ENABLING SECURITY AND RISK-BASED OPERATION OF CONTAINER LINE SUPPLY CHAINS UNDER HIGH UNCERTAINTIES

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Abstract

Container supply chains are vulnerable to many risks. Vulnerability can be defined as an exposure to serious disturbances arising from the risks within the supply chain as well as the risks external to the supply chain. Vulnerability can also be defined as exposure to serious disturbances arising from a hazard or a threat. Containers are one of the major sources of security concerns and have been used, for example, to smuggle illegal immigrants, weapons, and drugs. The consequences of the use of a weapon of mass destruction or discovery of such a device in a container are serious. Estimates suggest that a weapon of mass destruction explosion and the resulting port closure could cost billions of dollars. The annual cost of container losses as consequences of serious disturbances arising from hazards is estimated as $500 million per year. The literature review, historical failure data, and statistical analysis in the context of containerships' accidents from a safety point of view clearly indicate that the container cargo damage, machinery failure, collision, grounding, fire/explosion, and contact are the most significant accident categories with high percentages of occurrences. Another important finding from the literature review is that the most significant basic event contributing to the supply chains' vulnerability is human error. Therefore, *firstly,* this research makes full use of the Evidential Reasoning *(ER)* advantages and further develops and extends the Fuzzy Evidential Reasoning *(FER)* by exploiting a conceptual and sound methodology for the assessment of a seafarer's reliability. Accordingly, control options to enhance seafarers' reliability are suggested. The proposed methodology enables and facilitates the decision makers to measure the reliability of a seafarer before his/her designation to any activities and during his/her seafaring period. *Secondly,* this research makes full use of the Bayesian Networks *(BNs)* advantages and further develops and extends the Fuzzy Bayesian Networks *(FBNs)* and a "symmetric method" by exploiting a conceptual and sound methodology for the assessment of human reliability. Furthermore a *FBN* model (i.e. dependency network), which is capable of illustrating the dependency among the variables, is constructed. By exploiting the proposed *FBN* model, a general equation for the reduction of human reliability attributable to a person's continuous hours of wakefulness, acute sleep loss and cumulative sleep debt is formulated and tested.

A container supply chain includes dozens of stakeholders who can physically come into contact with containers and their contents and are potentially related with the container trade and transportation. Security-based disruptions can occur at various points along the supply chain. Experience has shown that a limited percentage of inspection, coupled with a targeted approach based on risk analysis, can provide an acceptable security level. Thus, in order not to hamper the logistics process in an intolerable manner, the number of physical checks should be chosen cautiously. *Thirdly,* a conceptual and sound methodology (i.e. *FBN* model) for evaluating a container's security score, based on the importer security filling, shipping documents, ocean or sea carriers' reliability, and the security scores of various commercial operators and premises, is developed. Accordingly, control options to avoid unnecessary delays and security scanning are suggested. *Finally,* a decision making model for assessing the security level of a port associated with ship/port interface and based on the security score of the ship's cargo containers, is developed. It is further suggested that regardless of scanning all import cargo containers, one realistic way to secure the supply chain, due to lack of information and number of variables, is to enhance the ocean or sea carriers' reliability through enhancing their ship staff's reliability. Accordingly a decision making model to analyse the cost and benefit (i.e. CBA) is developed.

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Abbreviations

ABS	American Bureau of Shipping
ACEP	Approved Container Examination Procedure
AHP	Analytic Hierarchy Process
AIS	Automatic identification systems
ALARP	As Low As Reasonably Practicable
APA	American Psychological Association
ARPA	Automated Radar Plotting Aids
ATS	Automated Targeting System
BBN	Bayesian Belief Networks
BL	Bill of Lading
BN	Bayesian Network
BRM	Bridge Resource Management
BST	Basic Safety Training
CBA	Cost Benefit Analysis
CBP	Customs and Border Protection
CI	Consistency Index
CLP	Container Load Plan
CLSC	Container Line Supply Chain
CPT	Conditional Probability Table
CSC	Container Supply Chain
CSD	Container Security Device
CSI	Container Security Initiative
CSS	Container's Security Score
C-TPAT	Customs-Trade Partnership Against Terrorism
CTSB	Canadian Transportation and Safety Board
DAG	Directed Acyclic Graphs
DNV	Det Norske Veritas
DOS	Declaration Of Security
DR	Dock Receipt
D-S	Dempster-Shafer
EIR	Equipment Interchange Receipt
ER	Evidential Reasoning
ETA	Event Tree Analysis
FBCP	Formal Business Continuity Planning
FBN	Fuzzy Bayesian Network
FCL	Full Container Loads
FER	Fuzzy Evidential Reasoning
FSA	Formal Safety Assessment
FST	Fuzzy Set Theory
FTA	Fault Tree Analysis
GDP	Gross Domestic Product
GMDSS	Global Maritime Distress Safety System
GPS	Global Positioning System
HAZID	HAZard IDentification
HAZOP	HAZard and OPerability studies
HSE	Health and Safety Executive
HTS	Harmonized Tariff Schedule
ICES	Intermodal Container Exit System
ICI	Independence of Casual Influence
ICSC	International Convention for Safe Container
ID	Influence Diagram
IDS	Intelligent Decision System via evidential reasoning

ILO	International Labour Organization
IMB	International Maritime Bureau
IMDG	International Maritime Dangerous Goods
IMO	International Maritime Organization
IOR	Importer Of Record
ISF	Importer Security Filling
ISL	Institute of Shipping and Logistics
ISM	International Safety Management code
ISO	International Standardized Organization
ISPS	International Ship and Port facility Security code
JPD	Joint Probability Distribution
LC	Letter of Credit
LCL	Less than Container Load
LMIS	Lloyds Maritime Information Services
MADM	Multiple Attribute Decision Making
MAIB	Marine Accident Investigation Branch (UK)
MAUT	Multiple Attribute Utility Theory
MCA	Maritime and Coastguard Agency
MCDM	Multiple Criteria Decision Making
MEU	Maximum Expected Utility
MF	Membership Function
MSA	Maritime Safety Agency
NED	Next Examination Date
NII	Non-Intrusive Inspection
NNSA	National Nuclear Security Administration
PFSO	Port Facility Security Officer
PFSP	Port Facility Security Plan
PPP	Purchasing Power Party
PRA	Probabilistic Risk Assessment
PSCO	Port State Control Officer
RCO	Risk Control Option
RFID	Radio Frequency Identification Device
RI	Random Index
ROB	Remain On Board
RPN	Risk Priority Numbers
SA	Sensitivity Analysis
SCM	Supply Chain Management
SFI	Secure Freight Initiative
SOLAS	Convention on the Safety of Life at Sea
SSA	Singapore Shipping Association
SSP	Ship Security Plan
STCW	Standard for Training Certification and Watch keeping
TEU	Twenty feet Equivalent Unit
TOPSIS	Technique for Order Preference by Similarity to an Ideal Solution
WMD	Weapon of Mass Destruction

Chapter One

Introduction

Summary

This chapter first introduces the key definition used in this research. The research aim and objectives are then defined, followed by the background. The objectives and hypotheses of this thesis will serve to set out a logical structure of this thesis which is aimed at addressing the inherent problems outlined. The main research methodology is briefly discussed as well as the scope and structure of the thesis.

1.1. Definition for Typical Terms Used in This Research

In the process of constructing a risk model for the safety and security of container line supply chains, definitions of the following terms are useful:

An unintended event involving fatality, injury, property loss or damage, and/or environmental damage is called an *Accident.*

Container supply chains can be defined as one logistics distribution service that extends liner shipping services (which are provided on a regularly scheduled basis to pre-determined ports) to inland transport services, to complete efficient flow and storage of container cargoes, information and related value added service from point of consumption for the purpose of conforming to consumers' requirement (Yang *et al.*, 2005a).

The process of sufficiently reducing uncertainty and doubt about alternatives to allow a reasonable choice to be made among them is called *Decision Making* (Harris, 1998).

The time between the first identification of abnormalities and actual failure time will vary depending on the deterioration rate of the component; this period is called the *Delay Time* or opportunity window to carry out the maintenance or an inspection (Pillary and Wang, 2003). The time to failure for any component cannot be predicted accurately. The failure can only be characterized by the stochastic properties of the population as a whole. The times to failure can be used to form a probability distribution which gives the likelihood that the component will have failed prior to sometime *"t"* (Andrews and Moss, 2002).

Formal Safety Assessment (FSA): FSA is based on the principles of identifying hazards, evaluating risks and cost benefit analysis (CBA), and has as its objective the development of a framework of safety requirements for shipping in which risks are addressed in a comprehensive and cost effective manner (MSA, 1993; MCA, 1996). The FSA methodology comprises five inter-related steps and is listed as follows (MSA, 1993; Pillary and Wang, 2003):

- The identification of hazards.
- The assessment of risks associated with those hazards.
- Ways of managing the risk identified.
- Cost benefits assessment of the options.
- Decision on which options to select.

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

An unforeseen or unexpected event, which may have the potential to become an accident but in which injury to personnel and or damage to the ship or to the environment does not materialised or remains minor is called an *Incident* (Wang and Trbojevic, 2007).

In the context of risk assessment, *Judgment* is not simply the final decision but is an integral part of the whole risk assessment progress with the essential nature as the ability to make a critical assessment of evidence (Chicken and Posner, 1998).

Knowledge encodes judgments about the general tendency of things to happen, *evidence* summarizes the impact of that which actually happened, whereas *belief* combines the two, it consists of assertions about a specific situation inferred by applying generic knowledge to a set of evidence sentences (Aleliunas, 198).

The characteristic of an item expressed by the probability that it will perform a required function under stated conditions for a stated period is called a *Probability distribution* (Henley and Kumamoto, 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 the environment or as the probability of the absence of failure affecting the performance of the system over a given time interval and under given environmental conditions. Reliability is therefore a measure of the probability of the successful performance of the system over a period of time (Andrews and Moss, 2002). Lusser (a German mathematician) queried the original assumption that the reliability of a chain of components was determined by the strength of its weakest link (Andrews and Moss, 2002).

A *Reliability Network* is a representation of the reliability dependencies between the components of a system. Dependencies are used in such a way as to represent the means by which the system will function. A system where component failure cannot be tolerated (a non-redundant system) is called a *Series Network* (Andrews and Moss, 2002).

A combination of probability of occurrence of an undesired event and the degree of its possible consequences is called *Risk* (Wang and Trbojevic, 2007).

A comprehensive estimation of the probability and the degree of the possible consequences in a hazardous situation in order to select appropriate safety measures is called *Risk Assessment* (Wang and Trbojevic, 2007).

Robustness can be defined as the extent to which a system is able to perform its intended function relatively well in the presence of failures of components or subsystems (Santa-Fe institute, 2001).

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

Reliability and safety analyses are different concepts that have a certain amount of overlap between them. Reliability analysis of an item involves studying its characteristics expressed by the probability that it will perform a required function under stated condition for a stated period. If such an analysis is extended to involve the study of the consequences of the failure in terms of possible damage to property and the environment or injury /deaths of the people, the study is referred to as *safety analysis* (Pillary and Wang, 2003).

An action or a potential action likely to cause damage, harm or loss is called a _Threat_ (Burns *et al.*, 2003).

Security is 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).

A situation in which a person does not have the appropriate quantitative and qualitative information to describe, prescribe or predict deterministically and numerically a system, its behaviour or other characteristics is called _Uncertainty_ (Zimmermann, 2000).

