n issuances, if k of them are issued within 3 days, l of them are issued after more than 3 days and up to 5 days and m of them are issued after more than 5 days

Then, $\frac{k}{n}$ = with high, $\frac{l}{n}$ = with medium, and $\frac{m}{n}$ = with low.

APPENDIX B-2: The Assessment Value of the ORC of Agency 'B'

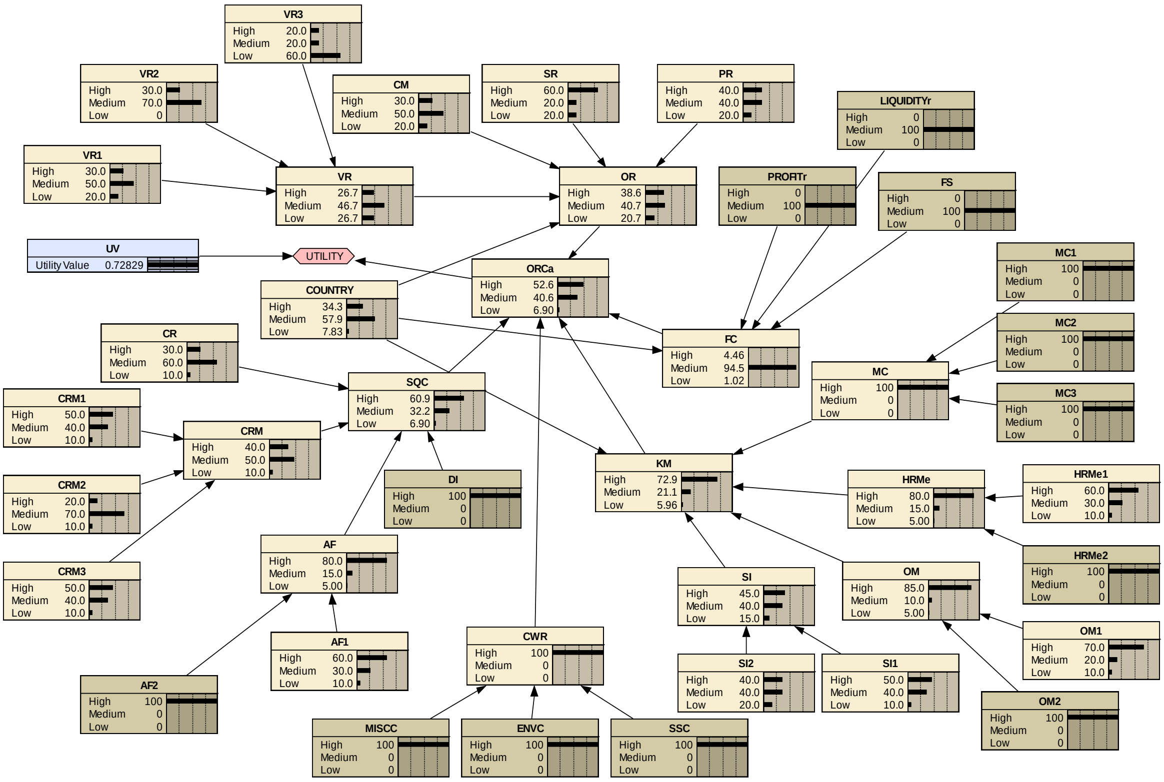

Figure B-2.1: The ORC value of Agency 'B'

APPENDIX C-1: The Tables of Consequents for Other Child Nodes in the Arrival Punctuality Model

Table C-1.1: Preference numbers for the child node "VC"

Vessel Condition States	Very Good	Good	Average	Poor	Very Poor
Preference Number	5	4	3	2	1

Table C-1.2: Consequents for the child node "VC"

Rules	*IF*			*THEN*				
	Maritime Passage	Vessel Operations	Unforeseen Events	Vessel Condition				
				E1	E2	E3	E4	Aggregation
1	Excellent	Highly Reliable	Not Occurred	5	5	5	5	5.0000
2	Excellent	Highly Reliable	Occurred	1	1	1	1	1.0000
3	Excellent	Medium Reliable	Not Occurred	4	5	4	3	3.9360
4	Excellent	Medium Reliable	Occurred	1	1	1	1	1.0000
5	Excellent	Lowly Reliable	Not Occurred	1	3	3	1	1.7321
6	Excellent	Lowly Reliable	Occurred	1	1	1	1	1.0000
7	Moderate	Highly Reliable	Not Occurred	5	4	4	3	3.9360
8	Moderate	Highly Reliable	Occurred	1	1	1	1	1.0000
9	Moderate	Medium Reliable	Not Occurred	3	3	3	2	2.7108
10	Moderate	Medium Reliable	Occurred	1	1	1	1	1.0000
11	Moderate	Lowly Reliable	Not Occurred	1	3	2	1	1.5651
12	Moderate	Lowly Reliable	Occurred	1	1	1	1	1.0000
13	Poor	Highly Reliable	Not Occurred	1	3	4	1	1.8612
14	Poor	Highly Reliable	Occurred	1	1	1	1	1.0000
15	Poor	Medium Reliable	Not Occurred	1	2	3	1	1.5651
16	Poor	Medium Reliable	Occurred	1	1	1	1	1.0000
17	Poor	Lowly Reliable	Not Occurred	1	2	2	1	1.4142
18	Poor	Lowly Reliable	Occurred	1	1	1	1	1.0000

Table C-1.3: Preference numbers for the child node "MPC"

Maritime Passage States	Excellent	Good	Moderate	Poor	Very Poor
Preference Number	5	4	3	2	1

Table C-1.4: Consequents for the child node "MPC"

Rules	*IF*			*THEN*				
	Canal	En-Route Weather Condition	En-Route Traffic Condition	Maritime Passage				
				E1	E2	E3	E4	Aggregation
1	No Problem OR Not Related	Excellent	Less Traffic	5	5	5	5	5.0000
2	No Problem OR Not Related	Excellent	Normal Traffic	5	5	4	4	4.4721
3	No Problem OR Not Related	Excellent	Dense Traffic	4	4	3	3	3.4641
4	No Problem OR Not Related	Moderate	Less Traffic	5	4	3	3	3.6628
5	No Problem OR Not Related	Moderate	Normal Traffic	4	4	3	3	3.4641
6	No Problem OR Not Related	Moderate	Dense Traffic	4	4	2	2	2.8284
7	No Problem OR Not Related	Rough	Less Traffic	2	4	4	1	2.3784
8	No Problem OR Not Related	Rough	Normal Traffic	2	4	3	1	2.2134
9	No Problem OR Not Related	Rough	Dense Traffic	1	3	3	1	1.7321
10	Missed Convoy	Excellent	Less Traffic	4	4	2	4	3.3636
11	Missed Convoy	Excellent	Normal Traffic	3	4	2	2	2.6321
12	Missed Convoy	Excellent	Dense Traffic	3	3	1	1	1.7321
13	Missed Convoy	Moderate	Less Traffic	3	3	4	2	2.9130
14	Missed Convoy	Moderate	Normal Traffic	3	3	3	2	2.7108
15	Missed Convoy	Moderate	Dense Traffic	2	3	3	1	2.0598
16	Missed Convoy	Rough	Less Traffic	2	3	1	1	1.5651
17	Missed Convoy	Rough	Normal Traffic	1	3	2	1	1.5651
18	Missed Convoy	Rough	Dense Traffic	1	1	1	1	1.0000

Table C-1.5: Preference numbers for the child node "VOP"

Vessel Operational Performances States	Highly Reliable	Fairly High Reliable	Medium Reliable	Fairly Medium Reliable	Lowly Reliable
Preference Number	5	4	3	2	1

Table C-1.6: Consequents for the child node "VOP"

Rules	*IF*			*THEN*				
	Ship's Staff	Vessel Speed	Machinery Breakdown	Vessel Operations				
				E1	E2	E3	E4	Aggregation
1	Highly Reliable	Planned Speed	Not Occurred	5	5	5	5	5.0000
2	Highly Reliable	Planned Speed	Minor Breakdown	4	4	2	4	3.3636
3	Highly Reliable	Planned Speed	Major Breakdown	1	2	1	1	1.1892
4	Highly Reliable	Slowed	Not Occurred	3	5	4	3	3.6628
5	Highly Reliable	Slowed	Minor Breakdown	2	4	3	2	2.6321
6	Highly Reliable	Slowed	Major Breakdown	1	2	1	1	1.1892
7	Highly Reliable	Disrupted	Not Occurred	1	1	1	1	1.0000
8	Highly Reliable	Disrupted	Minor Breakdown	1	1	1	1	1.0000
9	Highly Reliable	Disrupted	Major Breakdown	1	1	1	1	1.0000
10	Medium Reliable	Planned Speed	Not Occurred	5	4	3	4	3.9360
11	Medium Reliable	Planned Speed	Minor Breakdown	4	4	2	3	3.1302
12	Medium Reliable	Planned Speed	Major Breakdown	3	3	1	1	1.7321
13	Medium Reliable	Slowed	Not Occurred	4	4	3	4	3.7224
14	Medium Reliable	Slowed	Minor Breakdown	3	3	2	3	2.7108
15	Medium Reliable	Slowed	Major Breakdown	2	2	1	2	1.6818
16	Medium Reliable	Disrupted	Not Occurred	1	1	1	1	1.0000
17	Medium Reliable	Disrupted	Minor Breakdown	1	1	1	1	1.0000
18	Medium Reliable	Disrupted	Major Breakdown	1	1	1	1	1.0000
19	Lowly Reliable	Planned Speed	Not Occurred	4	3	2	1	2.2134
20	Lowly Reliable	Planned Speed	Minor Breakdown	3	3	1	1	1.7321
21	Lowly Reliable	Planned Speed	Major Breakdown	2	2	1	1	1.4142
22	Lowly Reliable	Slowed	Not Occurred	3	3	2	1	2.0598
23	Lowly Reliable	Slowed	Minor Breakdown	2	2	1	1	1.4142
24	Lowly Reliable	Slowed	Major Breakdown	1	1	1	1	1.0000

25	Lowly Reliable	Disrupted	Not Occurred	1	1	1	1	1.0000
26	Lowly Reliable	Disrupted	Minor Breakdown	1	1	1	1	1.0000
27	Lowly Reliable	Disrupted	Major Breakdown	1	1	1	1	1.0000

Table C-1.7: Preference numbers for the child node "UE"

Unforeseen Events States	Not Occurred	Average Possibility	Occurred
Preference Number	3	2	1

Table C-1.8: Consequents for the child node "UE"

Rules	*IF*		*THEN*				
	Dangerous Events	Other Unexpected Delays	Unforeseen Events				
			E1	E2	E3	E4	Aggregation
1	Not Occurred	Not Occurred	3	3	3	3	3.0000
2	Not Occurred	Occurred	1	1	1	1	1.0000
3	Occurred	Not Occurred	1	1	1	1	1.0000
4	Occurred	Occurred	1	1	1	1	1.0000

Table C-1.9: Preference numbers for the child node "SPEED"

Vessel Speed States	Planned Speed	Slow	Disrupted
Preference Number	3	2	1

Table C-1.10: Consequents for the child node "SPEED"

Rules	*IF*	*THEN*				
	Maritime Passage	Speed				
		E1	E2	E3	E4	Aggregation
1	Excellent	3	3	3	3	3.0000
2	Moderate	2	2	2	2	2.0000
3	Poor	1	1	1	1	1.0000

Table C-1.11: Preference numbers for the child node "PC"

Port Condition States	Smooth	Fairly Smooth	Crowded	Congested	Densely Congested
Preference Number	5	4	3	2	1

Table C-1.12: Consequents for the child node "PC"

Rules	*IF*			*THEN*				
	Port Channel Conditions	Terminal Conditions	Miscellaneous Factors	Port Condition				
				E1	E2	E3	E4	Aggregation
1	Smooth	Smooth	Smooth	5	5	5	5	5.0000
2	Smooth	Smooth	Average	5	5	4	5	4.7287
3	Smooth	Smooth	Poor	5	4	3	4	3.9360
4	Smooth	Crowded	Smooth	4	5	4	4	4.2295
5	Smooth	Crowded	Average	4	4	3	3	3.4641
6	Smooth	Crowded	Poor	4	4	2	3	3.1302
7	Smooth	Densely Congested	Smooth	4	4	3	3	3.4641
8	Smooth	Densely Congested	Average	3	4	2	2	2.6321
9	Smooth	Densely Congested	Poor	3	3	1	2	2.0598
10	Crowded	Smooth	Smooth	4	3	3	4	3.4641
11	Crowded	Smooth	Average	3	3	2	4	2.9130
12	Crowded	Smooth	Poor	2	3	1	3	2.0598
13	Crowded	Crowded	Smooth	2	3	2	3	2.4495
14	Crowded	Crowded	Average	2	2	2	3	2.2134
15	Crowded	Crowded	Poor	1	2	1	2	1.4142
16	Crowded	Densely Congested	Smooth	2	3	3	3	2.7108
17	Crowded	Densely Congested	Average	2	3	2	2	2.2134
18	Crowded	Densely Congested	Poor	1	2	1	1	1.1892
19	Densely Congested	Smooth	Smooth	2	3	2	2	2.2134
20	Densely Congested	Smooth	Average	2	3	2	2	2.2134
21	Densely Congested	Smooth	Poor	2	2	2	2	2.0000
22	Densely Congested	Crowded	Smooth	1	3	2	2	1.8612
23	Densely Congested	Crowded	Average	1	2	2	2	1.6818
24	Densely Congested	Crowded	Poor	1	2	1	2	1.4142

25	Densely Congested	Densely Congested	Smooth	1	2	1	2	1.4142
26	Densely Congested	Densely Congested	Average	1	2	1	1	1.1892
27	Densely Congested	Densely Congested	Poor	1	1	1	1	1.0000

Table C-1.13: Preference numbers for the child node "PCC"

Port Channel Conditions States	Smooth	Fairly Smooth	Crowded	Congested	Densely Congested
Preference Number	5	4	3	2	1

Table C-1.14: Consequents for the child node "PCC"

Rules	*IF*		*THEN*				
	Access Channel	Terminal Conditions	Port Channel Condition				
			E1	E2	E3	E4	Aggregation
1	Smooth	Smooth	5	5	5	5	5.0000
2	Smooth	Crowded	3	3	3	3	3.0000
3	Smooth	Densely Congested	1	1	1	1	1.0000
4	Average	Smooth	1	5	2	1	1.7783
5	Average	Crowded	1	3	1	1	1.3161
6	Average	Densely Congested	1	1	1	1	1.0000
7	Poor	Smooth	2	2	1	1	1.4142
8	Poor	Crowded	1	1	1	1	1.0000
9	Poor	Densely Congested	1	1	1	1	1.0000

Table C-1.15: Preference numbers for the child node "TC"

Terminal Condition States	Smooth	Fairly Smooth	Crowded	Congested	Densely Congested
Preference Number	5	4	3	2	1

Table C-1.16: Consequents for the child node "TC"

Rules	*IF*			*THEN*				
	Berthing Area Condition	Port Yard Condition	Miscellaneous Factors	Terminal Condition				
				E1	E2	E3	E4	Aggregation
1	Smooth	Smooth	Smooth	5	5	5	5	5.0000
2	Smooth	Smooth	Average	5	5	4	3	3.7606
3	Smooth	Smooth	Poor	4	4	3	1	2.6321
4	Smooth	Crowded	Smooth	4	4	4	3	3.7224
5	Smooth	Crowded	Average	4	4	3	2	3.1302
6	Smooth	Crowded	Poor	3	3	2	1	2.0598
7	Smooth	Densely Congested	Smooth	2	3	2	2	2.2134
8	Smooth	Densely Congested	Average	3	2	2	2	2.2134
9	Smooth	Densely Congested	Poor	2	2	1	1	1.4142
10	Crowded	Smooth	Smooth	4	4	3	3	3.4641
11	Crowded	Smooth	Average	4	3	2	2	2.6321
12	Crowded	Smooth	Poor	2	2	1	1	1.4142
13	Crowded	Crowded	Smooth	3	3	2	2	2.4495
14	Crowded	Crowded	Average	3	3	2	1	2.0598
15	Crowded	Crowded	Poor	2	2	1	1	1.4142
16	Crowded	Densely Congested	Smooth	2	3	1	1	1.5651
17	Crowded	Densely Congested	Average	2	2	1	1	1.4142
18	Crowded	Densely Congested	Poor	1	2	1	1	1.1892
19	Densely Congested	Smooth	Smooth	1	3	1	1	1.3161
20	Densely Congested	Smooth	Average	1	3	1	1	1.3161
21	Densely Congested	Smooth	Poor	1	2	1	1	1.1892
22	Densely Congested	Crowded	Smooth	1	3	1	1	1.3161
23	Densely Congested	Crowded	Average	1	2	1	1	1.1892
24	Densely Congested	Crowded	Poor	1	2	1	1	1.1892