1.2. Background

Prior to the development of the shipping container in 1960, maritime cargo was transported in two ways: "bulk cargo" and "break bulk cargo". Mixed cargo was placed on pallets and loaded and discharged from ships' cargo holds by crane. The break bulk method had many disadvantages. It was often extremely lengthy, labour intensive, highly susceptible to pilferage, breakage and weather factors, and involved a highly inefficient system for getting cargo from ports to their ultimate destination. However, with the introduction of the shipping container, a single container could be discharged from a containership directly to a truck chassis and could be out of a port facility in a matter of minutes. Containers loaded with cargo at a manufacturing site could now be delivered directly to a wholesaler, retailer or distributor without the container ever having been opened (Kelly, 2007). "The maritime transportation system is an industry that typifies the notion that *time is money*" (Kelly, 2007). The reasons for rapid development of container transport are as follows (Kelly, 2007):

- It helps to improve the cargo handling efficiency and speed up the turnover of ships.
- It helps to improve the transport quality and reduces the cargo damage and shortage.
- It helps to save different items of fee and reduces the transport cost.
- It helps to simplify the transport procedure and make the transport more convenient.
- It changes the traditional unitary transport into coherent unitised transport enhancing the development of international multimodal transport.

The container supply chain system integrates the service of shipping lines, ports and inland transport, and consequently extends "port to port" to "door to door" services. One of the most obvious properties of this evolution is that port and inland transport services are effectively integrated (rather than simply physically combined with the shipping lines) by many value added services and exchange of information. This integration provides the ability of a "one stop shop" service for the chains (Yang *et al.*, 2005b). The paradigm (i.e. one stop shop) has allowed the container supply chains to contribute to economic prosperity, but renders them uniquely vulnerable to many risks, ranging from the possibility of physical breaches in the integrity of shipping to interruption of communication (Yang *et al.*, 2005b).

Supply chain security has emerged as an area of vital importance for both the users and providers of the freight transportation system. This importance is in large part due to the economic importance of global international trade. Recent events have created a fundamental shift in thinking regarding the types of threats that may affect supply chain systems. Supply chain and freight transportation security now typically refers to a state of protection against various terrorist threats, most notably as the freight transport vehicle for the weapons of mass destruction (i.e. containership, aircraft, train, and truck).

Smuggling of terrorists and terrorist weapons using freight containers is another major threat. It is obvious that security against terrorist threats, similar to security against narcotics smuggling or security against hazardous materials spills, is a public good in the parlance of economics. Since risk probabilities are perceived to be very small and potential consequences are difficult to measure, firms are unlikely to bear protection costs, and market forces alone may not provide motivation for them to protect themselves against supply chain terrorism threats. However, the potential societal impact of terrorist attacks to supply chains and/or the transportation infrastructure supporting supply chains is high, and therefore societies have begun to employ regulation to ensure some degree of supply chain security (Savelsberg *et al.*, 2004).

The international trading system is composed of manufacturers, port authorities, terminal operators, transportation companies (both local and international), security companies (together with local and national governments), participating agencies (e.g., customs and immigration), and consumers. The cost of any security system will be allocated among these various actors. If the net security system cost is small (a few percent of shipping costs, or a few tenths of a percent of the value of the goods shipped), it may, in many cases, be possible to pass those costs on to the consumer without noticeable effect. However, as the net costs of security increase relative to shipping costs this option may become exhausted, and the political and economic dilemmas of deciding where in the system those costs will be absorbed will become more difficult to resolve (CIS, 2002). For instance, the economic impact on U.S. supply chains due to higher shipping costs, increased travel times, increased inventories, border delays, and other changes as a direct result of the 11 September 2001 terrorist attacks is estimated to be $150 billion per year (Bernasek, 2002).

1.3. Statement of Problem

Container supply chains are vulnerable to many risks. In a supply chain context, logistics internal and external risks together endanger the continuity and reliability of the chains. Yang *et al.* (2005a) discussed the risks in container line supply chains from four aspects (i.e. process, person, organization and environment). The work by Christopher and Lee (2004) hinted that the risks could be classified to be expected and non-expected. Furthermore, the complexity of supply chains' risks arises when it interacts with the other two risk characteristics (i.e. uncertainty and dependence). The complexity of container line supply chains' risk immediately leads to the lack of visibility to monitor the safety performance of supply chains. It is often the case that one member of a supply chain has no detailed knowledge of what goes on in other parts of the chain (e.g. not adequate risk mitigation or control measures for keeping the reliability and continuity of the chain). Because there is no visibility of upstream and downstream flows and stocks, confidence declines and decisions are made to apply safety and security control measures to the individual sections/sub-chains of the supply chain for preventing/mitigating risks. Obviously, uncertainty makes it extremely difficult to clearly identify the vulnerability of supply chains and assess their risks. Interactive dependence significantly discounts the effectiveness of risk control. Container supply chain systems suffer from high levels of dependence between their risk factors or components. In order to stay competitive, maintain cost-effectiveness, and achieve reasonable safety and reliability, the systems have to take into account such risk dependence.

Based on Savelsbergh *et al.* (2004)'s research, the challenges of conducting the research are listed as follows:

1. What are suitable metrics for measuring supply chain infrastructure risk?
2. What are appropriate systems for measuring and quantifying the indirect societal risk posed by supply chains and supporting supply chain infrastructure?
3. How should the transportation infrastructure component of risks be estimated?
4. How should vulnerability of infrastructure components be measured?
5. Are there appropriate metrics for understanding the importance of certain infrastructure components to supply chain performance, so that appropriate protection prioritization can be made?
6. How can supply chain risk be categorized and quantified?
7. What are appropriate methods for measuring the likelihood or probability of highly disruptive events?
8. How can the likelihood of rare events with limited historical precedents be estimated?
9. How can a supply chain's vulnerability to disruption be measured?
10. How can a supply chain's ability to react and recover from highly disruptive events be measured?

This research is primarily concerned with the uncertainties regarding the measurement parameters of container supply chains' risks and their factor relationships. This is because they are concerned with the types of uncertainties that can be expressed in probabilistic or/and possibilistic terms, and only probability and possibility are appropriate mediums to the effective risk assessment of supply chains. In many typical risk analysis approaches, risk measurement parameters are represented by empirical quantities. To be empirical, these quantities must be measurable, at least in principle. In other words, they must have a correct value, as opposed to an appropriate or good value (Morgan and Henrion, 1990). This is, however, not straightforward, and frequentists recognise that empirical quantities may be random and incomplete in some conditions and thus, require disparate data sources to be incorporated. The randomness depends on the variations between observations and the number of observations, and is usually expressed in terms of a sample variance or confidence intervals around the sample mean. The incompleteness indicates the unavailability of historical data. Consequently, subjective interpretations are incorporated using linguistic assessments. However, such linguistic descriptions define risk measurement parameters to a discrete extent so that fuzziness can at times be produced.

1.4. Research Objectives and Their Hypothesis

The primary aim of this research is to generate a novel quantitative risk assessment methodology for the operation of container line supply chains under high uncertainty. Providing such a methodology will enable the companies involved in container line supply chains to identify, manage and control the vulnerability of the chains and to support the safety and security planning for both mitigating and continuity actions. In order to achieve this aim, some contributory objectives need to be carefully addressed. They are listed as follows:

- To identify uncertainties in modelling both hazards and threads in container line supply chain operations.
- Producing sufficient conceptual and actual scenarios, to deal with lack of data.
- To develop a novel mathematical model using the fuzzy logic and evidential reasoning algorithm, for assessment of reliabilities.

- To develop a Fuzzy Bayesian Network (FBN) methodology to deal with dependencies between criteria using fuzzy logic and the expected utility to assist in appropriate distribution of prior probability.
- To produce an advance dynamic security assessment technique using Fuzzy Bayesian Network (FBN) to deal with dependencies between security factors.
- To conduct case studies to show how the proposed network, models and methods can be used to improve marine operations.

The hypothesis that the objectives depend on is that the most widely used uncertainty treatment theories such as fuzzy logic, Bayesian probability and Dempster-Shafer *(D-S)* can be the foundation of and have significant contribution in developing novel and advance risk assessment and decision making models in the context of container line supply chains.

1.5. Research Methodology and Scopes of Thesis

At an early stage in the work, the research was broken down into four key themes and it was these that directed the structural design of the research methodology, the acquisition of the data itself and its subsequent analysis. The four key themes were identified as being:

1. Identification of research problems and challenges.
2. Critical review of the supply chains' operation, accidents and literature related to the challenges identified in Step 1.
3. Using probability and possibility theories such as Bayesian network, fuzzy set method, and evidential reasoning to assess and aggregate the reliability of different variables from dissimilar universes, and to calculate the effect of their reliability on the vulnerability of supply chain systems.
4. The validation of the hypothesis by comparing and analysing the modelling produced in Step 3.

The supply chain flow can be segregated into two groups, which are described as links and nodes. The links are trucks, trains, containerships, information transmission facilities and their infrastructures, roads, rails, inland waterways, liner shipping lanes and cables/satellites. The nodes are warehouses, LCL premises, rail termini/stations and ports. No links or nodes will function without the people who understand how to operate and maintain them. Therefore, any activity deviation coming from such persons may lead to a severe disruption in the chains. The primary scope of this thesis is to develop a methodology for evaluating the human reliability. Furthermore, the container supply chain can be assumed as a series network and for a series network the reliability of a system can be calculated through the reliability of its components (i.e. importers, exporters, manufacturers, manufacturing sites, inland carriers, warehouses, ports, containerships, container consolidation and deconsolidation facilities, etc.). The secondary scope of this thesis is, firstly, to develop methodologies for assessing and aggregating the reliability of different commercial operators and premises; secondly, to determine the strength of the supply chain's weakest link via the components' reliability; thirdly to suggest the control options for increasing the reliability of the supply chain from the safety and security point of view; and finally, to develop decision making models based on analysing the cost and benefit.

1.6. Structure of Thesis

This thesis is divided into six chapters, excluding this introduction. **Chapter 2** reviews the important literature influencing the current study. It includes the demonstration of the operation processes of container supply chain systems, container security, technology overview, rules and regulations, the analysis of historical failure data, the review of risk assessment methodology (i.e. fault tree analysis) related to containerships and prior studies of using uncertainty treatment methods to risk assessment and decision making. This will serve to draw attention to the possible inadequacy and limitation of the current status, thus demonstrating the need and justification of this research thesis.

Chapter 3 gives a detailed and exhaustive review of root causes for human error. Based on the review, firstly, a generic model with a hierarchical structure for evaluating the seafarers' reliability is constructed. Secondly, a conceptual methodology for evaluating the seafarers' reliability based on Fuzzy Evidential Reasoning (FER) is generated. Thirdly, the methodology developed has been applied to a case study in order to demonstrate the process involved. Finally, control options to enhance seafarers' reliability are suggested. The proposed methodology enables and facilitates the decision makers to measure the reliability of a seafarer before his/her designation to any activities and during his/her seafaring period.

The seafarers' reliability depends upon many variables and alteration of a criterion value will ultimately alter their reliability. For instance, if the grade of a ship's design and habitability is very bad and the grade of the sea condition is very rough, then due to noise and vibration, a seafarer will not be able to sleep appropriately. Therefore, his/her rest hour's grade will descend from a good grade to an average grade. Consequently, his/her stress levels and the condition of his/her health will alter. Graphs have proven to be a very intuitive language for representing such dependence and independence statements, and thus provide an excellent language for communication and discussing dependence and independence relations among problem-domain variables. **Chapter 4** makes full use of the BNs' advantages and further develops and extends Fuzzy Bayesian Networks (FBNs) and a "symmetric method" by exploiting a conceptual and sound methodology for the assessment of human reliability. The methodology developed has been applied to a case study in order to demonstrate the process involved. Furthermore a FBN model (dependency network), which is capable of illustrating the dependency among the variables, is constructed. By exploiting the proposed FBN model, a general equation for the reduction of human reliability attributable to a person's continuous hours of wakefulness, acute sleep loss and cumulative sleep debt is formulated and tested. Based on the developed equation and a person's sleep/wake timelines, the control options for improving his/her reliability are suggested. The model applies FBN construction to allow researchers to appreciate a novel attempt of unifying possibility and probability theories by introduction of the FBN approach and symmetric model.

The container supply chain can be assumed as a series network and for a series network the reliability of a system can be calculated through the reliability of its components (i.e. importers, exporters, manufacturers, manufacturing sites, inland carriers, warehouses, ports, containerships, container consolidation and deconsolidation facilities, etc.). In **Chapter 5**, methodologies for evaluating the reliability of different commercial operators and premises are generated. Furthermore, by use of the Fuzzy Bayesian Network (FBN) a conceptual and sound methodology for evaluating a container's security score is developed. The methodology implemented in this chapter can be used for targeting those containers which pose high risk to the container supply chains. Furthermore, it can be used to identify the commercial operators that do not act appropriately to secure their supply chains. Based on the model output, in order to obtain a competitive advantage and to improve the commercial operators' motivations, the financial burden can be placed upon those operators that do not act appropriately. Thus the cost of any security system may be justified.

Based on IMO rules (2003, Codes 2.9-2.11, Part A), individual governments are required to assess the risk facing their ports and establish a tree-tier security system. **Chapter 6** generates a new approach to pre-processing of input data that allows the use of standard BN techniques and software tools for evaluating the security level of a port. The aim of this study is to exploit a FBN decision making model for assessing the security level of a port, based on the security score of a ship's cargo containers prior to ship/port interface. It is further suggested that regardless of scanning all import cargo containers, one realistic way to secure the supply chain, due to lack of information and number of variables, is to enhance the ocean or sea carriers' reliability through enhancing their ship staff's reliability. Accordingly a decision making model to analyse the cost and benefit (i.e. CBA) is developed.

Chapter 7 provides conclusions from the overall study. The chapter begins by discussing the main conclusions and whether these conclusions have been addressed in this research project. This chapter will also ascertain as to whether this investigation has been a contribution to research. The limitations of this research are also given together with possible future research which can expand and explore this body of research.

Chapter Two

Literature Review

Summary

In this chapter, the important literature influencing the current study is reviewed. It includes the demonstration of the operation processes of container supply chain systems, container security, technology overview, rules and regulations, the analysis of historical failure data, the review of risk assessment methodology related to containerships and prior studies of using uncertainty treatment methods to risk assessment and decision-making.

2.1. Introduction

Legal maritime trade that is driven by global economic growth and flourishing international trade will be tripled by 2020 (CSI, 2006). The most significant growth will be in the container shipping industry with the trend toward larger ships carrying more containers. Global trade along with the volume of cargo and size of ships needs modified container terminals. Therefore, all container terminals have to expand their infrastructure, deepen the channels in their harbours and provide more virtual ports with online processing to remain competitive (CSI, 2006).

The commercial advantages of containerisation appear to have become a focus at the expense of safe operations. For the safe operation of a container vessel, the application of good seamanship and cautious operational practice is essential. Conversely, these requirements are not widely recognised by many in the containership industry (AIMS, 2008). Container carriers are unique from structural, strength, stability, cargo, ballast condition, manoeuvrability, cargo handling, and operational points of view. Currently the numbers of sea going officers and available maintenance timing have decreased. Due to short port stay and reducing the manning scale, working pressure on ships' staff are drastically increased and subsequently the fatigue level is increased. The annual cost of container losses as consequences of serious disturbances arising from hazards is estimated as $500 million per year (AIMS, 2008).

change for the bill of lading from the shipping company. When the loading is completed, the forwarders should send the shipping advice to the consignee, in order that the consignee could organise the payment, balance the bills and be ready to receive cargoes (ibid.).

2.2.2. Handover of Container Transport Cargo

Container transport includes FCL (Full Container Load) and LCL (Less Container Load). A consignor (e.g. a factory or a warehouse) boxes up FCL. Then it is delivered directly to the container terminal for loading. When the cargoes arrive at the destination, the consignee can pick them up directly from the destination container terminal or disembarkation port. The carrier is responsible for the whole goods, and handover of the box. As long as the container's appearance looks similar when being collected and the seal is intact, the carrier's job is completed. LCL refers to when the goods do not fill a whole container, the carrier should put small amount of goods of different consignors into a container at the container freight station. When the carrier is responsible for the container stuffing / consolidation and un-stuffing / deconsolidation, consignors pay the related fees. The carrier's responsibility for LCL is the same as the traditional break-bulk transportation (ibid.).

The general handover method of container goods can be categorised as follows (ibid.):

1. FCL/FCL refers to the carrier's handover of the goods in full container from departure place to destination.
2. FCL/LCL refers to one consignor with more than one consignee, so that after arrival, the goods should be delivered in break bulk.
3. LCL/ FCL refer to more than one consignor with one consignee.
4. LCL/LCL refers to the case where both consignors and consignees are more than one.

documents required for a container's transport (ibid.):

- Equipment Interchange Receipt (EIR) is used for picking empty containers and sending the loaded containers to a container terminal.
- Container load plan (CLP) records the name, weight, size, amount of the loaded goods in each container, according to the actual filled-in goods. A CLP is of five copies, each of which is given respectively to the terminal, the carrier, the shipping agent, the shipper and the party that stuffs the container.
- Dock Receipt (DR), the consignors send the containers to a container terminal, and get a DR in exchange for the bill of lading (BL).

2.3. Container Security

The degree of uncertainty is highly proportional to availability of data. Help of technology development can detect the contents of a container. As a result, the probability of detecting a container that contains illicit materials can be increased and consequently the security of the global supply chain can be enhanced.

Custom and Border Protection (CBP) targets vulnerabilities to containerised cargo destined for the United States in the maritime environment through advance and enhanced information and trade data. This is done using the twenty-four hour rule, implemented in January 2003. Based on this rule, manifest and bill of lading information has to be submitted to the CBP twenty-four hours in advance of the cargo being loaded on a ship at a foreign port. The twenty-four hour rule allows CBP officers to pre-screen and target high-risk shipments and containers before they arrive in a United States port (CSI, 2006). Failure to comply with the regulation may lead to a civil penalty, and permission to load or unload cargo to or from the vessel may be denied (CSI, 2006).

When examining a container, that poses a potential terrorist threat, the CBP officers are conducting either non-intrusive or physical inspections. The Non-Intrusive Inspection (NII) involves use of X-ray or gamma ray scanners to generate an image of the contents, which CBP officers review for anomalies (CSI, 2006). The CBP officers also scan a cargo container by using radiation detection devices. If an irregularity is identified, officers may physically examine all or a portion of the container's contents (CSI, 2006). Based on expert opinion added security provided by the container security initiative (CSI) is illusory since, in large part, targeting is based on the description of contents provided by supplier, statistically, less than one per cent of containers passing through CSI ports ever get scanned and only a tiny fraction of them are ever opened for inspection (Kelly, 2007)

The milestone of CBP personnel, working side-by-side with overseas customs partners, is to identify and embargo containers posing a high-risk of terrorism before they arrive at a U.S. port. As correspondence is achieved, this strategy will both secure global supply chains and reduce the number of security inspections required upon arrival at U.S. ports (CSI, 2006). The CSI programme guidelines for securing global supply chains are listed as follows (CSI, 2006):

- All shipments have to be screened through an Automated Targeting System (ATS).
- CBP officers have to use ATS to review and hold all high-risk shipments for examination.
- Cooperation and intelligence sharing has to be established.
- Foreign countries need to conduct thorough risk assessments of each nation's exports.

2.3.1. Technology Overview

Essentially two types of scanning systems are deployed or tested on maritime cargo containers at different ports. The first type is the radiation portal monitors, which are designed to detect the presence of radioactive material in containers. The second type of scanning equipment is the gamma ray, which is used to scan the contents of a container for dense material that would indicate the presence of explosives or, more likely, explosives shielded in lead (CSI, 2006). Both technologies are provided for enhancing the security of global supply chains but still substantial vulnerabilities exist.

Portal monitors and gamma ray machines have their limits. Although they can do a creditable job of addressing two types of threat (i.e. radioactive materials and dense materials), they leave other potential threats untouched. These technologies cannot detect the presence of chemical or biological agents. They cannot determine if a container has been breached at some point in time from its stuffing to its final destination and they add little overall value in supply chain visibility in the event of an actual detonation (Kelly, 2007).

To reduce the possibility of pilferage and/or tampering incidents a combination of container's seal, tracking system and smart box is suggested by experts. Tracking systems rely on three principal technologies. The advantages and limitations of these technologies are listed as follows (Balog *et al.*, 2005):

1. *Bar Code Scanning* is the most widely used data capture method for tracking and tracing. A broad spectrum of industries has adopted this method for the last several decades. Consequently, its wide usage has led to consistent research into improving the technology of capturing bar codes. Holographic scanners can now read codes from almost any orientation and pen-based portable scanners allow workers to read bar codes anywhere. These technological advances have greatly increased distribution efficiency and data integrity. However, the bar code scanning system possesses a few inherent limitations that include the need for human intervention at several points along the distribution route, non-continuous updates of the container location, and inadequate safeguard against theft.

2. *Radio Frequency Identification Device* (RFID) uses radio frequencies to communicate information from a small tag, implanted on pallets or containers, to readers. Tags are passive, drawing their power from the reader, or active, drawing their power from an internal battery. Passive systems have limited range, but can be useful in close quarters. Active systems have greater range, but cost more and

require regular maintenance, all due to the batteries. Once information from RFID tags is read, it is organised and stored in users' computers. RFID tags reduce the amount of manual inventory work that the industry conventionally performs, trimming both labour and logistical costs. For effective deployment of RFID tags, the device's limitations have to be adequately addressed in order to fuel further justification for using them.

3. *Global Positioning System* (GPS) appears to be an ideal tracking system for containers while they are on vessels. The software is relatively inexpensive to implement and the system provides instant information on the vessel's location using satellites to fix geographical positions. The system does have drawbacks, including the limited coverage in remote areas of the world, battery dependence, reliance on human intervention, and requirement of extensive maintenance. The remote coverage limitation is the main drawback that prevents GPS from tracking individual container positions on land. GPS offers significant prospects in the future as its area of coverage increases and if its ability to promote system flexibility, by reported ease of integration with other systems is improved.

"The RFID and GPS are the technologies of information storage and transfer that must then be integrated into a security system. One way of doing this is through the "Smart Box" technology, promoted by the U.S. Customs, and beginning to be used in the industry" (Balog, *et al.*, 2005). "A smart box uses an electronic seal to register every opening of the container, legitimate or illegal. Combined with an access code, the smart box records each access to the container and maintains a register of the container number, time, date, and seal number. The container security device transmits this information to a receiver, which can then be attached to any cell phone with global capability" (Balog, *et al.*, 2005).