25	Densely Congested	Densely Congested	Smooth	1	1	1	1	1.0000
26	Densely Congested	Densely Congested	Average	1	1	1	1	1.0000
27	Densely Congested	Densely Congested	Poor	1	1	1	1	1.0000

Table C-1.17: Preference numbers for the child node "MISC"

Miscellaneous Factors States	Smooth	Fairly Smooth	Average	Poor	Very Poor
Preference Number	5	4	3	2	1

Table C-1.18: Consequents for the child node "MISC"

Rules	*IF*			*THEN*				
	Administration Process	Inland Corridors	Country Reliability	MISC Factors States				
				E1	E2	E3	E4	Aggregation
1	Highly Efficient	Freely Flow	Highly Reliable	5	5	5	5	5.0000
2	Highly Efficient	Freely Flow	Medium Reliable	5	5	4	5	4.7287
3	Highly Efficient	Freely Flow	Lowly Reliable	4	5	3	4	3.9360
4	Highly Efficient	Crowded	Highly Reliable	4	5	4	4	4.2295
5	Highly Efficient	Crowded	Medium Reliable	4	5	3	4	3.9360
6	Highly Efficient	Crowded	Lowly Reliable	4	4	2	3	3.1302
7	Highly Efficient	Densely Congested	Highly Reliable	3	4	3	4	3.4641
8	Highly Efficient	Densely Congested	Medium Reliable	3	4	2	3	2.9130
9	Highly Efficient	Densely Congested	Lowly Reliable	2	4	1	2	2.0000
10	Medium Efficient	Freely Flow	Highly Reliable	4	4	3	4	3.7224
11	Medium Efficient	Freely Flow	Medium Reliable	4	4	2	4	3.3636
12	Medium Efficient	Freely Flow	Lowly Reliable	3	4	1	3	2.4495
13	Medium Efficient	Crowded	Highly Reliable	3	3	2	3	2.7108
14	Medium Efficient	Crowded	Medium Reliable	3	3	2	3	2.7108
15	Medium Efficient	Crowded	Lowly Reliable	3	3	1	3	2.2795
16	Medium Efficient	Densely Congested	Highly Reliable	3	2	3	3	2.7108
17	Medium Efficient	Densely Congested	Medium Reliable	3	2	2	2	2.2134

18	Medium Efficient	Densely Congested	Lowly Reliable	2	2	1	2	1.6818
19	Lowly Efficient	Freely Flow	Highly Reliable	2	3	2	1	1.8612
20	Lowly Efficient	Freely Flow	Medium Reliable	2	2	2	1	1.6818
21	Lowly Efficient	Freely Flow	Lowly Reliable	2	2	2	1	1.6818
22	Lowly Efficient	Crowded	Highly Reliable	1	2	2	1	1.4142
23	Lowly Efficient	Crowded	Medium Reliable	1	2	2	1	1.4142
24	Lowly Efficient	Crowded	Lowly Reliable	1	2	1	1	1.1892
25	Lowly Efficient	Densely Congested	Highly Reliable	1	2	1	1	1.1892
26	Lowly Efficient	Densely Congested	Medium Reliable	1	2	1	1	1.1892
27	Lowly Efficient	Densely Congested	Lowly Reliable	1	1	1	1	1.0000

Table C-1.19: Preference numbers for the child node "ACC"

Access Channel States	Smooth	Fairly Smooth	Average	Poor	Very Poor
Preference Number	5	4	3	2	1

Table C-1.20: Consequents for the child node "ACC"

Rules	***IF***			***THEN***				
	Weather Condition at Port	**Pilotage Punctuality**	**Tidal Window**	**Access Channel**				
				E1	**E2**	**E3**	**E4**	**Aggregation**
1	Excellent	On-time	Not Restrictive	5	5	5	5	5.0000
2	Excellent	On-time	Restrictive	2	3	2	1	1.8612
3	Excellent	Delay	Not Restrictive	5	5	4	3	4.1618
4	Excellent	Delay	Restrictive	1	2	2	1	1.4142
5	Excellent	Serious Delay	Not Restrictive	1	2	2	1	1.4142
6	Excellent	Serious Delay	Restrictive	1	2	1	1	1.1892
7	Moderate	On-time	Not Restrictive	4	4	4	3	3.7224
8	Moderate	On-time	Restrictive	1	2	1	1	1.1892
9	Moderate	Delay	Not Restrictive	4	4	3	1	2.6321
10	Moderate	Delay	Restrictive	1	2	1	1	1.1892

11	Moderate	Serious Delay	Not Restrictive	1	2	2	1	1.4142
12	Moderate	Serious Delay	Restrictive	1	2	1	1	1.1892
13	Rough	On-time	Not Restrictive	2	3	3	1	2.0598
14	Rough	On-time	Restrictive	2	2	1	1	1.4142
15	Rough	Delay	Not Restrictive	2	3	2	1	1.8612
16	Rough	Delay	Restrictive	1	1	1	1	1.0000
17	Rough	Serious Delay	Not Restrictive	1	1	1	1	1.0000
18	Rough	Serious Delay	Restrictive	1	1	1	1	1.0000

APPENDIX C-2: The CPTs for All Other Child Nodes in the Arrival Punctuality Model

Table C-2.1: CPT for the child node "VC"

Rules	*IF*			*THEN*			
				Vessel Condition			
	Maritime Passage	**Vessel Operations**	**Unforeseen Events**	**Expert Judgements (Average Output)**	**CPT**		
					Good	**Average**	**Poor**
1	Excellent	Highly Reliable	Not Occurred	5.0000	1	0	0
2	Excellent	Highly Reliable	Occurred	1.0000	0	0	1
3	Excellent	Medium Reliable	Not Occurred	3.9360	0.4680	0.5320	0
4	Excellent	Medium Reliable	Occurred	1.0000	0	0	1
5	Excellent	Lowly Reliable	Not Occurred	1.7321	0	0.366	0.634
6	Excellent	Lowly Reliable	Occurred	1.0000	0	0	1
7	Moderate	Highly Reliable	Not Occurred	3.9360	0.4680	0.5320	0
8	Moderate	Highly Reliable	Occurred	1.0000	0	0	1
9	Moderate	Medium Reliable	Not Occurred	2.7108	0	0.8554	0.1446
10	Moderate	Medium Reliable	Occurred	1.0000	0	0	1
11	Moderate	Lowly Reliable	Not Occurred	1.5651	0	0.2825	0.7175
12	Moderate	Lowly Reliable	Occurred	1.0000	0	0	1
13	Poor	Highly Reliable	Not Occurred	1.8612	0	0.4306	0.5694
14	Poor	Highly Reliable	Occurred	1.0000	0	0	1
15	Poor	Medium Reliable	Not Occurred	1.5651	0	0.2825	0.7175
16	Poor	Medium Reliable	Occurred	1.0000	0	0	1
17	Poor	Lowly Reliable	Not Occurred	1.4142	0	0.2071	0.7929
18	Poor	Lowly Reliable	Occurred	1.0000	0	0	1

Table C-2.2: CPT for the child node "MPC"

Rules	*IF*			*THEN*			
				Maritime Passage			
	Possibility of Canal Miss	**En-Route Weather Condition**	**En-route Traffic Condition**	**Expert Judgements (Average Output)**	**CPT**		
					Excellent	**Moderate**	**Poor**
1	No Problem OR Not Related	Excellent	Less Traffic	5.0000	1	0	0
2	No Problem OR Not Related	Excellent	Normal Traffic	4.4721	0.7360	0.2640	0
3	No Problem OR Not Related	Excellent	Dense Traffic	3.4641	0.2320	0.7680	0
4	No Problem OR Not Related	Moderate	Less Traffic	3.6628	0.3314	0.6686	0
5	No Problem OR Not Related	Moderate	Normal Traffic	3.4641	0.2320	0.7680	0
6	No Problem OR Not Related	Moderate	Dense Traffic	2.8284	0	0.9142	0.0858
7	No Problem OR Not Related	Rough	Less Traffic	2.3784	0	0.6892	0.3108
8	No Problem OR Not Related	Rough	Normal Traffic	2.2134	0	0.6067	0.3933
9	No Problem OR Not Related	Rough	Dense Traffic	1.7321	0	0.3660	0.6340
10	Missed Convoy	Excellent	Less Traffic	3.3636	0.1818	0.8182	0
11	Missed Convoy	Excellent	Normal Traffic	2.6321	0	0.816	0.184
12	Missed Convoy	Excellent	Dense Traffic	1.7321	0	0.3660	0.6340
13	Missed Convoy	Moderate	Less Traffic	2.9130	0	0.9565	0.0435
14	Missed Convoy	Moderate	Normal Traffic	2.7108	0	0.8554	0.1446
15	Missed Convoy	Moderate	Dense Traffic	2.0598	0	0.5299	0.4701
16	Missed Convoy	Rough	Less Traffic	1.5651	0	0.2825	0.7175
17	Missed Convoy	Rough	Normal Traffic	1.5651	0	0.2825	0.7175
18	Missed Convoy	Rough	Dense Traffic	1.0000	0	0	1

Table C-2.3: CPT for the child node "VOP"

Rules	*IF*			*THEN*			
				Vessel Operational Performances			
	Ship's Staff	**Vessel Speed**	**Machinery Breakdown**	**Expert Judgements (Average Output)**	**CPT**		
					Highly Reliable	**Medium Reliable**	**Lowly Reliable**
1	Highly Reliable	Planned Speed	Not Occurred	5.0000	1	0	0
2	Highly Reliable	Planned Speed	Minor Breakdown	3.3636	0.1818	0.8182	0
3	Highly Reliable	Planned Speed	Major Breakdown	1.1892	0	0.0946	0.9054
4	Highly Reliable	Slowed	Not Occurred	3.6628	0.3314	0.6686	0
5	Highly Reliable	Slowed	Minor Breakdown	2.6321	0	0.8115	0.1885
6	Highly Reliable	Slowed	Major Breakdown	1.1892	0	0.0946	0.9054
7	Highly Reliable	Disrupted	Not Occurred	1.0000	0	0	1
8	Highly Reliable	Disrupted	Minor Breakdown	1.0000	0	0	1
9	Highly Reliable	Disrupted	Major Breakdown	1.0000	0	0	1
10	Medium Reliable	Planned Speed	Not Occurred	3.9360	0.468	0.532	0
11	Medium Reliable	Planned Speed	Minor Breakdown	3.1302	0.0651	0.9349	0
12	Medium Reliable	Planned Speed	Major Breakdown	1.7321	0	0.366	0.634
13	Medium Reliable	Slowed	Not Occurred	3.7224	0.3612	0.6388	0
14	Medium Reliable	Slowed	Minor Breakdown	2.7108	0	0.8554	0.1446
15	Medium Reliable	Slowed	Major Breakdown	1.6818	0	0.3409	0.6591
16	Medium Reliable	Disrupted	Not Occurred	1.0000	0	0	1
17	Medium Reliable	Disrupted	Minor Breakdown	1.0000	0	0	1
18	Medium Reliable	Disrupted	Major Breakdown	1.0000	0	0	1
19	Lowly Reliable	Planned Speed	Not Occurred	2.2134	0	0.6067	0.3933
20	Lowly Reliable	Planned Speed	Minor Breakdown	1.7321	0	0.366	0.634
21	Lowly Reliable	Planned Speed	Major Breakdown	1.4142	0	0.2071	0.7929
22	Lowly Reliable	Slowed	Not Occurred	2.0598	0	0.5299	0.4701
23	Lowly Reliable	Slowed	Minor Breakdown	1.4142	0	0.2071	0.7929
24	Lowly Reliable	Slowed	Major Breakdown	1.0000	0	0	1
25	Lowly Reliable	Disrupted	Not Occurred	1.0000	0	0	1
26	Lowly Reliable	Disrupted	Minor Breakdown	1.0000	0	0	1
27	Lowly Reliable	Disrupted	Major Breakdown	1.0000	0	0	1

Table C-2.4: CPT for the child node "UE"

Rules	*IF*		*THEN*		
			Unforeseen Events		
	Dangerous Events	**Other Unexpected Delays**	**Expert Judgements (Average Output)**	**CPT**	
				Not Occurred	Occurred
1	Not Occurred	Not Occurred	3.0000	1	0
2	Not Occurred	Occurred	1.0000	0	1
3	Occurred	Not Occurred	1.0000	0	1
4	Occurred	Occurred	1.0000	0	1

Table C-2.5: CPT for the child node "SPEED"

Rules	*IF*	*THEN*			
		Vessel Speed			
	Maritime Passage	**Expert Judgements (Average Output)**	**CPT**		
			Planned Speed	**Slow**	**Disrupted**
1	Excellent	3.0000	1	0	0
2	Moderate	2.0000	0	1	0
3	Poor	1.0000	0	0	1

Table C-2.6: CPT for the child node "PC"

Rules	*IF*			*THEN*			
				Port Conditions			
	Port Channel Conditions	**Terminal Conditions**	**Miscellaneous Factors**	**Expert Judgements (Average Output)**	**CPT**		
					Smooth	**Crowded**	**Densely Congested**
1	Smooth	Smooth	Smooth	5.0000	1	0	0
2	Smooth	Smooth	Average	4.7287	0.8644	0.1356	0
3	Smooth	Smooth	Poor	3.9360	0.468	0.532	0
4	Smooth	Crowded	Smooth	4.2295	0.6148	0.3852	0
5	Smooth	Crowded	Average	3.4641	0.232	0.768	0
6	Smooth	Crowded	Poor	3.1302	0.0651	0.9349	0
7	Smooth	Densely Congested	Smooth	3.4641	0.232	0.768	0
8	Smooth	Densely Congested	Average	2.6321	0	0.816	0.184
9	Smooth	Densely Congested	Poor	2.0598	0	0.5299	0.4701
10	Crowded	Smooth	Smooth	3.4641	0.232	0.768	0
11	Crowded	Smooth	Average	2.9130	0	0.9565	0.0435
12	Crowded	Smooth	Poor	2.0598	0	0.5299	0.4701
13	Crowded	Crowded	Smooth	2.4495	0	0.7247	0.2753
14	Crowded	Crowded	Average	2.2134	0	0.6067	0.3933
15	Crowded	Crowded	Poor	1.4142	0	0.2071	0.7929
16	Crowded	Densely Congested	Smooth	2.7108	0	0.8554	0.1446
17	Crowded	Densely Congested	Average	2.2134	0	0.6067	0.3933
18	Crowded	Densely Congested	Poor	1.1892	0	0.0946	0.9054
19	Densely Congested	Smooth	Smooth	2.2134	0	0.6067	0.3933
20	Densely Congested	Smooth	Average	2.2134	0	0.6067	0.3933
21	Densely Congested	Smooth	Poor	2.0000	0	0.5	0.5
22	Densely Congested	Crowded	Smooth	1.8612	0	0.4306	0.5694
23	Densely Congested	Crowded	Average	1.6818	0	0.3409	0.6591
24	Densely Congested	Crowded	Poor	1.4142	0	0.2071	0.7929
25	Densely Congested	Densely Congested	Smooth	1.4142	0	0.2071	0.7929
26	Densely Congested	Densely Congested	Average	1.1892	0	0.0946	0.9054
27	Densely Congested	Densely Congested	Poor	1.0000	0	0	1