Advantages of the smart box include the minimal cost to implement and the ability to track the container in real time. Several disadvantages also accompany this technology choice such as the visual presence of the smart box acting as a restriction and being tampered with and disrupting the viability of data. The system runs from batteries, which require maintenance and testing to ensure that they are always in working order (Balog, *et al.*, 2005).

Based on expert opinion the limitation of container seals and Container Security Devices (CSDs) can be listed as follows (Maritime Security Expo, 2006):

1. A container seal verification requirement could not be realistically implemented without the deployment of technology on a global scale.
2. The deployment of RFID container technology, dependent on fixed readers at thousands of locations around the world.
3. The uncertain number of false alarms that CSDs may generate, would cause many containers to be stopped for an undetermined time.
4. Most security experts think that, if terrorists were to use a container, they would be involved in the container stuffing origin of the shipment, and almost certainly affix appropriate container seals or devices to the container.
5. Contrary to many container device-marketing efforts, such devices have not been shown to have significant supply chain management benefits to commercial shippers.
6. A number of the technology vendors interested in such products apparently can only find a profit if they capture the devices' readings in a proprietary data network that they control and resell, a proposition that has clearly received little interest or support from container owners or from their customers.

Based on expert opinion two determined strategies that can be focused by CBP are listed as follows (Maritime Security Expo, 2006):

1. Using of better shipment data for better container targeting capability.
2. Complete inspection and 100% scanning of all containers.

2.3.2. Detection of Nuclear Material

Detecting smuggled fissile material that can be used to make a nuclear weapon is an onerous task, since highly enriched uranium has a relatively low level of radioactivity and is therefore very difficult to be detected by radiation detection equipment (Hecker, 2002). Because of the complexity of detecting nuclear material, the customs officers responsible for operating the equipment must also be trained in using handheld radiation detectors to pinpoint the source of an alarm, identifying false alarms, and responding to cases of illicit nuclear smuggling (Hecker, 2002). Radioactive materials that can be used in conjunction with conventional explosives to create a so-called dirty bomb are somewhat easier to detect, because they have much higher levels of radioactivity (Hecker, 2002).

Detection of nuclear materials inside a container relies on three principal technologies, the advantages and limitations of those technologies are listed as follows (Hecker, 2002):

1. *X- Ray Compatible Detectors:* these radiation detectors are installed on X-ray machines, which are able to screen the small packages. These detectors are not large enough to screen entire containers or other large cargo.
2. *Portal Monitors:* these detectors are larger than X-ray machines and are capable of screening the entire contents of containers, cars, or trucks.
3. *Radiation-Detection Pagers:* customs acquired radiation-detection pagers, which are worn on a belt, have limited range, and were not designed to detect weapons-usable radioactive materials. These pagers are more effectively used in conjunction with other detection equipment rather than as a primary means of detection.

2.4. Rules and Regulations

For conducting any kind of safety and security research, reviewing the international rules and regulations is essential. The rules and regulations concerning cargo containers, container vessels, and security of the CLSCs are elucidated in Appendix 1.

2.5. Containership Accident

Within this section, accident reports of containerships are reviewed and the most significant factors that have contributed to those accidents recorded. Subsequently generic data are extracted and used as a tool for hazard identification.

2.5.1. Collision between P&O Nedlloyd Vespucci and Wahkuna

The contributing factors concerning the collision between the containership P&O Nedlloyd Vespucci and the yacht Wahkuna in English Channel on 28 May 2003, are listed as follows (MIAB, 2003):

- Wahkuna's skipper misunderstood the collision regulations that are applicable in the fog.
- The containership's Master was highly confident in the accuracy of ARPA.
- The Master of the containership accepted a small passing distance.
- Yacht's skipper was unable to use the radar effectively.
- The failure of both vessels to keep an effective radar lookout.
- To meet the commercial schedules the container vessel maintained the high speed.
- Both vessels visibility was poor due to the fog.
- Poor bridge resources management.

The overreliance on the electronic equipments and automations is affected the deck and engineering officers. The engineers mostly recorded the information in the logbook from electronic data within the control room without even approaching the concerned machinery. They started auxiliary engines automatically from the control room, without even blowing through the engines and knowing the consequences of existing water or fuel on top of the pistons.

2.5.2. P&O Nedlloyd Genoa (Loss of Cargo Containers)

The contributing factors concerning the loss of cargo containers (P&O Nedlloyd Genoa) at North Atlantic Ocean on 27 January 2006, are listed as follows (MIAB, 2006):

- The process of lashing containers is physically highly demanding and potentially dangerous, and if the process is not closely supervised then shortfalls are likely to occur.
- The cargo-planning program used by "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.
- No mechanism existed for verifying declared container weights.
- In countering the effects of heavy weather, the Master generated the preconditions for parametric rolling.
- The current container inspection requirements do not consider structural strength and rigidity.

Parametric rolling can be a particular problem on ships (e.g. P&O Nedlloyd Genoa) designed with a flat transom and with large bow flare. This is a common design, found on many modern containerships in order to maximise deck cargo capacity while minimising water resistance with fine hull lines (MIAB, 2006).

2.5.3. Annabella (Loss of Cargo Containers)

The contributing factors concerning the loss of cargo containers (Annabella) on passage in the Baltic Sea on 25 February 2007, are listed as follows (MIAB, 2008a; MAIB, 2008b; Learning from Annabella, 2008; Time for Some Serious Rethinking, 2008; British Steam Ship Insurance Association Limited, 2007):

- Effective communications and procedures should exist between all parties involved in the planning and delivery of containers to ensure that ship staff have the resources and the opportunity to supervise the loading and securing of cargo safely.
- Cargo securing manuals should be comprehensive and in a format which provides ready and easy access to all relevant cargo loading and securing information.
- Loading computer programmes should incorporate the full requirements of a vessel's cargo securing manual. Such computers should be properly approved to ensure that officers could place full reliance on the information provided.
- The availability or otherwise of a reliable, approved, loading computer programme is a factor to be included in determining an appropriate level of manning for vessels on intensive schedules.
- The resultant increase in acceleration forces and consequent reduction in allowable stack weights when a vessel's GM is increased above the value quoted in the cargo-securing manual has to be understood by vessels' officers. The consequential effect on container stack weight, height and lashing arrangement for changes in the vessel's GM should be readily available and clearly displayed to ships' staff.
- Those involved in container operations are aware that containers with allowable stack weights below the ISO standard are in regular use. Therefore, they must be clearly identified at both the planning and loading stages to avoid the possibility of being crushed.
- Cargo planners should have appropriate marine experience or undergo training to ensure that ship safety considerations are fully recognised.
- Cargo planning software provided should be capable of recognising and alerting planners to the consequences of variable data (e.g. metacenteric height (GM), non-standard container specifications).
- Ships' staff should be provided with sufficient time to verify/approve proposed cargo plans.
- The shipping companies must ensure that when officers are promoted into the senior ranks they receive sufficient familiarisation.

- Officers should be fully familiar with the contents of the vessel's cargo securing manual before taking responsibility for loading and securing cargo.
- The officers and crews allocated to the vessel have to be sufficient to ensure that the requirements of the company's safety management system can be fully met.

2.5.4. Total Loss of Napoli

In January 2007, Napoli experienced heavy weather in the English Channel, causing heavy pitching and a reduction in speed over the ground. A catastrophic hull failure in the engine room resulted in flooding, abandonment of the vessel, its stranding, and total loss. The contributing factors concerning the total loss of Napoli are listed as follows (MAIB, 2008c; AIMS, 2008; Lessons to be learned from Napoli, 2008):

- Napoli when built had been one of the largest containerships ever constructed. Based on the design of earlier and smaller vessels, the ship was built in 1991 to Bureau Veritas class with no buckling strength requirement in the area of hull failure. Although the engine room was sited, further forward than most other ships being built at the time, because it was outside of the 0.4L amidships area, class rules did not require the buckling strength to be calculated at that point.
- It is almost certain that a reduction of speed would have significantly reduced the risk of hull failure.
- It was also revealed that the ship's electronic main engine governor that prevents the engine from over speeding or tripping when the propeller emerges from the sea in heavy weather was out of action at the time of accident.
- A check of containers removed from Napoli indicated that the declared weights of many of them were inaccurate. This discrepancy is widespread within the container ship industry.
- As most containerships invariably sail very close to the permissible seagoing maximum bending moments, the additional undeclared weight can cause vessels to exceed these maxima.

Container shipping is the only sector of shipping in which the weight of a cargo is not known. If the stresses acting on container ships are to be accurately controlled, it is essential that containers be weighed before loading (AIMS, 2008).

2.5.5. Fire Breakout Onboard Maersk Doha

The contributing factors concerning the breakdown and subsequent fire onboard Maersk Doha in Chesapeake Bay, off Norfolk, Virginia, USA on 2nd October 2006, are listed as follows (MIAB, 2007c; MAIB, 2007e):

- Inappropriate techniques were used to fight the fire initially, because the crew did not understand enough about the construction of the exhaust gas economiser (EGE). Moreover, they did not know how to deal with the fire effectively.
- The vessel had an extensive Quality and Safety Management System, but it lacked sufficient detail to assist the crew in dealing with either the machinery breakdown, or the subsequent fire.
- Further problems became evident during the emergency when other equipment did not work correctly. The records of emergency drills and maintenance of machinery made it difficult for the vessel's managers to assess the quality of the work being conducted onboard. Neither these systems, nor the quality and technical audits carried out on the vessel, had been able to detect the underlying condition of equipment, which subsequently failed during the emergency.
- The crew, with the exception of the Chief Engineer, were from Eastern European countries. Despite meeting the requirements for gaining UK Certificates of Equivalent Competency and being able to use the working language of the ship, there was a tendency for the majority of the crew to revert to their shared native language. This had the effect of isolating the Chief Engineer and hindered his ability to understand and control the response to the emergency.

2.5.6. Collision between Skagern and Samskip Courier

The contributing factors concerning the collision between cargo ship Skagern and containership Samskip Courier in the Humber Estuary on 7 June 2006, are listed as follows (MIAB, 2007a):

- Failure in applying long established methods concerning collision avoidance by the Masters and Pilots of both vessels.
- Both Masters were highly confident and over reliant on the Pilots.
- The communication and interaction was poor among the bridge teams.
- Samskip Courier's Pilot level of situation awareness was low.
- During manoeuvring, the Pilot on the bridge was using a mobile phone.

2.6. Container Cargo Claims

With around 12,000,000 containers in circulation and 95,000,000 loaded container movements each year the cargo container claim is a real problem for the industry. Within this section, the data that are provided by UK Protection and Indemnity Club (P&I Club) are reviewed.

The incident categories involving containerships, as shown in Figure 2.3, clearly indicate that 54% of Incidents belong to the category of container cargo damage (Wang and Foinikis, 2001). Based on UK P&I Club (2008) reports, "a considerable proportion of the club's time is taken up handling container cargo claims". The comparison of container cargo claims and all other cargo claims is illustrated in Figure 2.4. The main reasons for container cargo damage are listed as follows (UK P&I Club, 2008):

- One of the biggest contributory causes of container cargo damage is found to be bad stowage, causing nearly 20% of the claims.
- Shore error accounts for around 27% of large container cargo claims compared with 19% for all types of cargo claims. The problem originates at the time of stuffing.

2.7. Human Error

Containerships are a unique type of vessel. The existing high level of human stress on board containerships is unique. The consequences of such highly stressful environment will be error and negligence. The result of a safety study showed conclusively that the poor manning levels and human fatigue are the major causal factors in collisions and groundings (MAIB, 2004). "It is an anachronism in the 21st century that seafarers are falsifying their timesheets to prove that they are working only ninety-eight hours per week. In addition, many of these seafarers work every week, without a break, for between four and nine months before getting leave" (MAIB, 2004).

The vulnerability of CLSCs from the employees as internal people and others as external people during operations can be categorised as follows (Peck and Jüttner, 2002):

- Human errors can be due to lack of knowledge, wrongdoing, and negligence.
- People can deliberately take risks by putting late arriving containers on a vessel that is ready to sail, under the insistence of shippers.
- Employee health and safety scare, which is considered as the fourth most important scenario covered by Formal Business Continuity Planning (*FBCP*).
- Stevedores and crane operators can deliberately or unintentionally destroy the containers due to careless loading/unloading.
- Baleful attacks of external people, such as terrorist attacks and hacker activities, which are beyond the chains' direct control.

2.8. Historical Failure Data & Statistical Analysis

In order to conduct any kind of safety analysis, obtaining the reliable failure data is essential. Accident statics on generic vessel types and its effect on supply chains can be obtained from two sources, field experience and agreed judgmental estimates of experts (Wang and Foinikis, 2001).

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Several organisations conducted statistical analysis of marine accidents, for instance the Lloyds Maritime Information Service (LMIS), and the Institute of London Underwriters (ILU). On the other hand, classification societies such as Det Norske Veritas (DNV) conducted their own statistical updates of marine causalities, which are used mostly for their own internal purposes. Each marine accident can be described by a series of distinct events that take place in a specific order, for example, it is possible that a ship experiences a main engine problem, which under certain circumstances can cause drifting, grounding and eventual sinking. The existing problem with statistical data is the fact that the collected data only divulge the outcome without concerning a "proximate cause" (i.e. the first event in a chain of events that gives rise to an accident or claim). To overcome the mentioned problem, the accident statistics by nature of accident for UK vessels and non-UK vessels in UK waters are extracted from MAIB annual reports (2007d) and presented in Tables 2.1-2.3. The percentages of five accident categories (i.e. collision, contact, fire/explosion, grounding, and machinery failure) relative to the total number of accidents, extracted from Table 2.3, are shown in Table 2.4. Surveillance of Table 2.4 clearly indicates that from year 2000 onwards, the five mentioned accident categories contribute to 80% of total accidents. The percentage of each accident relative to the total number of accidents involving UK dry cargo vessels, extracted from Table 2.1, is shown in Figure 2.5. Based on Figure 2.5, the machinery failure contributes to 40% of accidents followed by grounding (18%), contact (18%) and collision (10%).

Based on port state control annual reports, as shown in Figure 2.6, the percentage of detention by the type of ship in 2006 for containerships is estimated as 37% (Port State Control in New Zealand, 2006). The highest percentage of deficiencies by category, as shown in Figure 2.7, are associated with life saving appliances (12%), fire safety measures (12%), safety of navigation (11%), and propulsion & auxiliary machinery (11%).

Table 2.1: UK Merchant Vessels in Accident by Nature of Accident and Vessel Category

[Source: MAIB, 2007]

	Dry Cargo	Passenger	Passenger Cargo	Tanker/Combination carrier	Other	Total
Capsize/Listing	0	0	0	0	2	2
Cargo Handling Failure	1	0	0	0	0	1
Collision	4	3	0	2	5	14
Contact	7	13	1	1	8	30
Escape of Harmful Substances	0	1	0	0	1	2
Fire/Explosion	0	2	0	1	3	6
Flooding/Foundering	1	1	0	0	0	2
Grounding	7	1	0	0	3	11
Heavy Weather	2	1	0	0	1	4
Machinery Failure	15	10	0	2	9	36
Person Overboard	1	4	0	0	2	7
Total	38	36	1	6	34	115

Table 2.2: Non-UK Vessels in UK Water by Nature of Accident and Vessel Category

[Source: MAIB, 2007]

	Dry Cargo	Passenger	Passenger Cargo	Tanker/Combination carrier	Other	Total
Capsize/Listing	2	0	0	0	0	2
Cargo Handling Failure	1	0	0	0	0	1
Collision	8	0	0	5	4	17
Contact	13	2	1	8	1	25
Escape of Harmful Substances	2	0	0	0	0	2
Fire/Explosion	1	0	0	0	0	1
Flooding/Foundering	0	0	0	0	0	0
Grounding	23	3	0	3	2	31
Heavy Weather	0	0	0	0	1	1
Machinery Failure	21	0	0	3	4	28
Person Overboard	1	0	0	0	1	2
Pollution	0	0	0	1	1	2
Total	72	5	1	20	14	112

2.9. Hazard/Threat Identification

Container supply chains are vulnerable to many risks. Based on the previous discussions (Section 2.1-2.7) the generic contributing factors concerning vulnerability (i.e. exposure to serious disturbances arising from a hazard or a threat) of the container line supply chain are listed as follows:

1. Direct attack to ports by a terrorist group.
2. Transport of illicit materials through ports for use in terrorist plot elsewhere.
3. Using a containership as a weapon of mass destruction.
4. Using a container as a weapon of mass destruction.
5. Commercial pressure to sail rather than to be safe.
6. Ignoring reduction in speed during bad weather due to the commercial pressure.
7. Overreliance on electronic equipments.
8. Shortfall of container lashing material.
9. Inability to verify the exact container weight.
10. Miscalculation of parametric rolling.
11. Untrained cargo planner.
12. Lack of ship staff competency and familiarisation.
13. The poor manning levels.
14. Unavailability of maintenance timing and wrong planning during dry-docking.
15. Lack of communication.
16. Lack of situation awareness.
17. Lack of teamwork.
18. Masters' overreliance on the pilots.
19. Environments.
20. Machinery failure.
21. Wrong packaging and stuffing.
22. Wrong handling of a container.
23. Wrong container loading/unloading.
24. Wrong container stowage and response procedure associated with what is in that container.

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2.10. Risk Assessment Techniques

In the 1960s, significant progress in the effectiveness and sophistication of risk assessment was achieved due to the application of risk assessment methodologies in different areas in industry. Fault Tree Analysis (FTA) was developed at the beginning of 1960s and was used as a tool in risk assessment. At the same time, a PhD thesis was published that introduced a methodology for probabilistic integrated systems for analysing the safety of nuclear power plants (Garrick *et al.*, 2004). The breakthrough in Probabilistic Risk Assessment (PRA) of technological systems came in 1975 with the publication of the 'Reactor Safety Study' by the US Atomic Energy Commission.

2.10.1. Fault Tree Analysis

Watson between 1961 and 1962 developed fault tree analysis (FTA) during an Air Force study contract for the Minuteman Launch Control System. Since the early 1970s, FTA technique has been utilised as a tool in risk assessment methodologies (Kumamoto and Henley, 1992). It is probably the most widely used technique for hazard identification and risk estimation. This technique is a process of deductive reasoning, which can be applied to a system of any size for risk assessment purposes (Wang and Trbojevic, 2007). FTA is particularly suitable for the risk assessment of large marine and offshore engineering systems for which the associated undesired events (i.e. top events) can be identified by experience (i.e. from previous accident and incident reports). FTA is a diagrammatic method used to estimate the probability of an accident (i.e. top event) resulting from sequences and combinations of faults and failure events (i.e. basic events). This technique can handle both quantitative and qualitative assessments. However, qualitative assessment may not always be possible because FTA requires knowledge of probabilities associated with basic events (Mauri, 2000).

A fault tree contains gates, which serve to permit or inhibit the passage of fault logic up the tree. The gates show the relationship of events needed for the occurrence of a higher event [i.e. top event] (Wang and Trbojevic, 2007). Based on the historical failure data and statistical analysis (Section 2.8), the five accident categories (i.e. machinery failure,

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Table 2.5: Top and Lower Events [Source: IMO, 2007]

TOP EVENT	LOWER EVENTS					
Collision	Navigational Error	Technical Failure	External Environmental Conditions	Visibility Line	Terminal Location	Main Engine (High Power)
Contact	Navigational Error	Technical Failure	External Assistance Failure	Mooring Failure	Submerged Undetected Objects	Wind
Grounding	Navigational Error	Technical Failure	Bad Weather			
Fire/Explosion	Technical Failure	Bad Stowage	Collision	Weather	Human Error	

Based on Table 2.5 and by further scrutiny of lower events, fault tree diagrams are illustrated (Figures 2.8-2.11). The gate symbol denotes the type of relationship of the input events required for the output event. For example an AND gate denotes the output occurs if all inputs occur while an OR gate denotes the output occur if at least one of the input faults occurs (Wang and Trbojevic, 2007). The pathways through the fault tree diagram represent all the events, which give rise to a top event. These pathways are known as cut sets. Basic events (e.g. E, H, and S) are those events with sufficient data. For instance, navigational error can be due to ship staff error (wrong decisions on course, speed or timing of manoeuvres) or machinery failure (e.g. failure of bridge equipment). The machinery failures are mostly due to one or combination of the following:

- Unreliability of supplied component or spare parts.
- Unreliability of designated person, the one designated to carry out maintenance and operation (i.e. human error).

- Incorrect maintenance timing and procedures.
- Insufficient time to carry out maintenance.
- Design failure.
- Incorrect dry docking procedures and timing.

Based on Figures 2.8-2.11 and the above discussions, the most significant failure event is the ship staff error.