Table C-2.7: CPT for the child node "PCC"

Rules	*IF*		*THEN*			
			Port Channel Condition			
	Access Channel	Terminal Conditions	Expert Judgements (Average Output)	CPT		
				Smooth	Crowded	Densely Congested
1	Smooth	Smooth	5.0000	1	0	0
2	Smooth	Crowded	3.0000	0	1	0
3	Smooth	Densely Congested	1.0000	0	0	1
4	Average	Smooth	1.7783	0	0.3891	0.6109
5	Average	Crowded	1.3161	0	0.158	0.842
6	Average	Densely Congested	1.0000	0	0	1
7	Poor	Smooth	1.4142	0	0.2071	07929
8	Poor	Crowded	1.0000	0	0	1
9	Poor	Densely Congested	1.0000	0	0	1

Table C-2.8: CPT for the child node "TC"

Rules	*IF*			*THEN*			
				Terminal Condition			
	Berthing Area Condition	Port Yard Condition	Miscellaneous Factors	Expert Judgements (Average Output)	CPT		
					Smooth	Crowded	Densely Congested
1	Smooth	Smooth	Smooth	5.0000	1	0	0
2	Smooth	Smooth	Average	3.7606	0.3803	0.6197	0
3	Smooth	Smooth	Poor	2.6321	0	0.816	0.184
4	Smooth	Crowded	Smooth	3.7224	0.3612	0.6388	0
5	Smooth	Crowded	Average	3.1302	0.0651	0.9349	0
6	Smooth	Crowded	Poor	2.0598	0	0.5299	0.4701
7	Smooth	Densely Congested	Smooth	2.2134	0	0.6067	0.3933
8	Smooth	Densely Congested	Average	2.2134	0	0.6067	0.3933
9	Smooth	Densely Congested	Poor	1.4142	0	0.2071	0.7929
10	Crowded	Smooth	Smooth	3.4641	0.232	0.768	0
11	Crowded	Smooth	Average	2.6321	0	0.816	0.184
12	Crowded	Smooth	Poor	1.4142	0	0.2071	0.7929

13	Crowded	Crowded	Smooth	2.4495	0	0.7247	0.2753
14	Crowded	Crowded	Average	2.0598	0	0.5299	0.4701
15	Crowded	Crowded	Poor	1.4142	0	0.2071	0.7929
16	Crowded	Densely Congested	Smooth	1.5651	0	0.2825	0.7175
17	Crowded	Densely Congested	Average	1.4142	0	0.2071	0.7929
18	Crowded	Densely Congested	Poor	1.1892	0	0.0946	0.9054
19	Densely Congested	Smooth	Smooth	1.3161	0	0.1580	0.8420
20	Densely Congested	Smooth	Average	1.3161	0	0.1580	0.8420
21	Densely Congested	Smooth	Poor	1.1892	0	0.0946	0.9054
22	Densely Congested	Crowded	Smooth	1.3161	0	0.1580	0.8420
23	Densely Congested	Crowded	Average	1.1892	0	0.0946	0.9054
24	Densely Congested	Crowded	Poor	1.1892	0	0.0946	0.9054
25	Densely Congested	Densely Congested	Smooth	1.0000	0	0	1
26	Densely Congested	Densely Congested	Average	1.0000	0	0	1
27	Densely Congested	Densely Congested	Poor	1.0000	0	0	1

Table C-2.9: CPT for the child node "MISC"

Rules	***IF***			***THEN***			
	Administration Process	**Inland Corridors**	**Country Reliability**	**Miscellaneous Factors States**			
				Expert Judgements (Average Output)	**CPT**		
					Smooth	**Average**	**Poor**
1	Highly Efficient	Freely Flow	Highly Reliable	5.0000	1	0	0
2	Highly Efficient	Freely Flow	Medium Reliable	4.7287	0.8644	0.1356	0
3	Highly Efficient	Freely Flow	Lowly Reliable	3.9360	0.468	0.532	0
4	Highly Efficient	Crowded	Highly Reliable	4.2295	0.6148	0.3852	0
5	Highly Efficient	Crowded	Medium Reliable	3.9360	0.468	0.532	0
6	Highly Efficient	Crowded	Lowly Reliable	3.1302	0.0651	0.9349	0
7	Highly Efficient	Densely Congested	Highly Reliable	3.4641	0.232	0.768	0
8	Highly Efficient	Densely Congested	Medium Reliable	2.9130	0	0.9565	0.0435
9	Highly Efficient	Densely Congested	Lowly Reliable	2.0000	0	0.5	0.5
10	Medium Efficient	Freely Flow	Highly Reliable	3.7224	0.3612	0.6388	0
11	Medium Efficient	Freely Flow	Medium Reliable	3.3636	0.1818	0.8182	0
12	Medium Efficient	Freely Flow	Lowly Reliable	2.4495	0	0.7248	0.2752

13	Medium Efficient	Crowded	Highly Reliable	2.7108	0	0.8554	0.1446
14	Medium Efficient	Crowded	Medium Reliable	2.7108	0	0.8554	0.1446
15	Medium Efficient	Crowded	Lowly Reliable	2.2795	0	0.6398	0.3602
16	Medium Efficient	Densely Congested	Highly Reliable	2.7108	0	0.8554	0.1446
17	Medium Efficient	Densely Congested	Medium Reliable	2.2134	0	0.6067	0.3933
18	Medium Efficient	Densely Congested	Lowly Reliable	1.6818	0	0.3408	0.6592
19	Lowly Efficient	Freely Flow	Highly Reliable	1.8612	0	0.4306	0.5694
20	Lowly Efficient	Freely Flow	Medium Reliable	1.6818	0	0.3408	0.6592
21	Lowly Efficient	Freely Flow	Lowly Reliable	1.6818	0	0.3408	0.6592
22	Lowly Efficient	Crowded	Highly Reliable	1.4142	0	0.2071	0.7929
23	Lowly Efficient	Crowded	Medium Reliable	1.4142	0	0.2071	0.7929
24	Lowly Efficient	Crowded	Lowly Reliable	1.1892	0	0.0946	0.9054
25	Lowly Efficient	Densely Congested	Highly Reliable	1.1892	0	0.0946	0.9054
26	Lowly Efficient	Densely Congested	Medium Reliable	1.1892	0	0.0946	0.9054
27	Lowly Efficient	Densely Congested	Lowly Reliable	1.0000	0	0	1

Table C-2.10: CPT for the child node "ACC"

Rules	*IF*			*THEN*			
				Access Channel Conditions			
	Weather Condition at Port	Pilotage Punctuality	Tidal Window	Expert Judgements (Average Output)	CPT		
					Smooth	Average	Poor
1	Excellent	On-time	Not Restrictive	5.0000	1	0	0
2	Excellent	On-time	Restrictive	1.8612	0	0.4306	0.5694
3	Excellent	Delay	Not Restrictive	4.1618	0.5809	0.4191	0
4	Excellent	Delay	Restrictive	1.4142	0	0.2071	0.7929
5	Excellent	Serious Delay	Not Restrictive	1.4142	0	0.2071	0.7929
6	Excellent	Serious Delay	Restrictive	1.1892	0	0.0946	0.9054
7	Moderate	On-time	Not Restrictive	3.7224	0.3612	0.6388	0
8	Moderate	On-time	Restrictive	1.1892	0	0.0946	0.9054
9	Moderate	Delay	Not Restrictive	2.6321	0	0.816	0.184
10	Moderate	Delay	Restrictive	1.1892	0	0.0946	0.9054
11	Moderate	Serious Delay	Not Restrictive	1.4142	0	0.2071	0.7929
12	Moderate	Serious Delay	Restrictive	1.1892	0	0.0946	0.9054
13	Rough	On-time	Not Restrictive	2.0598	0	0.5299	0.4701
14	Rough	On-time	Restrictive	1.4142	0	0.2071	0.7929
15	Rough	Delay	Not Restrictive	1.8612	0	0.4306	0.5694
16	Rough	Delay	Restrictive	1.0000	0	0	1
17	Rough	Serious Delay	Not Restrictive	1.0000	0	0	1
18	Rough	Serious Delay	Restrictive	1.0000	0	0	1

APPENDIX C-3: The Assessment of the Unconditional Probabilities of the Root Nodes in the Arrival Punctuality Model (Test Case 2)

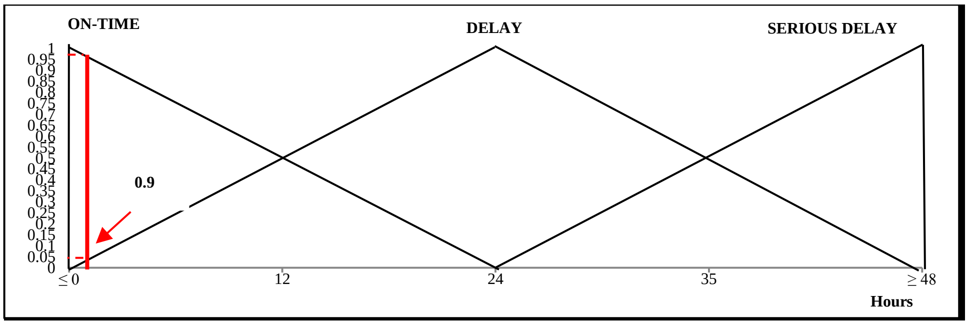

Figure C-3.1: Membership functions for the node "DPfPP" (arrival test case 2)

Based on Figure C-3.1, the set for the departure punctuality from the previous port is evaluated as:

DPfPP = {(On-time, 0.9625), (Delay, 0.0375), (Serious Delay, 0)}

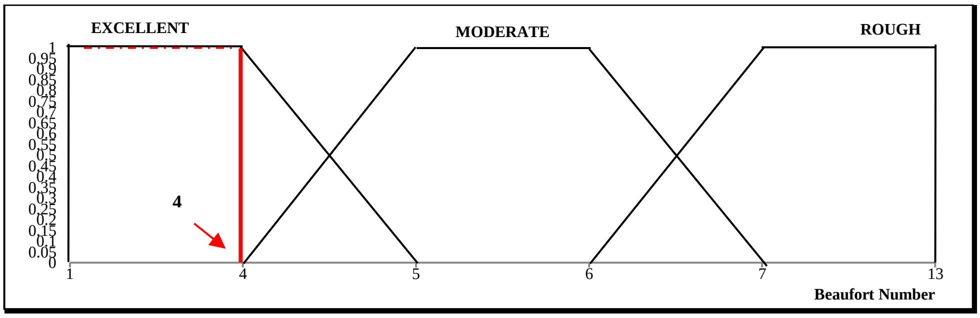

Figure C-3.2: Membership functions for the node "WCaP" (arrival test case 2)

Based on Figure C-3.2, the set for the weather condition at the port is evaluated as:

WCaP = {(Excellent, 1), (Moderate, 0), (Rough, 0)}

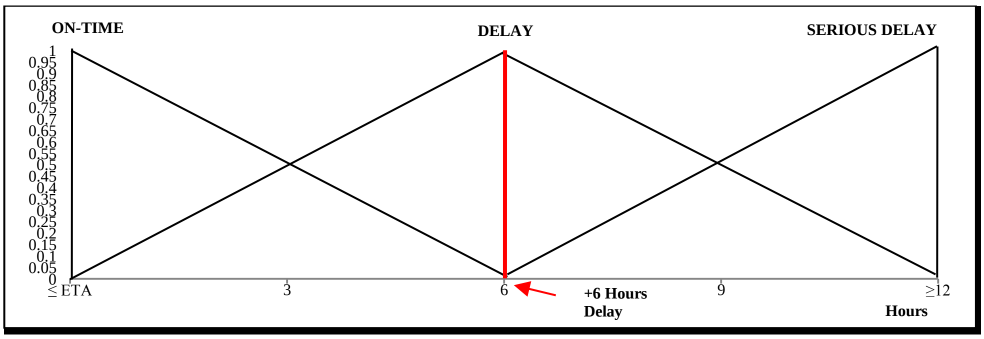

Figure C-3.3: Membership functions for the node "PPfAP" (arrival test case 2)

Based on Figure C-3.3, the set for the punctuality of pilotage operation for the arrival process is evaluated as:

$$PPfAP = \{(\text{On-time}, 0), (\text{Delay}, 1), (\text{Serious Delay}, 0)\}$$

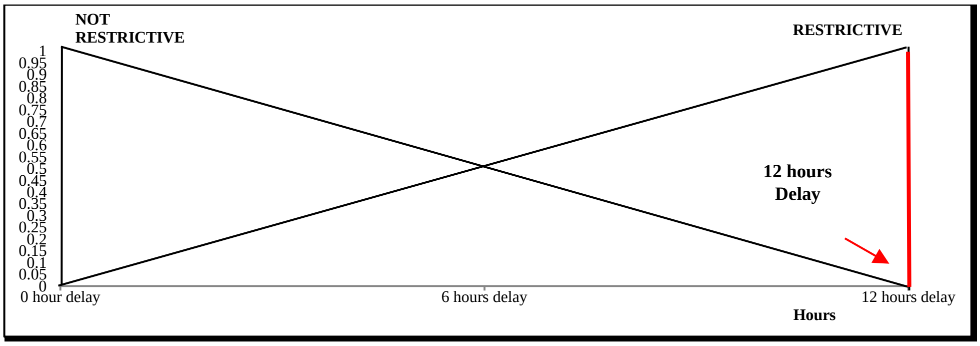

Figure C-3.4: Membership functions for the node "TW" (arrival test case 2)

Based on Figure C-3.4, the set for the tidal window is evaluated as:

$$TW = \{(\text{Not Restrictive}, 0), (\text{Restrictive}, 1)\}$$

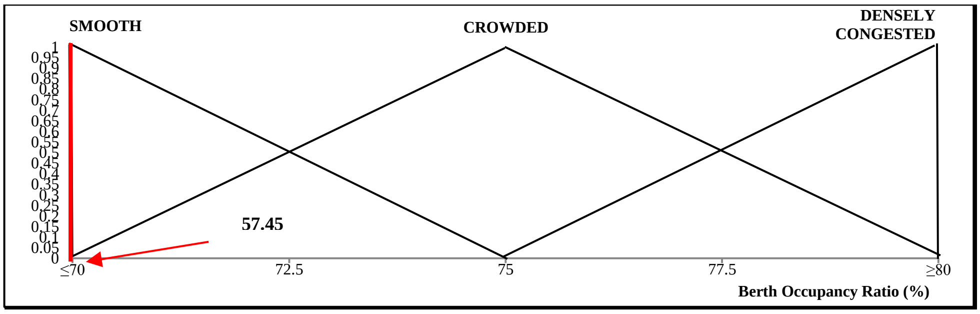

Figure C-3.5: Membership functions for the node "BAC" (arrival test case 2)

Based on Figure C-3.5, the set for the berthing area condition is evaluated as:

$$BAC = \{(\text{Smooth}, 1), (\text{Crowded } 0), (\text{Densely Congested}, 0)\}$$

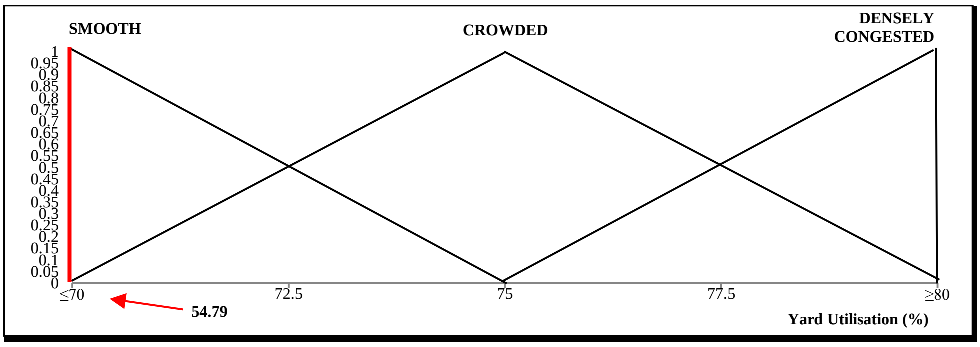

Figure C-3.6: Membership functions for the node "PYC" (arrival test case 2)