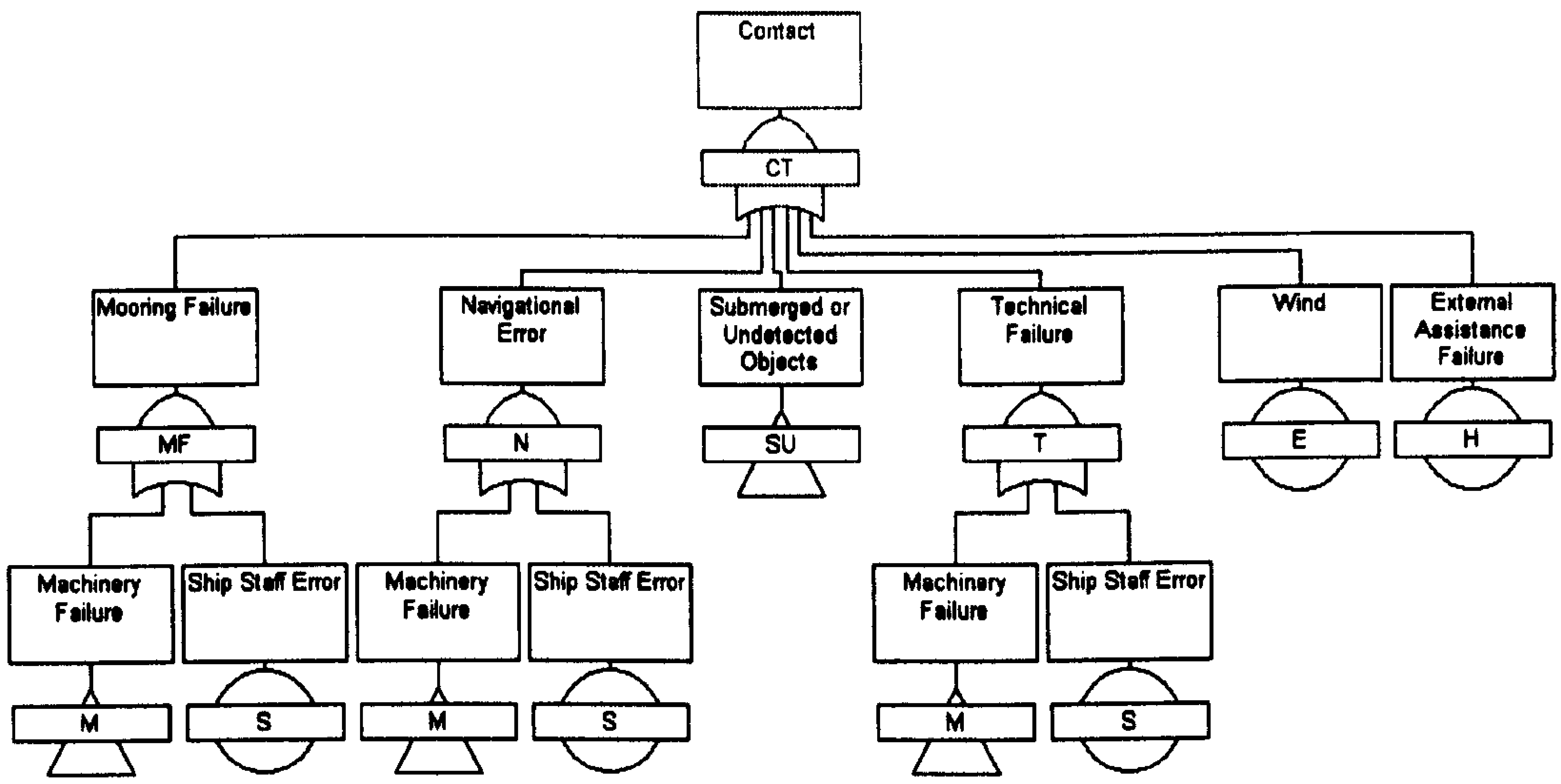

Figure 2.8: Fault Tree Diagram for Contact

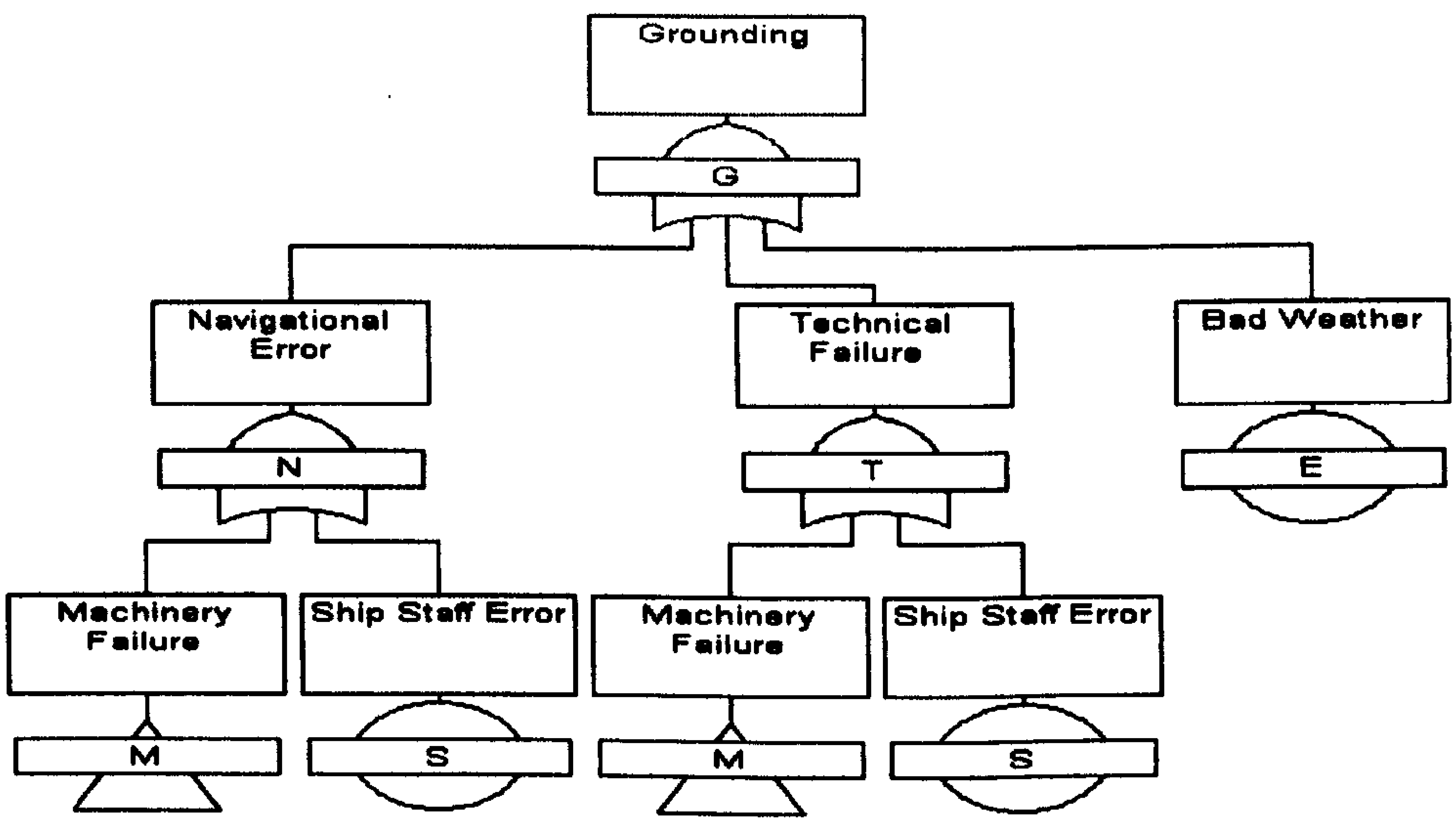

Figure 2.9: Fault Tree Diagram for Grounding

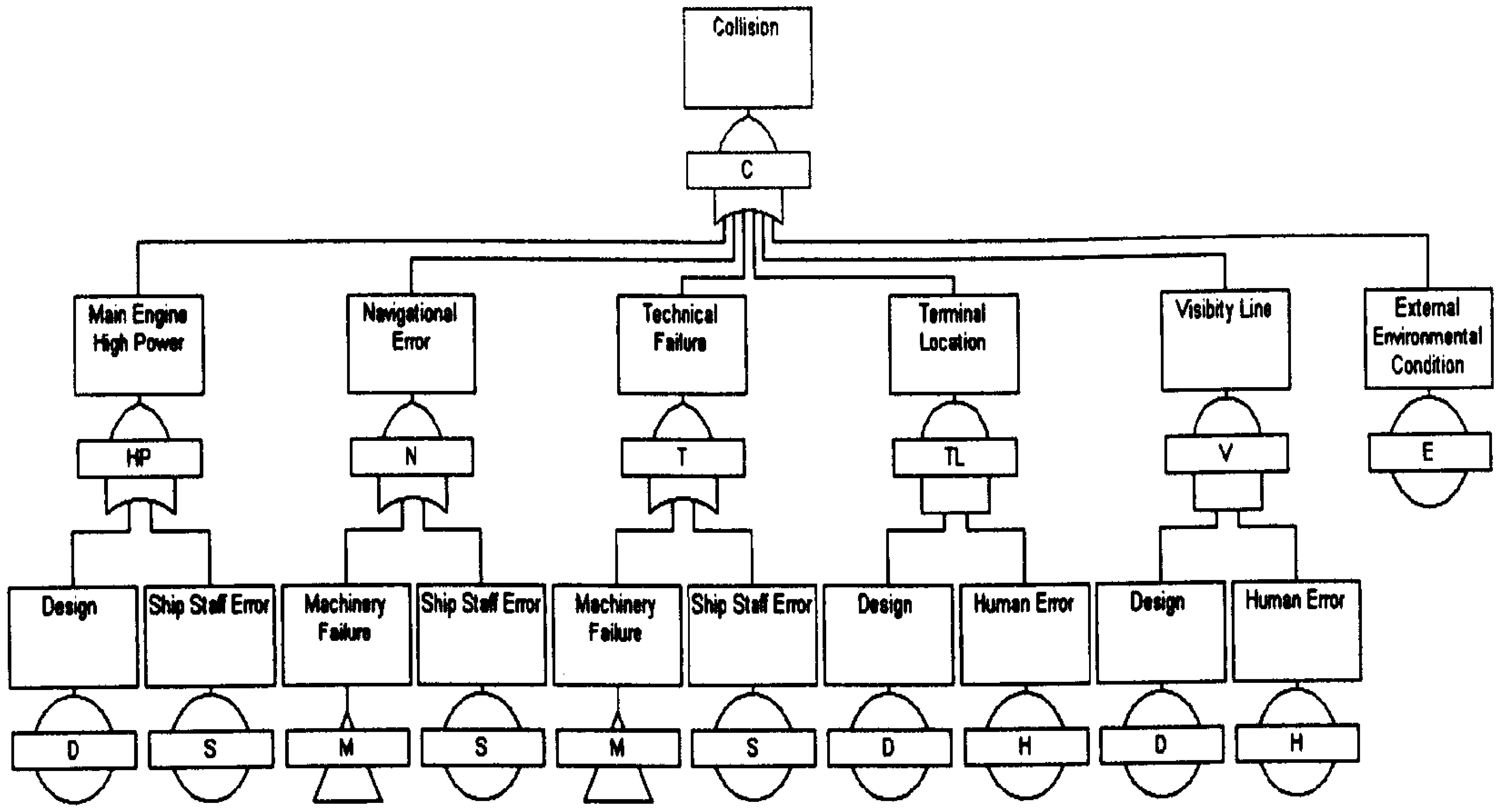

Figure 2.10: Fault Tree Diagram for Collision

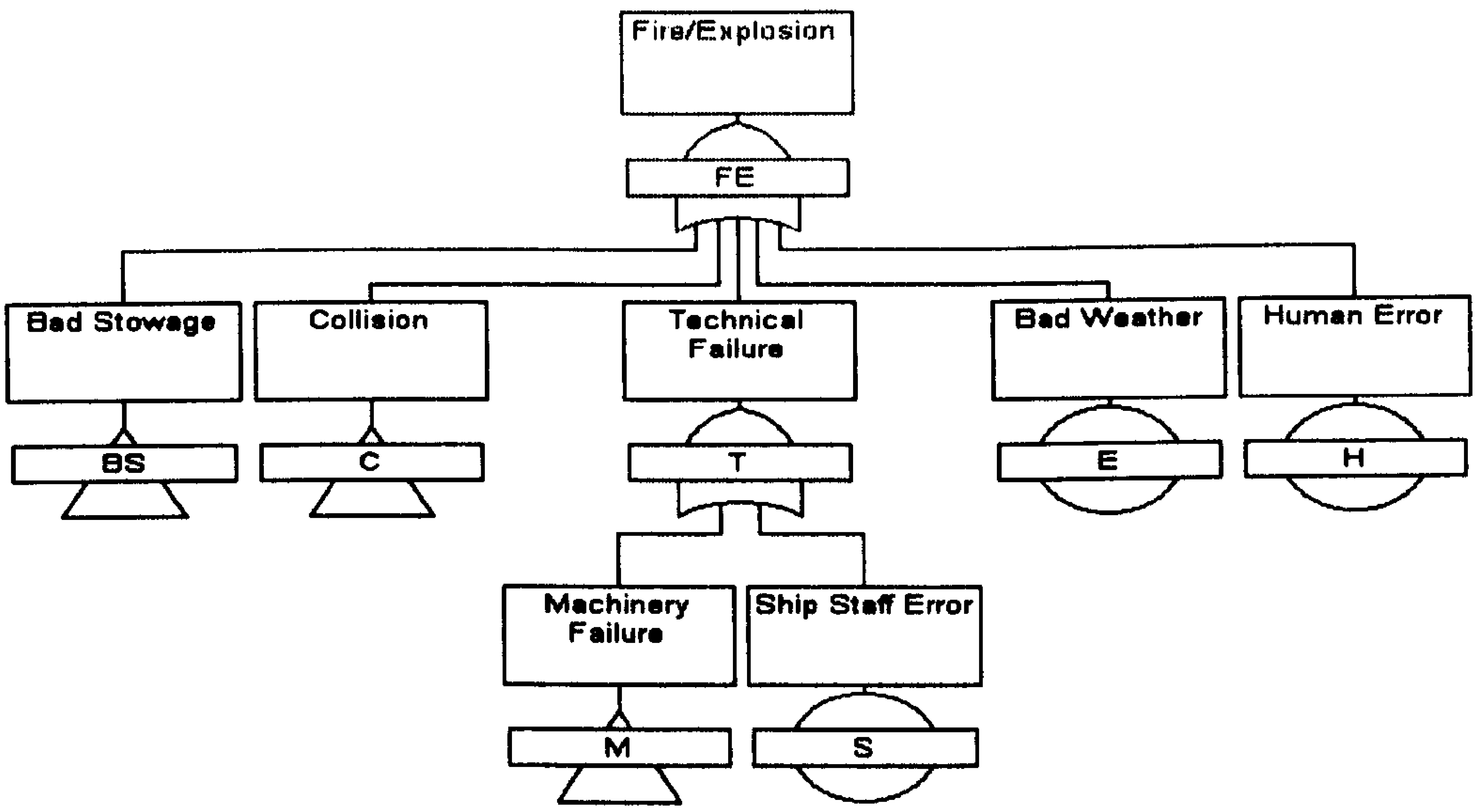

Figure 2.11: Fault Tree Diagram for Fire/Explosion

2.11. Decision Making Techniques

Bayesian networks (BNs), fuzzy logic and multiple attribute utility theory (MAUT) have proven to be powerful tools for decision-making. While BNs and fuzzy logic deal with the decisions under uncertainty, MAUT focuses on the problems with multiple attributes or criteria. In complex safety critical systems, decisions are usually made on multiple uncertain attributes. Therefore, it is possible to consider the synthesis of BNs, fuzzy logic and MAUT (or its extension – Multiple Criteria Decision Making (MCDM)) together in the forming of a more powerful risk based decision support tool. Although the work by Fenton and Neil (2001) has provided a theoretical foundation for the combination of BNs and MCDM, it uses subjective point estimation to define attribute states, which may not be well suited to modelling the safety attribute, and thus, cannot be appropriately applied to the risk domain without further research. Actually, the attempt to synthesise these techniques can be better considered as an alternative explanation to simple Influence Diagrams (IDs) including one decision node (Howard and Matheson 1981). In order to make use of the advantages of BNs, fuzzy logic and MCDM in risk based decisions; the relevant literature needs to be reviewed in the following context and in Chapter 4 (BNs is discussed in Chapter 4).

2.11.1. Fuzzy Logic

An important point of dealing with uncertainty came in 1965 with the publication of a fuzzy logic based paper by Zadeh (1965). Fuzzy logic is a superset of conventional Boolean logic with extensions to account for imprecise information. There is nothing fuzzy on the subject of fuzzy logic. Fuzzy logic permits vague information, knowledge and concepts to be used in an exact mathematical manner. Simply, it can be said that the nature of possibility theory differs from the probability theory, because in possibility theory the values are not indicated by numbers, but words, in natural or artificial language. Linguistic variables such as "definite", "likely", "average", "unlikely" and "impossible" are necessary media used to describe continuous and overlapping states. This enables qualitative and imprecise reasoning statements to be incorporated with fuzzy algorithms. Since linguistic variables are useful properties of possibility theory, fuzzy logic modelling was quickly developed in the 1970s and became one of the most recognised approaches in the expert decision system.

Fuzzy logic is based on the principle that every crisp value belongs to all relevant fuzzy sets to various extents, called the degrees of membership. Furthermore, membership functions of fuzzy sets are regularly used to deal with the ambiguity inherent in the description of the event itself. Fuzzy logic has various techniques, which can be used in uncertainty treatment. They are namely fuzzy sets and fuzzy rule base. The application of these fuzzy logic techniques depends on the situation and they are widely used in many applications. Fuzzy sets have two other categories namely discrete and continuous fuzzy sets. Fuzzy sets are based on possibility theory and most of the fuzzy techniques are developed by using fuzzy sets (Yen and Langari, 1999).

2.11.2. Fuzzy Set Theory and Fuzzy Membership Function

Zadeh (1965) introduced the notion of fuzzy sets to model vague predicates and informal reasoning in the form of fuzzy logic. The theory of fuzzy set has, one of its aims, the development of a methodology for formulation and solution of problems that are too complex, or too ill defined, to be susceptible to analysis by conventional techniques (Kandel, 1986).