Based on Figure C-3.6, the set for the port yard condition is evaluated as:

PYC = {(Smooth, 1), (Crowded 0), (Densely Congested, 0)}

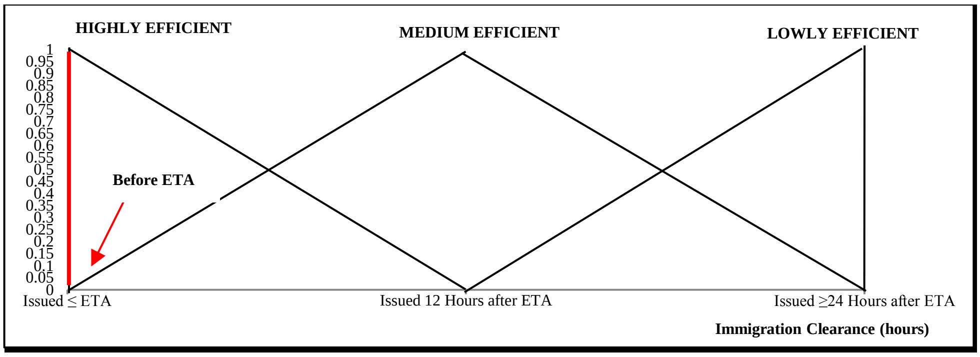

Figure C-3.7: Membership functions for the node "PAP" (arrival test case 2)

Based on Figure C-3.7, the set for the port administration process is evaluated as:

PAP = {(Highly Efficient, 1), (Medium Efficient, 0), (Lowly Efficient, 0)}

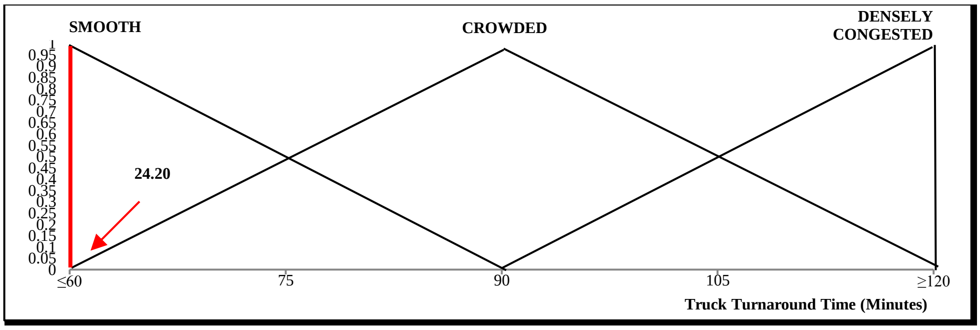

Figure C-3.8: Membership functions for the node "IC" (arrival test case 2)

Based on Figure C-3.8, the set for the inland corridors is evaluated as:

IC = {(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}

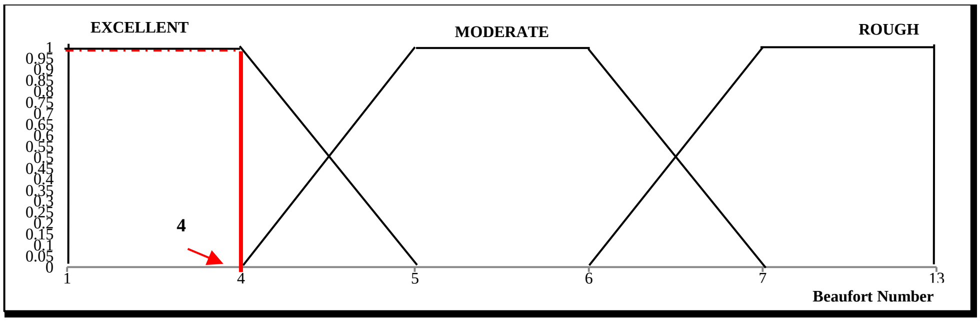

Figure C-3.9: Membership functions for the node "ERWC" (arrival test case 2)

Based on Figure C-3.9, the set for the en- route weather condition is evaluated as:

$$ERWC = \{(\text{Excellent}, 1), (\text{Moderate}, 0), (\text{Rough}, 0)\}$$

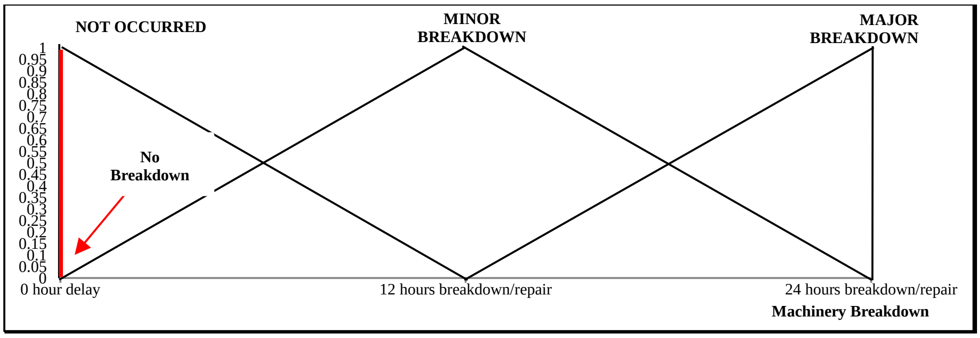

Figure C-3.10: Membership functions for the node "MB" (arrival test case 2)

Based on Figure C-3.10, the set for the vessel's machinery breakdown is evaluated as:

$$MB = \{(\text{Not Occurred}, 1), (\text{Minor Breakdown}, 0), (\text{Major Breakdown}, 0)\}$$

For assessing the occurrence probabilities of the nodes "PoCM", "DE" and "OUD", assessments are made by the ship captain as shown in Table C-3.1.

Table C-3.1: Occurrence probability of the nodes "PoCM", "DE" and "OUD" (arrival test case 2)

Qualitative Criteria	Assessment Grades		
	Source	Not Occur	Occur
PoCM	Ship Captain	1	0
DE	Ship Captain	1	0
OUD	Ship Captain	1	0

For assessing qualitative criteria in the arrival punctuality model (i.e. test case 2), assessments are made by the nominated evaluators (i.e. ship captain (Evaluator 1), operation manager (Evaluator 2) and ship manager (Evaluator 3)) under fuzzy environments. Then, assessments from these evaluators are aggregated by using an ER algorithm (i.e. Tables C-3.2 and C-3.3).

Table C-3.2: Assessment of the node "ERTC" (arrival test case 2)

Qualitative Criteria	Assessment Grades			
	Source	Less Traffic	Normal Traffic	Dense Traffic
ERTC	Evaluator 1	0.2	0.4	0.4
	Evaluator 2	0.3	0.5	0.2
	Evaluator 3	0.3	0.4	0.3
	Aggregation (ER)	0.2565	0.4513	0.2922

Table C-3.3: Assessment of the node "SSR" (arrival test case 2)

Qualitative Criteria	Assessment Grades			
	Source	Highly Reliable	Medium Reliable	Lowly Reliable
SSR	Evaluator 1	0.8	0.15	0.05
	Evaluator 2	0.8	0.2	0
	Evaluator 3	0.7	0.2	0.1
	Aggregation (ER)	0.8136	0.1487	0.0377

For assessing the reliability value of the host country (CR) the assessment model that has been developed in Chapter 3 is used. For assessing the reliability value of the agency (AGENCY), the assessment model that has been developed in Chapter 4 is used. The results are shown in Table C-3.4.

Table C-3.4: Reliability values of the country and agency (arrival test case 2)

Qualitative Criteria	Assessment Grades			
	Source	Highly Reliable	Medium Reliable	Lowly Reliable
CR	Chapter 3	0.3429	0.5788	0.0783
AGENCY	Chapter 4	0.7700	0.2092	0.0208

APPENDIX C-4: The Assessment of the Unconditional Probabilities of the Root Nodes in the Arrival Punctuality Model (Test Case 3)

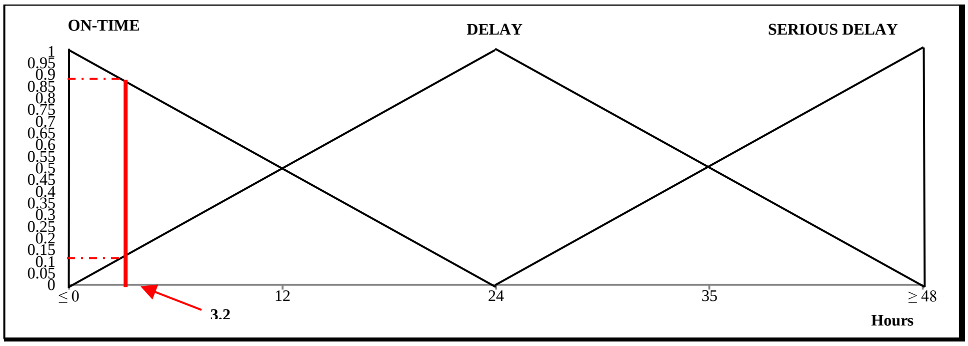

Figure C-4.1: Membership functions for the node "DPfPP" (arrival test case 3)

Based on Figure C-4.1, the set for the departure punctuality from the previous port is evaluated as:

DPfPP = {(On-time, 0.8667), (Delay, 0.1333), (Serious Delay, 0)}

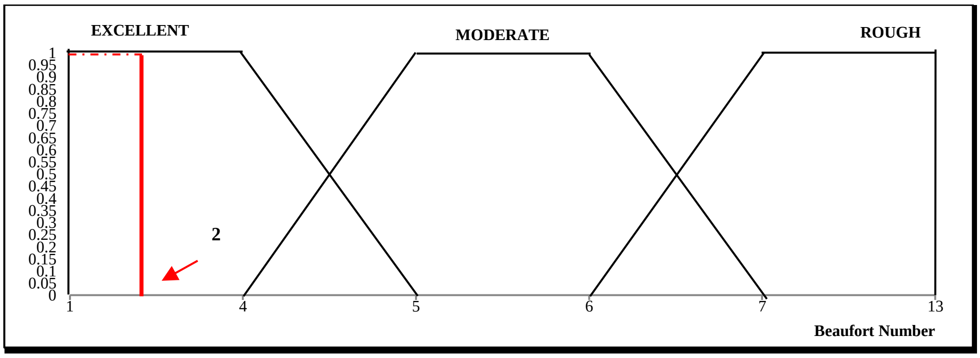

Figure C-4.2: Membership functions for the node "WCaP" (arrival test case 3)

Based on Figure C-4.2, the set for the weather condition at the port is evaluated as:

WCaP = {(Excellent, 1), (Moderate, 0), (Rough, 0)}

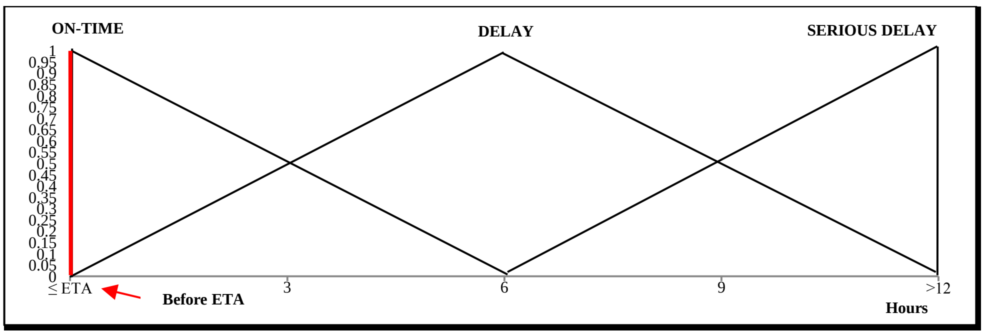

Figure C-4.3: Membership functions for the node "PPfAP" (arrival test case 3)

Based on Figure C-4.3, the set for the punctuality of pilotage operation for the arrival process is evaluated as:

$$PPfAP = \{(\text{On-time}, 1), (\text{Delay}, 0), (\text{Serious Delay}, 0)\}$$

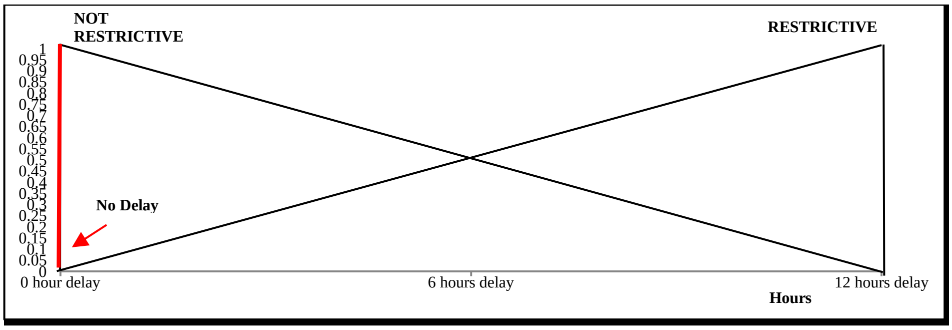

Figure C-4.4: Membership functions for the node "TW" (arrival test case 3)

Based on Figure C-4.4, the set for the tidal window is evaluated as:

$$TW = \{(\text{Not Restrictive}, 1), (\text{Restrictive}, 0)\}$$

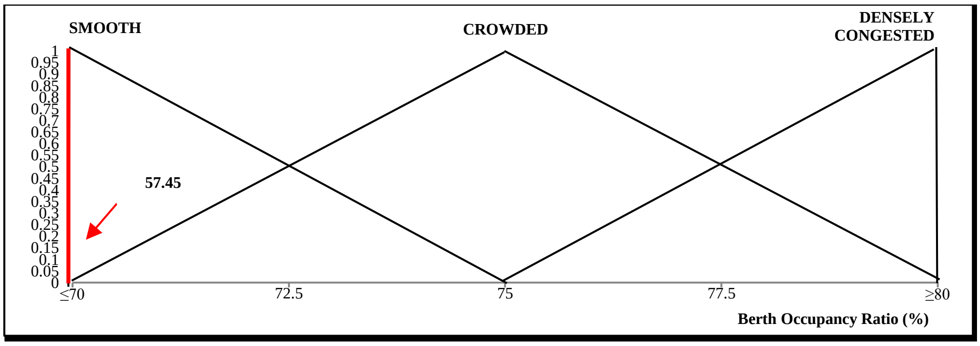

Figure C-4.5: Membership functions for the node "BAC" (arrival test case 3)

Based on Figure C-4.5, the set for the berthing area condition is evaluated as:

$$BAC = \{(\text{Smooth}, 1), (\text{Crowded } 0), (\text{Densely Congested}, 0)\}$$

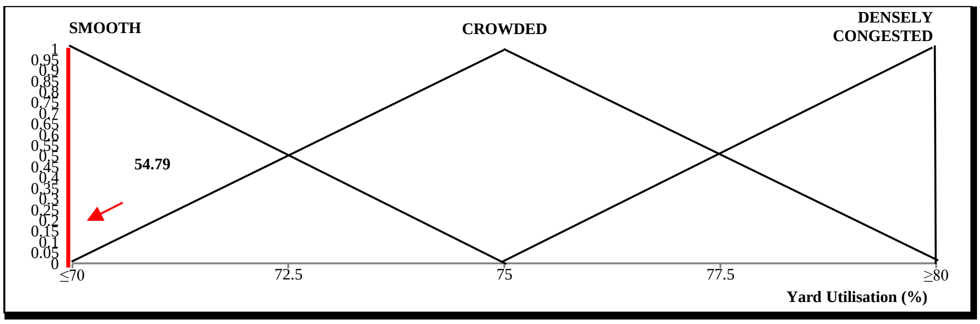

Figure C-4.6: Membership functions for the node "PYC" (arrival test case 3)

Based on Figure C-4.6, the set for the port yard condition is evaluated as:

PYC = {(Smooth, 1), (Crowded 0), (Densely Congested, 0)}

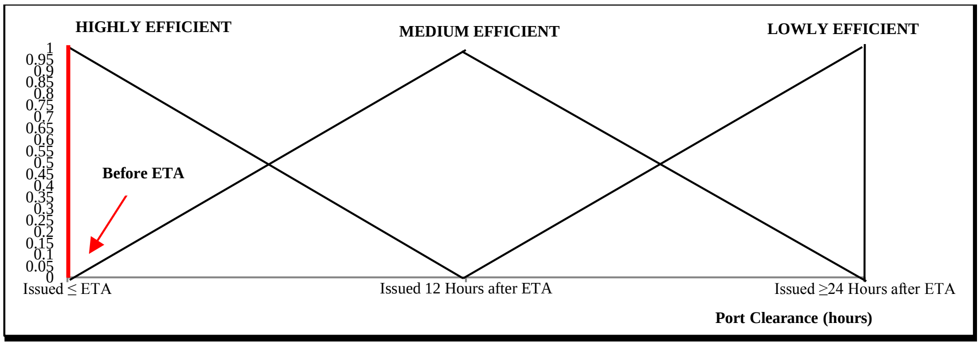

Figure C-4.7: Membership functions for the node "PAP" (arrival test case 3)

Based on Figure C-4.7, the set for the port administration process is evaluated as:

PAP = {(Highly Efficient, 1), (Medium Efficient, 0), (Lowly Efficient, 0)}

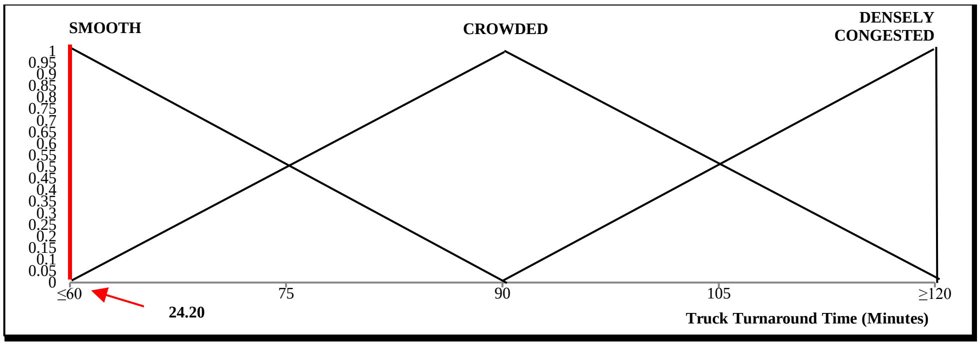

Figure C-4.8: Membership functions for the node "IC" (arrival test case 3)

Based on Figure C-4.8, the set for the inland corridors is evaluated as:

IC = {(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}

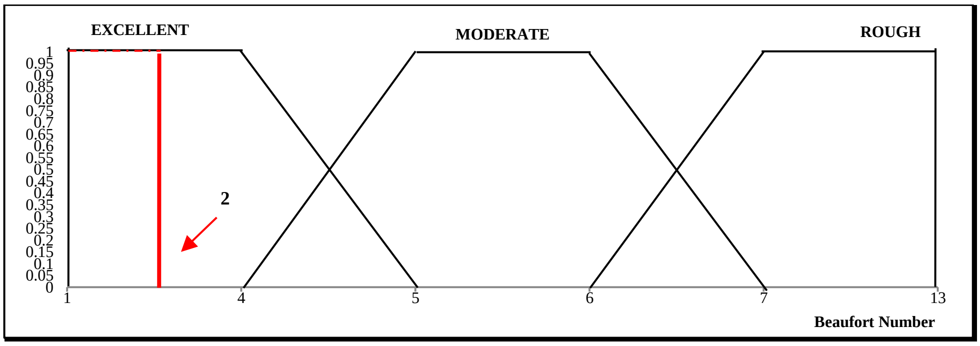

Figure C-4.9: Membership functions for the node "ERWC" (arrival test case 3)

Based on Figure C-4.9, the set for the en-route weather condition is evaluated as:

$$ERWC = \{(\text{Excellent}, 1), (\text{Moderate}, 0), (\text{Rough}, 0)\}$$

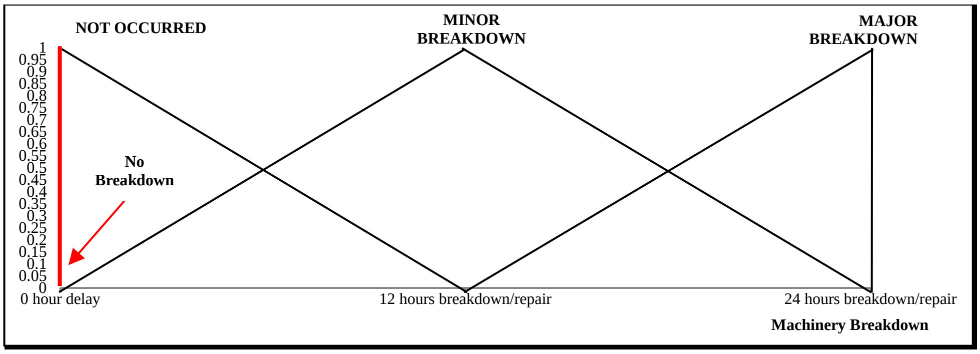

Figure C-4.10: Membership functions for the node "MB" (arrival test case 3)

Based on Figure C-4.10, the set for the vessel's machinery breakdown is evaluated as:

$$MB = \{(\text{Not Occurred}, 1), (\text{Minor Breakdown}, 0), (\text{Major Breakdown}, 0)\}$$

For assessing the occurrence probabilities of the nodes "PoCM", "DE" and "OUD", assessments are made by the ship captain as shown in Table C-4.1.

Table C-4.1: Occurrence probability of the nodes "PoCM", "DE" and "OUD" (arrival test case 3)

Qualitative Criteria	Assessment Grades		
	Source	Not Occur	Occur
PoCM	Ship Captain	1	0
DE	Ship Captain	1	0
OUD	Ship Captain	1	0

For assessing qualitative criteria in the arrival punctuality model (i.e. test case 3), assessments are made by the nominated evaluators (i.e. ship captain (Evaluator 1), operation manager (Evaluator 2) and ship manager (Evaluator 3)) under fuzzy environments. Then, assessments from these evaluators are aggregated by using an ER algorithm (i.e. Tables C-4.2 and C-4.3).

Table C-4.2: Assessment of the node "ERTC" (arrival test case 3)

Qualitative Criteria	Assessment Grades			
	Source	Less Traffic	Normal Traffic	Dense Traffic
ERTC	Evaluator 1	1	0	0
	Evaluator 2	1	0	0
	Evaluator 3	1	0	0
	Aggregation (ER)	1	0	0

Table C-4.3: Assessment of the node "SSR" (arrival test case 3)

Qualitative Criteria	Assessment Grades			
	Source	**Highly Reliable**	**Medium Reliable**	**Lowly Reliable**
SSR	Evaluator 1	0.7	0.25	0.05
	Evaluator 2	0.8	0.2	0
	Evaluator 3	0.7	0.3	0
	Aggregation (ER)	0.7759	0.2116	0.0125

For assessing the reliability value of the host country (CR) the assessment model that has been developed in Chapter 3 is used. For assessing the reliability value of the agency (AGENCY), the assessment model that has been developed in Chapter 4 is used. The results are shown in Table C-4.4.

Table C-4.4: Reliability values of the country and agency (arrival test case 3)

Qualitative Criteria	Assessment Grades			
	Source	**Highly Reliable**	**Medium Reliable**	**Lowly Reliable**
CR	Chapter 3	0.3429	0.5788	0.0783
AGENCY	Chapter 4	0.7700	0.2092	0.0208

APPENDIX D-1: The Tables of Consequents for Other Child Nodes in the Departure Punctuality Model

Table D-1.1: Preference numbers for the child node "PC" (departure)

Port Condition States	Smooth	Fairly Smooth	Crowded	Congested	Densely Congested
Preference Number	5	4	3	2	1

Table D-1.2: Consequents for the child node "PC" (departure)

Rules	*IF*			*THEN*				
				Port Conditions				
	Terminal Conditions	Channel Conditions during Departing Process	Miscellaneous Factors	E1	E2	E3	E4	Aggregation
1	Smooth	Smooth	Smooth	5	5	5	5	5.0000
2	Smooth	Smooth	Average	5	5	4	5	4.7287
3	Smooth	Smooth	Poor	5	4	3	4	3.9360
4	Smooth	Average	Smooth	4	5	4	4	4.2295
5	Smooth	Average	Average	4	4	3	3	3.4641
6	Smooth	Average	Poor	4	4	2	3	3.1302
7	Smooth	Poor	Smooth	3	3	2	1	2.0598
8	Smooth	Poor	Average	3	3	2	1	2.0598
9	Smooth	Poor	Poor	3	3	1	1	1.7321
10	Crowded	Smooth	Smooth	4	3	3	4	3.4641
11	Crowded	Smooth	Average	3	3	2	4	2.9130
12	Crowded	Smooth	Poor	2	3	1	3	2.0598
13	Crowded	Average	Smooth	2	3	2	3	2.4495
14	Crowded	Average	Average	2	2	2	3	2.2134
15	Crowded	Average	Poor	1	2	1	2	1.4142
16	Crowded	Poor	Smooth	2	3	2	1	1.8612
17	Crowded	Poor	Average	2	2	2	1	1.6818
18	Crowded	Poor	Poor	1	2	1	1	1.1892
19	Densely Congested	Smooth	Smooth	2	3	2	2	2.2134
20	Densely Congested	Smooth	Average	2	3	2	2	2.2134
21	Densely Congested	Smooth	Poor	2	2	2	2	2.0000
22	Densely Congested	Average	Smooth	1	3	2	2	1.8612

23	Densely Congested	Average	Average	1	2	2	2	1.6818
24	Densely Congested	Average	Poor	1	2	1	2	1.4142
25	Densely Congested	Poor	Smooth	1	1	1	1	1.0000
26	Densely Congested	Poor	Average	1	1	1	1	1.0000
27	Densely Congested	Poor	Poor	1	1	1	1	1.0000

Table D-1.3: Preference numbers for the child node "CCdDP"

Channel Condition during Departing Process States	Smooth	Fairly Smooth	Average	Poor	Very Poor
Preference Number	5	4	3	2	1

Table D-1.4: Consequents for the child node "CCdDP"

Rules	*IF*			*THEN*				
	Weather Condition at Port	Punctuality of Pilotage Operation	Tidal Window	Channel Conditions during Departing Process				
				E1	E2	E3	E4	Aggregation
1	Excellent	On-time	Not Restrictive	5	5	5	5	5.0000
2	Excellent	On-time	Restrictive	2	3	2	1	1.8612
3	Excellent	Delay	Not Restrictive	5	5	4	3	4.1618
4	Excellent	Delay	Restrictive	1	2	2	1	1.4142
5	Excellent	Serious Delay	Not Restrictive	1	2	2	1	1.4142
6	Excellent	Serious Delay	Restrictive	1	2	1	1	1.1892
7	Moderate	On-time	Not Restrictive	4	4	4	3	3.7224
8	Moderate	On-time	Restrictive	1	2	1	1	1.1892
9	Moderate	Delay	Not Restrictive	4	4	3	1	2.6321
10	Moderate	Delay	Restrictive	1	2	1	1	1.1892
11	Moderate	Serious Delay	Not Restrictive	1	2	2	1	1.4142
12	Moderate	Serious Delay	Restrictive	1	2	1	1	1.1892
13	Rough	On-time	Not Restrictive	2	3	3	1	2.0598
14	Rough	On-time	Restrictive	2	2	1	1	1.4142
15	Rough	Delay	Not Restrictive	2	3	2	1	1.8612
16	Rough	Delay	Restrictive	1	1	1	1	1.0000

17	Rough	Serious Delay	Not Restrictive	1	1	1	1	1.0000
18	Rough	Serious Delay	Restrictive	1	1	1	1	1.0000

Table D-1.5: Preference numbers for the child node "TC" (departure)

Terminal Condition States	Smooth	Fairly Smooth	Crowded	Congested	Densely Congested
Preference Number	5	4	3	2	1

Table D-1.6: Consequences for the child node "TC" (departure)

Rules	*IF*			*THEN*				
	Berthing Area Condition	Port Yard Condition	Miscellaneous Factors	Terminal Conditions				
				E1	E2	E3	E4	Aggregation
1	Smooth	Smooth	Smooth	5	5	5	5	5.0000
2	Smooth	Smooth	Average	5	5	4	3	3.7606
3	Smooth	Smooth	Poor	4	4	3	1	2.6321
4	Smooth	Crowded	Smooth	4	4	4	3	3.7224
5	Smooth	Crowded	Average	4	4	3	2	3.1302
6	Smooth	Crowded	Poor	3	3	2	1	2.0598
7	Smooth	Densely Congested	Smooth	2	3	2	2	2.2134
8	Smooth	Densely Congested	Average	3	2	2	2	2.2134
9	Smooth	Densely Congested	Poor	2	2	1	1	1.4142
10	Crowded	Smooth	Smooth	4	4	3	3	3.4641
11	Crowded	Smooth	Average	4	3	2	2	2.6321
12	Crowded	Smooth	Poor	2	2	1	1	1.4142
13	Crowded	Crowded	Smooth	3	3	2	2	2.4495
14	Crowded	Crowded	Average	3	3	2	1	2.0598
15	Crowded	Crowded	Poor	2	2	1	1	1.4142
16	Crowded	Densely Congested	Smooth	2	3	1	1	1.5651
17	Crowded	Densely Congested	Average	2	2	1	1	1.4142
18	Crowded	Densely Congested	Poor	1	2	1	1	1.1892
19	Densely Congested	Smooth	Smooth	1	3	1	1	1.3161
20	Densely Congested	Smooth	Average	1	3	1	1	1.3161
21	Densely Congested	Smooth	Poor	1	2	1	1	1.1892

22	Densely Congested	Crowded	Smooth	1	3	1	1	1.3161
23	Densely Congested	Crowded	Average	1	2	1	1	1.1892
24	Densely Congested	Crowded	Poor	1	2	1	1	1.1892
25	Densely Congested	Densely Congested	Smooth	1	1	1	1	1.0000
26	Densely Congested	Densely Congested	Average	1	1	1	1	1.0000
27	Densely Congested	Densely Congested	Poor	1	1	1	1	1.0000

Table D-1.7: Preference numbers for the child node "MISC" (departure)

Miscellaneous Factors States	Smooth	Fairly Smooth	Average	Poor	Very Poor
Preference Number	5	4	3	2	1

Table D-1.8: Consequences for the child node "MISC" (departure)

Rules	*IF*			*THEN*				
	Port Administration Process	Inland Corridors	Country Reliability	Miscellaneous Factors				
				E1	E2	E3	E4	Aggregation
1	Highly Efficient	Freely Flow	Highly Reliable	5	5	5	5	5.0000
2	Highly Efficient	Freely Flow	Medium Reliable	5	5	4	5	4.7287
3	Highly Efficient	Freely Flow	Lowly Reliable	4	5	3	4	3.9360
4	Highly Efficient	Crowded	Highly Reliable	4	5	4	4	4.2295
5	Highly Efficient	Crowded	Medium Reliable	4	5	3	4	3.9360
6	Highly Efficient	Crowded	Lowly Reliable	4	4	2	3	3.1302
7	Highly Efficient	Densely Congested	Highly Reliable	3	4	3	4	3.4641
8	Highly Efficient	Densely Congested	Medium Reliable	3	4	2	3	2.9130
9	Highly Efficient	Densely Congested	Lowly Reliable	2	4	1	2	2.0000
10	Medium Efficient	Freely Flow	Highly Reliable	4	4	3	4	3.7224
11	Medium Efficient	Freely Flow	Medium Reliable	4	4	2	4	3.3636
12	Medium Efficient	Freely Flow	Lowly Reliable	3	4	1	3	2.4495
13	Medium Efficient	Crowded	Highly Reliable	3	3	2	3	2.7108
14	Medium Efficient	Crowded	Medium Reliable	3	3	2	3	2.7108
15	Medium Efficient	Crowded	Lowly Reliable	3	3	1	3	2.2795
16	Medium Efficient	Densely Congested	Highly Reliable	3	2	3	3	2.7108
17	Medium Efficient	Densely Congested	Medium Reliable	3	2	2	2	2.2134