Crisp variables or traditional variables do not have the natural capability to express and deal with observation and measurement of uncertainties, but the significance of fuzzy variables is that they facilitate gradual transition between states and consequently gain the natural capability (Klir and Yuan, 1995; Pillary and Wang, 2001). Although the definition of states by crisp sets is mathematically correct, in many cases, it is unrealistic in the face of unavoidable measurement errors. A measurement that falls into a close neighbourhood of each precisely defined border between states of crisp variables is taken as evidential support for only one state, in spite of the inevitable uncertainty involved in the problem.

Let X be a classical set of objects, denoted by x, called the universe. Let C be a classical subset of X and $m(x)$ be a function from X to the pair of values {0, 1} such that if $x \in C$, $m(x) = 1$, and if $x \notin C$, $m(x) = 0$. In classical sets, then, either elements of the universe belong to a set or they do not. The set is characterized by a sharp boundary and is identical with its members. By contrast, a fuzzy set $\widetilde{F}$, is a subset characterized by the set of pairs "$\widetilde{F} = \{(x, \mu\widetilde{F}(x)), \ x \in X\}$", where $\mu\widetilde{F}(x)$ represents the degree of membership with possible values ranging over the real interval [0, 1]. A membership function (MF) value of one means full representation of the set under consideration. A MF value of zero implies that the value does not belong to the set under consideration. A membership somewhere between these two limits indicates the degree of membership. In each context of application of the predicate $\tilde{F}$, the fuzzy set $\tilde{F}$ will be 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.

The fuzzy set is characterized by a membership function and there is no sharp boundary. In this way, fuzziness formalizes a kind of deterministic uncertainty and ambiguity. For instance, if $\tilde{F}$ represents the vague predicate "Tall", the fuzzy set of tall individuals will include "Very Tall" individuals, with $\mu\tilde{F}(x)$ closer to one, and "Short" individuals, with $\mu\tilde{F}(x)$ closer to zero (Cat, 2006). As an interpretation of fuzzy logic, the membership function designates a degree of truth valuation for statements of the form 'x is $\tilde{F}$'. This provides the extensional semantics for multivalent logic (Cat, 2006).

For fuzzy sets, one can introduce an algebra of set-theoretic operations. The most basic ones, introduced by Zadeh (1965), are listed as follows:

- *Union:* $\mu(\tilde{F} \cup \tilde{G})(x) = max\,(\mu\tilde{F}(x), \mu\tilde{G}(x))$
- *Intersection:* $\mu\,(\tilde{F} \cap \tilde{G})(x) = min\,(\mu\tilde{F}(x), \mu\tilde{G}(x))$
- *Complement:* $\bar{F}$ is the set of x such that, $\mu'\,\bar{F}(x) = 1 - \mu\tilde{F}(x)$, where $\mu\tilde{F}(x)$ is the degree of membership in $\tilde{F}$ (but $\mu'\,\bar{F}(x)$ is the degree of membership in $\bar{F}$) and $\bar{F}$ is the complement of $\tilde{F}$. Unlike classical sets, for fuzzy sets, $\tilde{F} \cup \bar{F} \neq \Omega$ where Ω is the universe and $\tilde{F} \cap \bar{F} \neq \emptyset$.
- *Subset:* $\tilde{F} \subset \tilde{G}$ *iff* $\mu\tilde{F}(x) \leq \mu\tilde{G}(x)$, for all x.

2.11.3. Operation of Triangular Fuzzy Numbers

Let F and G be two triangular fuzzy numbers parameterized by triples $(f1, f2, f3)$ and $(g1, g2, g3)$ respectively as shown in Figure 2.12. Then the operation laws of these two triangular fuzzy numbers are as follows (Wang and Chang, 2007):

$$(f1, f2, f3) + (g1, g2, g3) = (f1 + g1, f2 + g2, f3 + g3)$$
$$(f1, f2, f3) - (g1, g2, g3) = (f1 - g3, f2 - g2, f3 - g1)$$
$$(f1, f2, f3) \times (g1, g2, g3) = (f1 \times g1, f2 \times g2, f3 \times g3)$$
$$(f1, f2, f3) \div (g1, g2, g3) = \left(\frac{f1}{g3}, \frac{f2}{g2}, \frac{f3}{g1}\right)$$

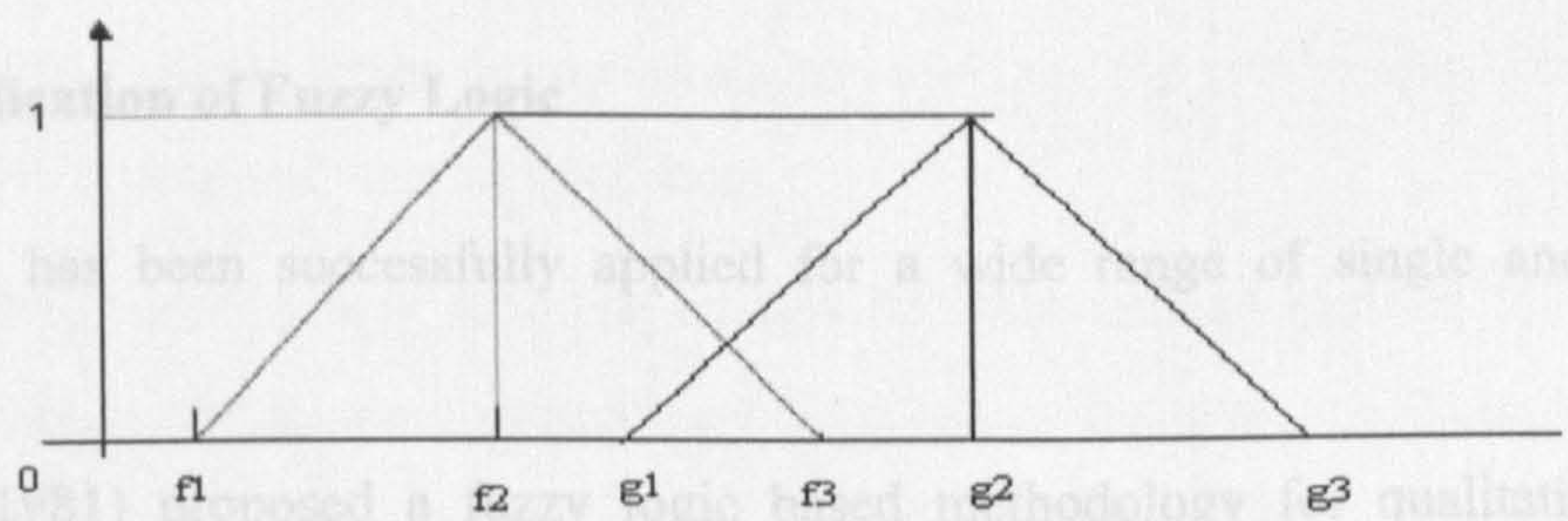

Figure 2.12: Operation of Triangular Fuzzy Numbers

2.11.4. Discrete Fuzzy Sets

Discrete fuzzy sets have been applied to many activities in the marine industry. This is because discrete fuzzy sets have several useful characteristics:

1. A linguistic term is defined by its own set of categories and their associated membership values.
2. The numerical value calculation process of each linguistic term is not complex.