18	Medium Efficient	Densely Congested	Lowly Reliable	2	2	1	2	1.6818
19	Lowly Efficient	Freely Flow	Highly Reliable	2	3	2	1	1.8612
20	Lowly Efficient	Freely Flow	Medium Reliable	2	2	2	1	1.6818
21	Lowly Efficient	Freely Flow	Lowly Reliable	2	2	2	1	1.6818
22	Lowly Efficient	Crowded	Highly Reliable	1	2	2	1	1.4142
23	Lowly Efficient	Crowded	Medium Reliable	1	2	2	1	1.4142
24	Lowly Efficient	Crowded	Lowly Reliable	1	2	1	1	1.1892
25	Lowly Efficient	Densely Congested	Highly Reliable	1	2	1	1	1.1892
26	Lowly Efficient	Densely Congested	Medium Reliable	1	2	1	1	1.1892
27	Lowly Efficient	Densely Congested	Lowly Reliable	1	1	1	1	1.0000

Table D-1.9: Preference numbers for the child node "VC" (departure)

Vessel Condition States	Very Good	Good	Average	Poor	Very Poor
Preference Number	5	4	3	2	1

Table D-1.10: Consequences for the child node "VC" (departure)

Rules	*IF*		*THEN*				
	Vessel Operational Performance	Unforeseen Events	Vessel Conditions				
			E1	E2	E3	E4	Aggregation
1	Highly Reliable	Not Occurred	5	5	5	5	5.0000
2	Highly Reliable	Occurred	1	1	1	1	1.0000
3	Medium Reliable	Not Occurred	4	4	3	5	3.9360
4	Medium Reliable	Occurred	1	1	1	1	1.0000
5	Lowly Reliable	Not Occurred	3	1	1	3	1.7321
6	Lowly Reliable	Occurred	1	1	1	1	1.0000

Table D-1.11: Preference numbers for the child node "VOP" (departure)

Vessel Operational Performances States	Highly Reliable	Fairly High Reliable	Medium Reliable	Fairly Medium Reliable	Lowly Reliable
Preference Number	5	4	3	2	1

Table D-1.12: Consequents for the child node "VOP" (departure)

Rules	IF		THEN				
	Ship's Staff	Machinery Breakdown	Vessel Operational Performance				
			E1	E2	E3	E4	Aggregation
1	Highly Reliable	Not Occurred	5	5	5	5	5.0000
2	Highly Reliable	Minor Breakdown	5	5	3	2	3.4996
3	Highly Reliable	Major Breakdown	2	2	1	1	1.4142
4	Medium Reliable	Not Occurred	5	4	3	3	3.6628
5	Medium Reliable	Minor Breakdown	4	3	2	2	2.6321
6	Medium Reliable	Major Breakdown	2	1	1	1	1.1892
7	Lowly Reliable	Not Occurred	4	3	2	1	2.2134
8	Lowly Reliable	Minor Breakdown	3	2	1	1	1.5651
9	Lowy Reliable	Major Breakdown	1	1	1	1	1.0000

Table D-1.13: Preference numbers for the child node "UE" (departure)

Unforeseen Events States	Not Occurred	Average Possibility	Occurred
Preference Number	3	2	1

Table D-1.14: Consequences for the child node "UE" (departure)

Rules	IF		THEN				
	Dangerous Events	Other Unexpected Delays	Unforeseen Events				
			E1	E2	E3	E4	Aggregation
1	Not Occurred	Not Occurred	3	3	3	3	3.0000
2	Not Occurred	Occurred	1	1	1	1	1.0000
3	Occurred	Not Occurred	1	1	1	1	1.0000
4	Occurred	Occurred	1	1	1	1	1.0000

APPENDIX D-2: The CPTs for All Other Child Nodes in the Departure Punctuality Model

Table D-2.1: CPT for the child node of "PC" (departure)

Rules	*IF*			*THEN*			
	Terminal Conditions	**Channel Conditions during Departing Process**	**Miscellaneous Factors**	**Port Conditions**			
				Expert Judgements (Average Output)	**CPT**		
					Smooth	**Crowded**	**Densely Congested**
1	Smooth	Smooth	Smooth	5.0000	1	0	0
2	Smooth	Smooth	Average	4.7287	0.8644	0.1356	0
3	Smooth	Smooth	Poor	3.9360	0.468	0.532	0
4	Smooth	Average	Smooth	4.2295	0.6148	0.3852	0
5	Smooth	Average	Average	3.4641	0.232	0.768	0
6	Smooth	Average	Poor	3.1302	0.0651	0.9349	0
7	Smooth	Poor	Smooth	2.0598	0	0.5299	0.4701
8	Smooth	Poor	Average	2.0598	0	0.5299	0.4701
9	Smooth	Poor	Poor	1.7321	0	0.366	0.634
10	Crowded	Smooth	Smooth	3.4641	0.232	0.768	0
11	Crowded	Smooth	Average	2.9130	0	0.9565	0.0435
12	Crowded	Smooth	Poor	2.0598	0	0.5299	0.4701
13	Crowded	Average	Smooth	2.4495	0	0.7247	0.2753
14	Crowded	Average	Average	2.2134	0	0.6067	0.3933
15	Crowded	Average	Poor	1.4142	0	0.2071	0.7929
16	Crowded	Poor	Smooth	1.8612	0	0.4306	0.5694
17	Crowded	Poor	Average	1.6818	0	0.3409	0.6591
18	Crowded	Poor	Poor	1.1892	0	0.0946	0.9054
19	Densely Congested	Smooth	Smooth	2.2134	0	0.6067	0.3933
20	Densely Congested	Smooth	Average	2.2134	0	0.6067	0.3933
21	Densely Congested	Smooth	Poor	2.0000	0	0.5	0.5
22	Densely Congested	Average	Smooth	1.8612	0	0.4306	0.5694
23	Densely Congested	Average	Average	1.6818	0	0.3409	0.6591
24	Densely Congested	Average	Poor	1.4142	0	0.2071	0.7929
25	Densely Congested	Poor	Smooth	1.0000	0	0	1
26	Densely Congested	Poor	Average	1.0000	0	0	1

27	Densely Congested	Poor	Poor	1.0000	0	0	1

Table D-2.2: CPT for the child node of "CCdDP"

Rules	*IF*			*THEN*			
				Departing Process			
	Weather Condition at Port	**Punctuality of Pilotage Operation**	**Tidal Window**	**Expert Judgements (Average Output)**	**Channel Conditions during Departing Process**		
					Smooth	**Average**	**Poor**
1	Excellent	On-time	Not Restrictive	5.0000	1	0	0
2	Excellent	On-time	Restrictive	1.8612	0	0.4306	0.5694
3	Excellent	Delay	Not Restrictive	4.1618	0.5809	0.4191	0
4	Excellent	Delay	Restrictive	1.4142	0	0.2071	0.7929
5	Excellent	Serious Delay	Not Restrictive	1.4142	0	0.2071	0.7929
6	Excellent	Serious Delay	Restrictive	1.1892	0	0.0946	0.9054
7	Moderate	On-time	Not Restrictive	3.7224	0.3612	0.6388	0
8	Moderate	On-time	Restrictive	1.1892	0	0.0946	0.9054
9	Moderate	Delay	Not Restrictive	2.6321	0	0.816	0.184
10	Moderate	Delay	Restrictive	1.1892	0	0.0946	0.9054
11	Moderate	Serious Delay	Not Restrictive	1.4142	0	0.2071	0.7929
12	Moderate	Serious Delay	Restrictive	1.1892	0	0.0946	0.9054
13	Rough	On-time	Not Restrictive	2.0598	0	0.5299	0.4701
14	Rough	On-time	Restrictive	1.4142	0	0.2071	0.7929
15	Rough	Delay	Not Restrictive	1.8612	0	0.4306	0.5694
16	Rough	Delay	Restrictive	1.0000	0	0	1
17	Rough	Serious Delay	Not Restrictive	1.0000	0	0	1
18	Rough	Serious Delay	Restrictive	1.0000	0	0	1

Table D-2.3: CPT for the child node of "TC" (departure)

Rules	*IF*			*THEN*			
				Terminal Conditions			
	Berthing Area Condition	**Port Yard Condition**	**Miscellaneous Factors**	**Expert Judgements (Average Output)**	**CPT**		
					Smooth	**Crowded**	**Densely Congested**
1	Smooth	Smooth	Smooth	5.0000	1	0	0
2	Smooth	Smooth	Average	3.7606	0.3803	06197	0
3	Smooth	Smooth	Poor	2.6321	0	0.816	0.1840
4	Smooth	Crowded	Smooth	3.7224	0.3612	0.6388	0
5	Smooth	Crowded	Average	3.1302	0.0651	0.9349	0
6	Smooth	Crowded	Poor	2.0598	0	0.5299	0.4701
7	Smooth	Densely Congested	Smooth	2.2134	0	0.6067	0.3933
8	Smooth	Densely Congested	Average	2.2134	0	0.6067	0.3933
9	Smooth	Densely Congested	Poor	1.4142	0	0.2071	0.7929
10	Crowded	Smooth	Smooth	3.4641	0.232	0.768	0
11	Crowded	Smooth	Average	2.6321	0	0.816	0.184
12	Crowded	Smooth	Poor	1.4142	0	0.2071	0.7929
13	Crowded	Crowded	Smooth	2.4495	0	0.7247	0.2753
14	Crowded	Crowded	Average	2.0598	0	0.5299	0.4701
15	Crowded	Crowded	Poor	1.4142	0	0.2071	0.7929
16	Crowded	Densely Congested	Smooth	1.5651	0	0.2825	0.7175
17	Crowded	Densely Congested	Average	1.4142	0	0.2071	0.7929
18	Crowded	Densely Congested	Poor	1.1892	0	0.0946	0.9054
19	Densely Congested	Smooth	Smooth	1.3161	0	0.158	0.8420
20	Densely Congested	Smooth	Average	1.3161	0	0.158	0.8420
21	Densely Congested	Smooth	Poor	1.1892	0	0.0946	0.9054
22	Densely Congested	Crowded	Smooth	1.3161	0	0.158	0.8420
23	Densely Congested	Crowded	Average	1.1892	0	0.0946	0.9054
24	Densely Congested	Crowded	Poor	1.1892	0	0.0946	0.9054
25	Densely Congested	Densely Congested	Smooth	1.0000	0	0	1
26	Densely Congested	Densely Congested	Average	1.0000	0	0	1
27	Densely Congested	Densely Congested	Poor	1.0000	0	0	1

Table D-2.4: CPT for the child node of "MISC" (departure)

Rules	*IF*			*THEN*			
	Port Administration Process	Inland Corridors	Country Reliability	Miscellaneous Factors			
				Expert Judgements (Average Output)	CPT		
					Smooth	Average	Poor
1	Highly Efficient	Freely Flow	Highly Reliable	5.0000	1	0	0
2	Highly Efficient	Freely Flow	Medium Reliable	4.7287	0.8644	0.1356	0
3	Highly Efficient	Freely Flow	Lowly Reliable	3.9360	0.468	0.532	0
4	Highly Efficient	Crowded	Highly Reliable	4.2295	0.6148	0.3852	0
5	Highly Efficient	Crowded	Medium Reliable	3.9360	0.468	0.532	0
6	Highly Efficient	Crowded	Lowly Reliable	3.1302	0.0651	0.9349	0
7	Highly Efficient	Densely Congested	Highly Reliable	3.4641	0.232	0.768	0
8	Highly Efficient	Densely Congested	Medium Reliable	2.9130	0	0.9565	0.0435
9	Highly Efficient	Densely Congested	Lowly Reliable	2.0000	0	0.5	0.5
10	Medium Efficient	Freely Flow	Highly Reliable	3.7224	0.3612	0.6388	0
11	Medium Efficient	Freely Flow	Medium Reliable	3.3636	0.1818	0.8182	0
12	Medium Efficient	Freely Flow	Lowly Reliable	2.4495	0	0.7248	0.2752
13	Medium Efficient	Crowded	Highly Reliable	2.7108	0	0.8554	0.1446
14	Medium Efficient	Crowded	Medium Reliable	2.7108	0	0.8554	0.1446
15	Medium Efficient	Crowded	Lowly Reliable	2.2795	0	0.6398	0.3602
16	Medium Efficient	Densely Congested	Highly Reliable	2.7108	0	0.8554	0.1446
17	Medium Efficient	Densely Congested	Medium Reliable	2.2134	0	0.6067	0.3933
18	Medium Efficient	Densely Congested	Lowly Reliable	1.6818	0	0.3408	0.6592
19	Lowly Efficient	Freely Flow	Highly Reliable	1.8612	0	0.4306	0.5694
20	Lowly Efficient	Freely Flow	Medium Reliable	1.6818	0	0.3408	0.6592
21	Lowly Efficient	Freely Flow	Lowly Reliable	1.6818	0	0.3408	0.6592
22	Lowly Efficient	Crowded	Highly Reliable	1.4142	0	0.2071	0.7929
23	Lowly Efficient	Crowded	Medium Reliable	1.4142	0	0.2071	0.7929
24	Lowly Efficient	Crowded	Lowly Reliable	1.1892	0	0.0946	0.9054
25	Lowly Efficient	Densely Congested	Highly Reliable	1.1892	0	0.0946	0.9054
26	Lowly Efficient	Densely Congested	Medium Reliable	1.1892	0	0.0946	0.9054
27	Lowly Efficient	Densely Congested	Lowly Reliable	1.0000	0	0	1

Table D-2.5: CPT for the child node of "VC" (departure)

Rules	*IF*		*THEN*			
	Vessel Operational Performance	Unforeseen Events	Vessel Conditions			
			Expert Judgements (Average Output)	CPT		
				Good	Average	Poor
1	Highly Reliable	Not Occurred	5.0000	1	0	0
2	Highly Reliable	Occurred	1.0000	0	0	1
3	Medium Reliable	Not Occurred	3.9360	0.468	0.532	0
4	Medium Reliable	Occurred	1.0000	0	0	1
5	Lowly Reliable	Not Occurred	1.7321	0	0.366	0.634
6	Lowly Reliable	Occurred	1.4142	0	0	1

Table D-2.6: CPT for the child node of "VOP" (departure)

Rules	*IF*		*THEN*			
	Ship's Staff	Machinery Breakdown	Vessel Operational Performance			
			Expert Judgements (Average Output)	CPT		
				Highly Reliable	Medium Reliable	Lowly Reliable
1	Highly Reliable	Not Occurred	5.0000	1	0	0
2	Highly Reliable	Minor Breakdown	3.4996	0.2498	0.7502	0
3	Highly Reliable	Major Breakdown	1.4142	0	0.2071	0.7929
4	Medium Reliable	Not Occurred	3.6628	0.3314	0.6686	0
5	Medium Reliable	Minor Breakdown	2.6321	0	0.816	0.184
6	Medium Reliable	Major Breakdown	1.1892	0	0.0946	0.9054
7	Lowly Reliable	Not Occurred	2.2134	0	0.6067	0.3933
8	Lowly Reliable	Minor Breakdown	1.5651	0	0.2825	0.7175
9	Lowy Reliable	Major Breakdown	1.0000	0	0	1

Table D-2.7: CPT for the child node of "UE" (departure)

Rules	*IF*		*THEN*		
			Unforeseen Events		
	Dangerous Events	**Other Unexpected Delays**	**Expert Judgements (Average Output)**	**CPT**	
				Not Occurred	**Occurred**
1	Not Occurred	Not Occurred	3.0000	1	0
2	Not Occurred	Occurred	1.0000	0	1
3	Occurred	Not Occurred	1.0000	0	1
4	Occurred	Occurred	1.0000	0	1

APPENDIX D-3: The Assessment of the Unconditional Probabilities of the Root Nodes in the Departure Punctuality Model (Test Case 2)

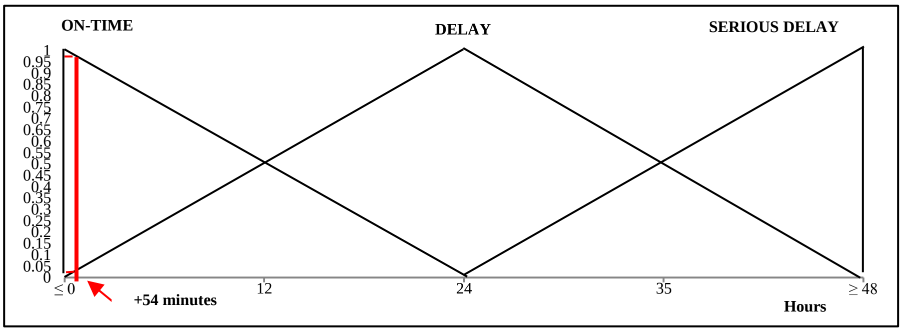

Figure D-3.1: Membership functions for the node "APSP" (departure test case 2)

Based on Figure D-3.1, the set for the arrival punctuality at the same port is evaluated as:

$$APSP = \{(\text{On-time}, 0.9625), (\text{Delay}, 0.0375), (\text{Serious Delay}, 0)\}$$

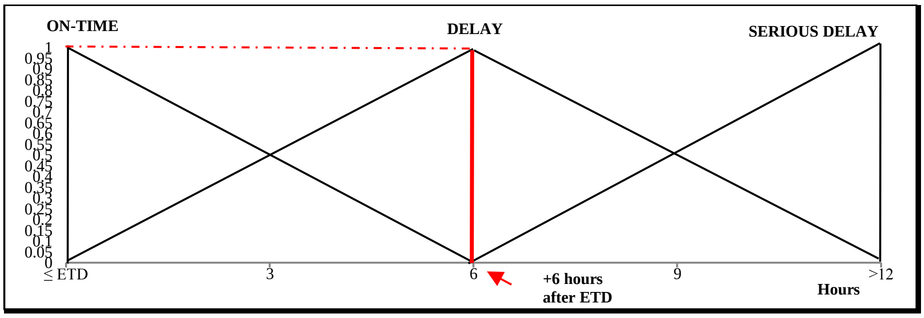

Figure D-3.2: Membership functions for the node "PPfDP" (departure test case 2)

Based on Figure D-3.2, the set for the punctuality of pilotage operation for the departure process is evaluated as:

$$PPfDP = \{(\text{On-time}, 0), (\text{Delay}, 1), (\text{Serious Delay}, 0)\}$$

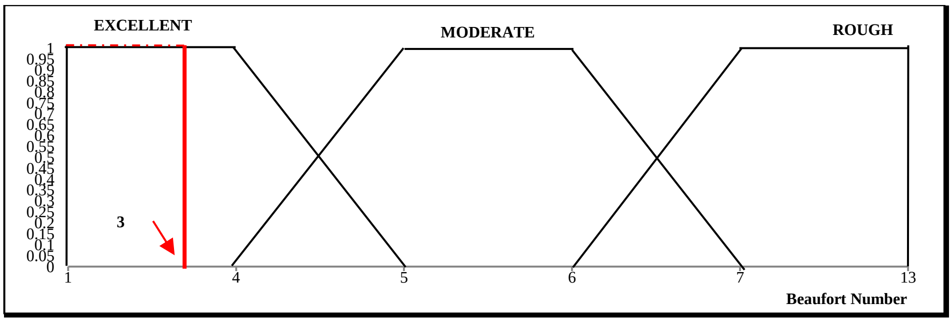

Figure D-3.3: Membership functions for the node "WCaP" (departure test case 2)

Based on Figure D-3.3, the set for the weather condition at the port is evaluated as:

$$WCaP = \{(\text{Excellent}, 1), (\text{Moderate}, 0), (\text{Rough}, 0)\}$$

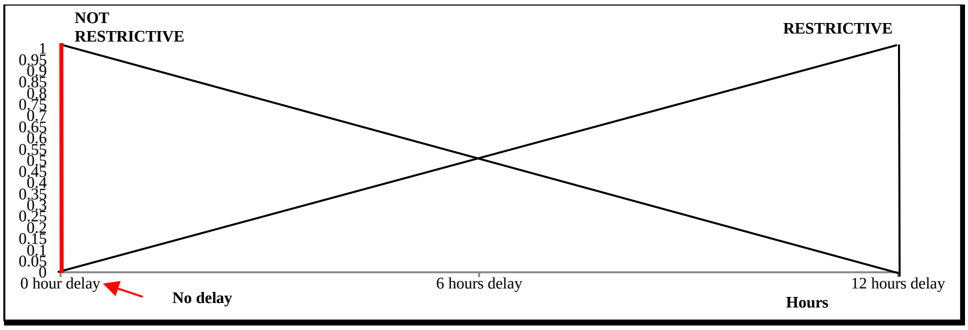

Figure D-3.4: Membership functions for the node "TW" (departure test case 2)

Based on Figure D-3.4, the set for the tidal window is evaluated as:

$$TW = \{(\text{Not Restrictive}, 1), (\text{Restrictive}, 0)\}$$

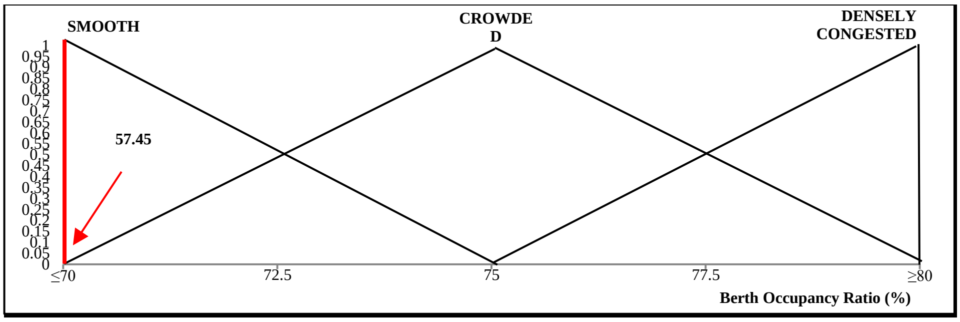

Figure D-3.5: Membership functions for the node "BAC" (departure test case 2)

Based on Figure D-3.5, the set for the berthing area condition is evaluated as:

$$BAC = \{(\text{Smooth}, 1), (\text{Crowded } 0), (\text{Densely Congested}, 0)\}$$

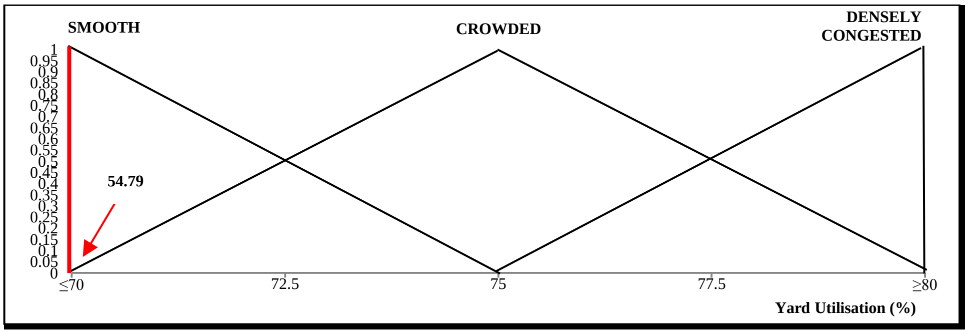

Figure D-3.6: Membership functions for the node "PYC" (departure test case 2)

Based on Figure D-3.6, the set for the port yard condition is evaluated as:

PYC = {(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}

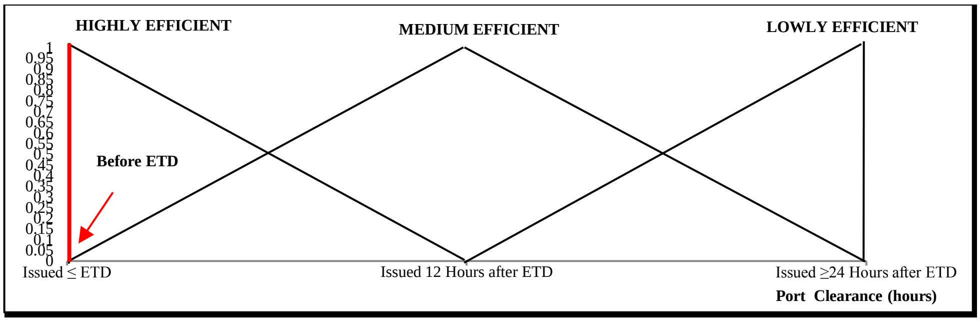

Figure D-3.7: Membership functions for the node "PAP" (departure test case 2)

Based on Figure D-3.7, the set for the port administration process is evaluated as:

PAP = {(Highly Efficient, 1), (Medium Efficient, 0), (Lowly Efficient, 0)}

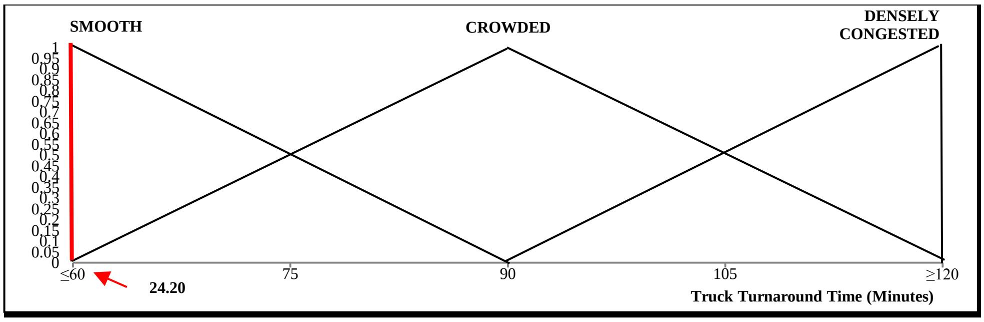

Figure D-3.8: Membership functions for the node "IC" (departure test case 2)

Based on Figure D-3.8, the set for the inland corridors is evaluated as:

IC = {(Smooth, 1), (Crowded, 0), (Densely Congested, 0)}

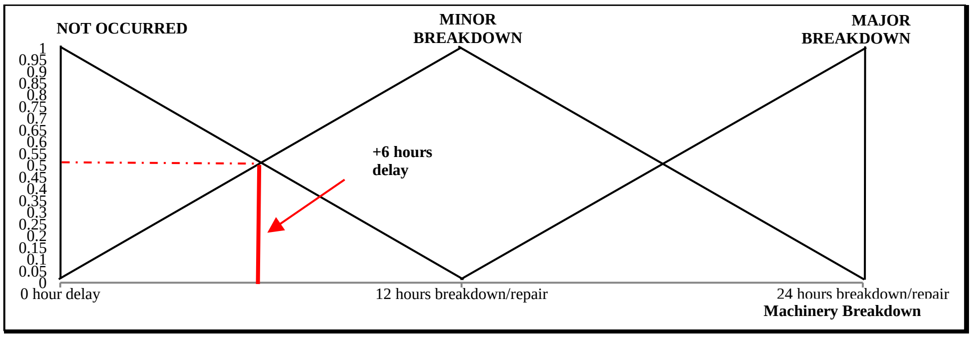

Figure D-3.9: Membership functions for the node "MB" (departure test case 2)

Based on Figure D-3.9, the set for the vessel's machinery breakdown during her port stays is evaluated as:

MB = {(Not Occurred, 0.5), (Minor Breakdown, 0.5), (Major Breakdown, 0)}

For assessing ship staff's reliability, assessments are made by the nominated evaluators (i.e. ship captain (Evaluator 1), operation manager (Evaluator 2) and ship manager (Evaluator 3)) using subjective judgements. Then, the assessments from these evaluators are aggregated by using an ER algorithm (i.e. Tables D-3.1).

Table D-3.1: Assessment of the node "SSR" (departure test case 2)

Qualitative Criteria	Assessment Grades			
	Source	Highly Reliable	Medium Reliable	Lowly Reliable
SSR	Evaluator 1	0.8	0.15	0.05
	Evaluator 2	0.8	0.2	0
	Evaluator 3	0.7	0.2	0.1
	Aggregation (ER)	0.8136	0.1487	0.0377

For assessing the occurrence probabilities of the nodes "DE" and "OUD" in the departure model, assessments are made by the ship captain of $Vessel_A$ as shown in Table D-3.2.

Table D-3.2: Occurrence probability of the nodes "DE" and "OUD" (departure test case 2)

Qualitative Criteria	Assessment Grades		
	Source	Not Occur	Occur
DE	Ship Captain	1	0
OUD	Ship Captain	1	0

For assessing the reliability value of the host country (CR) the assessment model that has been developed in Chapter 3 is used. For assessing the reliability value of the agency (AGENCY), the assessment model that has been developed in Chapter 4 is used. The results are shown in Table D-3.3.

Table D-3.3: Reliability values of the country and the agency (departure test case 2)

Qualitative Criteria	Assessment Grades			
	Source	Highly Reliable	Medium Reliable	Lowly Reliable
CR	Chapter 3	0.3429	0.5788	0.0783
AGENCY	Chapter 4	0.7700	0.2092	0.0208

APPENDIX D-4: The Assessment of the Unconditional Probabilities of the Root Nodes in the Departure Punctuality Model (Test Case 3)

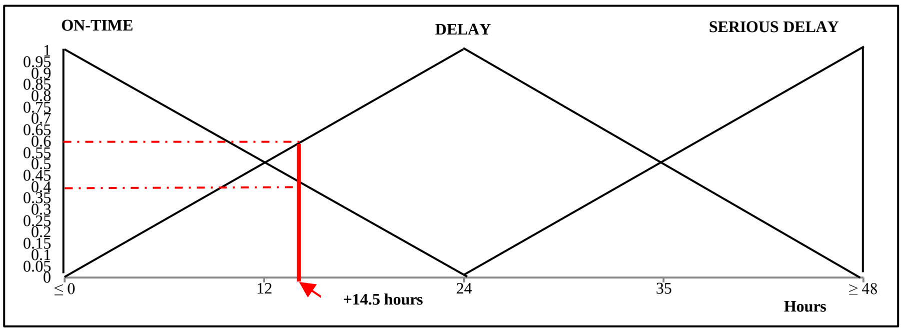

Figure D-4.1: Membership functions for the node "APSP" (departure test case 3)

Based on Figure D-4.1, the set for the arrival punctuality at the same port is evaluated as:

APSP = {(On-time, 0.3958), (Delay, 0.6042), (Serious Delay, 0)}

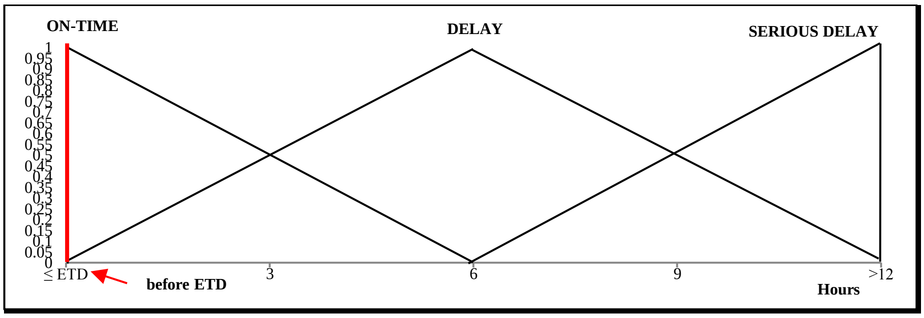

Figure D-4.2: Membership functions for the node "PPfDP" (departure test case 3)

Based on Figure D-4.2, the set for the punctuality of pilotage operation for the departure process is evaluated as:

PPfDP = {(On-time, 1), (Delay, 0), (Serious Delay, 0)}

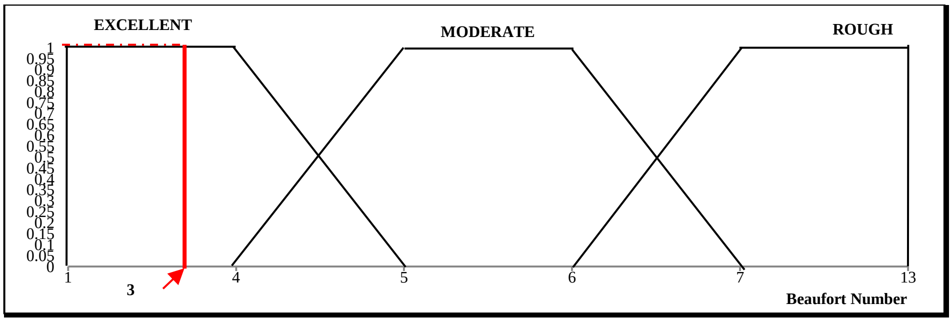

Figure D-4.3: Membership functions for the node "WCaP" (departure test case 3)

Based on Figure D-4.3, the set for the weather condition at the port is evaluated as:

$$WCaP = \{(\text{Excellent}, 1), (\text{Moderate}, 0), (\text{Rough}, 0)\}$$

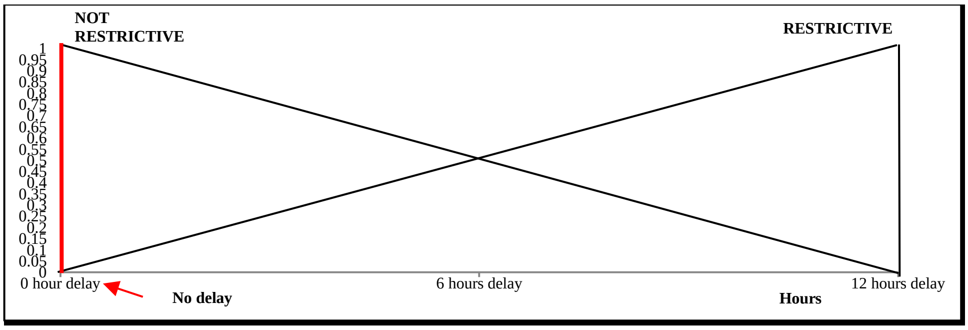

Figure D-4.4: Membership functions for the node "TW" (departure test case 3)

Based on Figure D-4.4, the set for the tidal window is evaluated as:

$$TW = \{(\text{Not Restrictive}, 1), (\text{Restrictive}, 0)\}$$

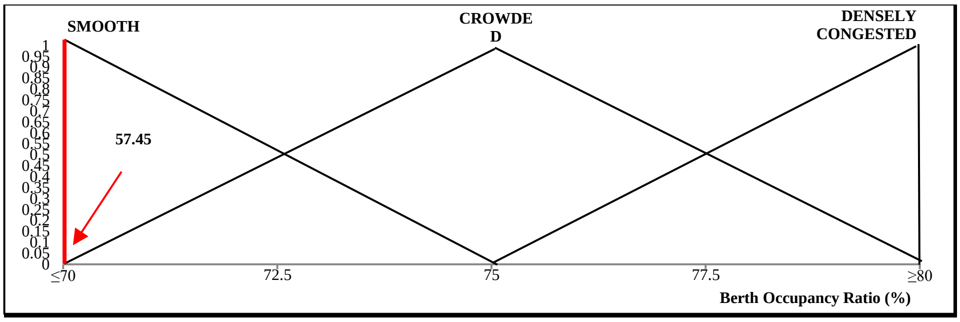

Figure D-4.5: Membership functions for the node "BAC" (departure test case 3)

Based on Figure D-4.5, the set for the berthing area condition is evaluated as:

$$BAC = \{(\text{Smooth}, 1), (\text{Crowded } 0), (\text{Densely Congested}, 0)\}$$

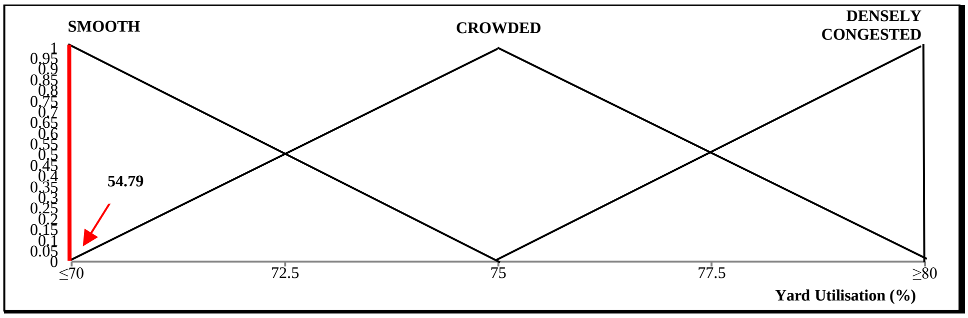

Figure D-4.6: Membership functions for the node "PYC" (departure test case 3)

Based on Figure D-4.6, the set for the port yard condition is evaluated as:

$$PYC = \{(\text{Smooth}, 1), (\text{Crowded}, 0), (\text{Densely Congested}, 0)\}$$

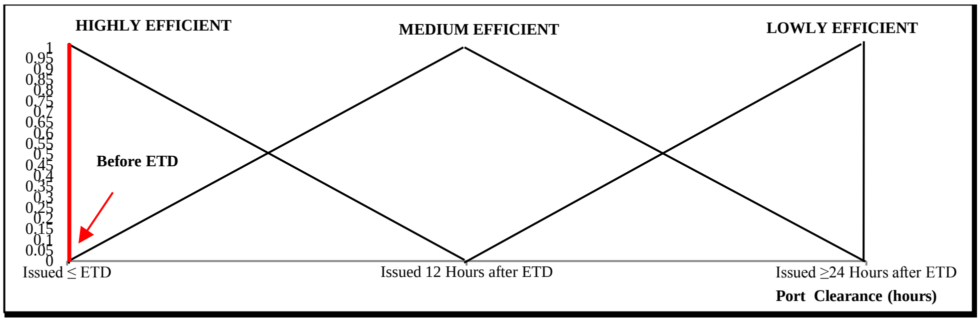

Figure D-4.7: Membership functions for the node "PAP" (departure test case 3)

Based on Figure D-4.7, the set for the port administration process is evaluated as:

$$PAP = \{(\text{Highly Efficient}, 1), (\text{Medium Efficient}, 0), (\text{Lowly Efficient}, 0)\}$$

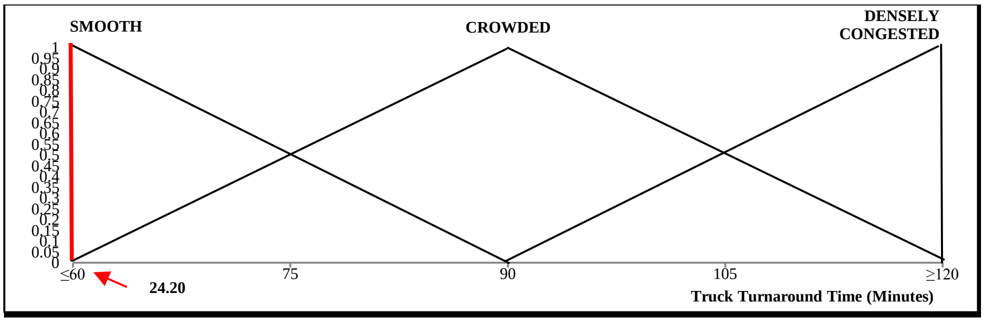

Figure D-4.8: Membership functions for the node "IC" (departure test case 3)

Based on Figure D-4.8, the set for the inland corridors is evaluated as:

$$IC = \{(\text{Smooth}, 1), (\text{Crowded}, 0), (\text{Densely Congested}, 0)\}$$

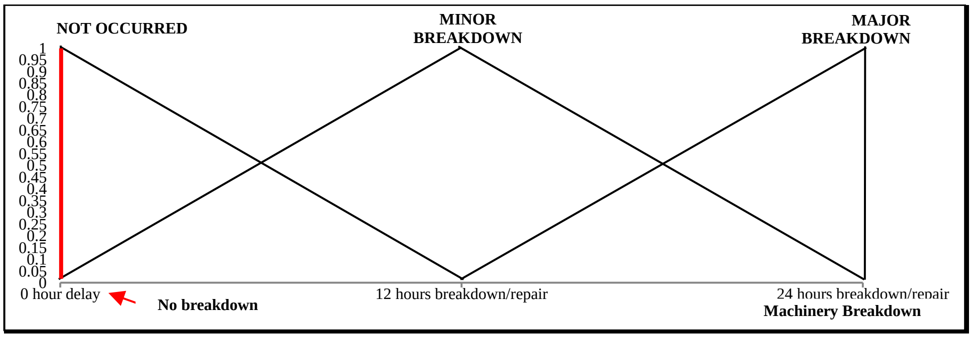

Figure D-4.9: Membership functions for the node "MB" (departure test case 3)

Based on Figure D-4.9, the set for the vessel's machinery breakdown during her port stays is evaluated as:

$$MB = \{(\text{Not Occurred}, 1), (\text{Minor Breakdown}, 0), (\text{Major Breakdown}, 0)\}$$

For assessing ship staff's reliability, assessments are made by the nominated evaluators (i.e. ship captain (Evaluator 1), operation manager (Evaluator 2) and ship manager (Evaluator 3)) using subjective judgements. Then, the assessments from these evaluators are aggregated by using an ER algorithm (i.e. Tables D-4.1).

Table D-4.1: Assessment of the node "SSR" (departure test case 3)

Qualitative Criteria	Assessment Grades			
	Source	Highly Reliable	Medium Reliable	Lowly Reliable
SSR	Evaluator 1	0.75	0.25	0.05
	Evaluator 2	0.8	0.2	0
	Evaluator 3	0.7	0.3	0
	Aggregation (ER)	0.7759	0.2116	0.0125

For assessing the occurrence probabilities of the nodes "DE" and "OUD" in the departure model, assessments are made by the ship captain of $Vessel_A$ as shown in Table D-4.2.

Table D-4.2: Occurrence probability of the nodes "DE" and "OUD" (departure test case 3)

Qualitative Criteria	Assessment Grades		
	Source	Not Occur	Occur
DE	Ship Captain	1	0
OUD	Ship Captain	1	0

For assessing the reliability value of the host country (CR) the assessment model that has been developed in Chapter 3 is used. For assessing the reliability value of the agency (AGENCY), the assessment model that has been developed in Chapter 4 is used. The results are shown in Table D-4.3.

Table D-4.3: Reliability values of the country and the agency (departure test case 3)

Qualitative Criteria	Assessment Grades			
	Source	Highly Reliable	Medium Reliable	Lowly Reliable
CR	Chapter 3	0.3429	0.5788	0.0783
AGENCY	Chapter 4	0.7700	0.2092	0.0208

APPENDIX E-1: Expert Validation Forms (Industrial Validation)

Expert 1

EXPERT VALIDATION FORM

The purpose of this form is to obtain a domain expert's review on the developed models and results achieved in the dissertation entitled "Supply Chain Risk and Reliability Assessment in the Container Liner Shipping Industry under High Uncertainties"

PART A: EXPERT BACKGROUND

Name:	[redacted]
Position:	SHIP MANAGER
Company/Organisation:	[redacted]
Year of Experience:	11 YEARS

PART B: REVIEW

Model 1: Business Environment-Based Risk Assessment

Criteria	Very Poor	Poor	Average	Good	Very Good
Factors/Criteria Consideration				✓	
Model Development					✓
Methodology Flexibility					✓
Mathematical Approach					✓
Result Relevancy					✓
Necessity of the Model for Industry				✓	

Comment: it is a positive results which is related to ~~my~~ the Malaysia shipping industry. with the current situation has neccesitated for liner shipping.

Model 2: Organisational Reliability and Capability Evaluation

Criteria	Very Poor	Poor	Average	Good	Very Good
Factors/Criteria Consideration					✓
Model Development				✓	
Methodology Flexibility				✓	
Mathematical Approach					✓
Result Relevancy					✓
Necessity of the Model for Industry					✓

Comment: It is ~~really~~ really neccessary in Liner shipping Operators to gain ~~company~~ company ~~performan~~ performance, security, and etc.

Model 3: Arrival Punctuality Analysis

Criteria	Very Poor	Poor	Average	Good	Very Good
Factors/Criteria Consideration					✓
Model Development					✓
Methodology Flexibility				✓	
Mathematical Approach				✓	
Result Relevancy					✓
Necessity of the Model for Industry					✓

Comment: ~~New term AVA: can It is really useful~~.
New term AVA, can be used in operation matters.
It is can be add ~~in~~ for example in daily position sheet.
It is really useful, ~~during~~ ~~[illegible]~~ for preparing for other plan in case vessel seriously delayed in certain ports.

Model 4: Departure Punctuality Analysis

Criteria	Very Poor	Poor	Average	Good	Very Good
Factors/Criteria Consideration					✓
Model Development					✓
Methodology Flexibility					✓
Mathematical Approach				✓	
Result Relevancy					✓
Necessity of the Model for Industry					✓

Comment: Same also for departure punctuality. Some ports need to improve technology such as new system, new facilities, new equipment and etc. It is to avoid delay in ports. Also to attract other shipping lines to do business.

- THANK YOU -

EXPERT VALIDATION FORM Expert 2

The purpose of this form is to obtain a domain expert's review on the developed models and results achieved in the dissertation entitled "Supply Chain Risk and Reliability Assessment in the Container Liner Shipping Industry under High Uncertainties"

PART A: EXPERT BACKGROUND

Name:	[redacted]
Position:	Operations Executive
Company/Organisation:	[redacted]
Year of Experience:	16 Years

PART B: REVIEW

Model 1: Business Environment-Based Risk Assessment

Criteria	Very Poor	Poor	Average	Good	Very Good
Factors/Criteria Consideration					✓
Model Development					✓
Methodology Flexibility				✓	
Mathematical Approach				✓	
Result Relevancy					✓
Necessity of the Model for Industry					✓

Comment:

Module very useful and valueable

Model 2: Organisational Reliability and Capability Evaluation

Criteria	Very Poor	Poor	Average	Good	Very Good
Factors/Criteria Consideration					✓
Model Development				✓	
Methodology Flexibility				✓	
Mathematical Approach				✓	
Result Relevancy					✓
Necessity of the Model for Industry					✓

Comment:

Good module for Shipping Lines to monitor all things for cost reducing and up to date technology.

Model 3: Arrival Punctuality Analysis

Criteria	Very Poor	Poor	Average	Good	Very Good
Factors/Criteria Consideration					✓
Model Development				✓	
Methodology Flexibility					✓
Mathematical Approach					✓
Result Relevancy					✓
Necessity of the Model for Industry					✓

Comment:

Complete analysis. Can be added with solutions to avoid the delay.

Model 4: Departure Punctuality Analysis

Criteria	Very Poor	Poor	Average	Good	Very Good
Factors/Criteria Consideration					✓
Model Development				✓	
Methodology Flexibility					✓
Mathematical Approach					✓
Result Relevancy					✓
Necessity of the Model for Industry					✓

Comment:

Similar with model 3.

This analysis can be adapted to terminal and county also to attracted other Shipping Lines.