2.11.5. Fuzzy Rule Base

Fuzzy rule base produces simpler, more intuitive and better-behaved models. In marine safety assessment, fuzzy *"if - then"* rules were used to model qualitative aspects (Sii *et al.*, 2001). Such a rule base has been used because Probabilistic Risk Assessment (PRA) was not well suited to deal with a system having a high level of uncertainty. "*If - then*" rules have two parts, namely, an antecedent (i.e. input) and a consequent part (i.e. the result) (Bowels and Pelaez, 1995; Pillary and Wang, 2003). For example, If occurrence is Low and severity is Very High and detectability is Moderate then the risk is Important. The fuzzy rule base has several useful properties that are listed as follows (Sii *et al.*, 2001; Bowles and Pelaez, 1995):

1. The rules are usually more conveniently formulated in linguistic terms than in numerical terms.
2. They are often expressed as "*if - then*" rules, which are easily implemented by fuzzy conditional statements.

2.11.6. Application of Fuzzy Logic

Fuzzy logic has been successfully applied for a wide range of single and *MCDM* problems.

- Yager (1981) proposed a fuzzy logic based methodology for qualitative multi-criteria decisions.
- Khouja and Booth (1995) applied a fuzzy cluster analysis to choose industrial robots.
- Wang *et al.* (1995) presented a new methodology for safety analysis and synthesis of a complex marine engineering system with a structure capable of being decomposed into a hierarchy of levels. In this methodology, discrete fuzzy sets were developed to describe each failure event and an evidential reasoning (ER) approach was then employed to synthesise the information thus produced to assess the safety of the whole system.
- Since fuzzy set theory (FST) was introduced more than four decades ago, it has found many useful applications in the electrical and electronic engineering, civil engineering, research and development projects, business management, information and control, economics and marketing, education, health and medicine, and safety engineering (Wang *et al.*, 1995; Yen and Langari, 1999).

- Lee (1996) applied fuzzy set theory to evaluate the rate of aggregative risk in software development.
- Liang (1999) combined the idea of the Technique for Order Preference by Similarity to an Ideal Solution (*TOPSIS*) with *FST* to propose a novel fuzzy *MCDM* based on the concepts of ideal and anti-ideal points.
- Fuzzy discrete *MCDM* algorithms for optimising the cost of steel structures developed and studied by Sarma and Adeli (2000).
- Singh and Tiong (2000) described a multiple criteria linguistic decision model using *FST* to evaluate the capability of a contractor to deliver projects as the owner's requirements.
- Chen (2001) used fuzzy group decision making for evaluating the rate of aggregative risk in software development.
- Chen (2001) used a new multiple criteria decision-making method to solve the "distribution centre location selection problem" under fuzzy environment.
- Shipley *et al.* (2001) described a multiple criteria linguistic decision model to satisfy goals for successful product/service introduction.
- Kapoor and Tak (2003) proposed a fuzzy logic based methodology for making qualitative multi-criteria decisions in facilities planning.
- Wang and Lin (2003) produced a fuzzy logic approach for configuration item selection in software development based on multiple qualitative criteria.
- A multi-criteria port competitiveness evaluation problem was solved by Huang *et al.*, (2003) using a fuzzy multi-criteria grade classification approach.
- A fuzzy rule based *ER* approach was used to analyse the safety of a marine and offshore engineering system (Liu *et al.*, 2005).
- Yang *et al.* (2005) carried out risk analysis of container supply chains. Combining discrete fuzzy sets and an *ER* approach, that study presented a subjective method for dealing with vulnerability.

- Sadiq and Hassan (2005) applied a fuzzy-based methodology for an aggregative environmental risk assessment of drilling waste.
- Zeng *et al.* (2006) applied an aggregative risk assessment model for information technology project development.
- A fuzzy rule based *ER* was employed in the location of key bus stations of a geographically featured Chinese city, Dalian (Xie *et al.*, 2006).
- Wand and Elhang (2007) used fuzzy group decision making for bridge risk assessment.

2.11.7. Evidential Reasoning

The theory of evidence was first generated by Dempster (1967) and further developed by Shafer (1976); it is often referred to as Dempster-Shafer theory of evidence or *D-S* theory. The *D-S* theory was originally used for information aggregation in expert systems as an approximate reasoning tool (Buchanan and Shortliffe, 1984; Lopez de Mantaras, 1990). Subsequently it has been used in decision making under uncertainty (Yager, 1992; 1995).

In the 1990s, to deal with Multiple Criteria Decision Making (MCDM) problems under uncertainty based on the D-S theory, evidential reasoning (ER) was developed. The use of *ER* as a decision making tool has been widely reported in the literature. An important achievement of applying *ER* to decision analysis is to incorporate it into traditional *MCDM* methods (Beynon *et al.*, 2000). The *ER* approach developed particularly for *MCDM* problems with both qualitative and quantitative criteria under uncertainty utilises individuals' knowledge, expertise and experience in the forms of belief functions.

The *ER* criteria aggregation process is in general a non-linear process as compared to traditional weighting *MCDM* methods. The non-linearity is decided by the weights of criteria and the way each criterion is assessed. Furthermore, the *ER* frameworks not only provide flexibility in describing a *MCDM* problem but also prevent any loss of information due to conversion from a distribution to a single value in the modelling process. To handle incomplete information, utility intervals can be established to describe the impact of missing information on decision analysis; this provides a basis for improving the quality of original data and for conducting sensitivity analysis.

2.11.8. Application of Evidential Reasoning

Several applications of the *ER* approach can be addressed in the literature (Wang *et al.*, 1995, 1996; Yang and Sen, 1996, 1997; Yang, 2001; Sii *et al.*, 2002; Yang *et al.*, 2004). Some typical studies making useful contributions towards the use of *ER* for representing and managing uncertainty in decision analysis include the works produced by Yen (1990), De Korvin and Shipley (1993), Xu (1997), Denoeux (1999), Murphy (2000) and Vourous (2000).

The *ER* approach was applied to select the best prime contractor for a civil engineering project (Sonmez *et al.*, 2001). In that study, the process of building a multiple criteria decision model of a hierarchical structure was presented with both quantitative and qualitative criteria. The process of converting lower level criterion assessments to upper level criterion was shown.

The *ER* algorithm, which was generated by Yang and Singh (1994), later updated by Yang (2001) and further modified by Yang and Xu (2002). Tang *et al.* (2004) used *ER* to assess the condition of a transformer. *ER* was combined with a diagnosis technique to provide a meaningful and accurate diagnosis. The result showed that *ER* was capable of producing the condition of a transformer. The major advantages of *ER* are listed as follows:

- It is capable of handling incomplete, uncertain and vague as well as complete and precise data.
- It is capable of providing its users with a greater flexibility by allowing them to express their judgements both subjectively and quantitatively.
- It is capable of accommodating or representing the uncertainty and risk that is

inherent in decision analysis.

- As a hierarchical evaluation process, it is capable of offering a rational and reproducible methodology to aggregate the data assessed.
- It is capable of obtaining the assessment output using mature computing software, Intelligent Decision System (IDS) (Yang and Xu, 2002).

2.11.9. Evidential Reasoning Algorithm

The combination of *D-S* theory and fuzzy set theory is an appropriate way to solve complex problems that include fuzzy information from multiple sources. One direction is to extend *D-S* theory to include the feature of fuzzy set theory so that its capability can be enhanced to process both crisp and fuzzy information. In *D-S's* rule of combination, suppose subsets *B* and *C* defined on θ are associated with confidence estimates m_1 and m_2 respectively that are obtained from two independent sources. The orthogonal sum of m_1 and m_2 is defined as follows:

$$(m_1 \oplus m_2)(A) = \frac{\sum_{B \cap C = A} m_1(B) \times m_2(C)}{1 - \sum_{B \cap C = \phi} m_1(B) \times m_2(C)}$$

In continuously researching and practicing processes, based on the *D-S* theory the *ER* algorithm has been developed, improved and modified towards a more rational way (Yang and Xu, 2002). The algorithm can be analysed and explained as follows:

Let *"S"* represent the set of the four safety expressions and be synthesised by two subsets S_1 and S_2 from two different assessors. Then *S*, S_1 and S_2 can separately be expressed by:

$$S = \{ \beta^1 \text{ "Poor"}, \beta^2 \text{ "Fair"}, \beta^3 \text{ "Average"}, \beta^4 \text{ "Good"} \}$$
$$S_1 = \{ \beta_1^1 \text{ "Poor"}, \beta_1^2 \text{ "Fair"}, \beta_1^3 \text{ "Average"}, \beta_1^4 \text{ "Good"} \}$$
$$S_2 = \{ \beta_2^1 \text{ "Poor"}, \beta_2^2 \text{ "Fair"}, \beta_2^3 \text{ "Average"}, \beta_2^4 \text{ "Good"} \}$$

where *"Poor", "Fair", "Average", "Good"* are assessed with their corresponding degrees of belief.

Suppose the normalised relative weights of two safety assessors in the safety evaluation process are given as ω_1 and ω_2 ($\omega_1 + \omega_2 = 1$) and ω_1 and ω_2 can be estimated by using established methods such as simple rating methods or more elaborate methods based on pair wise comparisons (Yang *et al.*, 2001). Suppose $M^m{}_1$ and $M^m{}_2$ ($m = 1, 2, 3$ or 4) are individual degrees to which the subsets S_1 and S_2 support the hypothesis that the safety evaluation is confirmed to the four safety expressions. Then, $M^m{}_1$ and $M^m{}_2$ can be obtained as follows:

$$M^m{}_1 = \omega_1 \beta_1^m$$

$$M^m{}_2 = \omega_2 \beta_2^m$$

where $m = 1, 2, 3, 4$. Therefore,

$$\begin{array}{ll} M^1{}_1 = \omega_1 \beta_1^1 & M^1{}_2 = \omega_2 \beta_2^1 \\ M^2{}_1 = \omega_1 \beta_1^2 & M^2{}_2 = \omega_2 \beta_2^2 \\ M^3{}_1 = \omega_1 \beta_1^3 & M^3{}_2 = \omega_2 \beta_2^3 \\ M^4{}_1 = \omega_1 \beta_1^4 & M^4{}_2 = \omega_2 \beta_2^4 \end{array}$$

Suppose H_1 and H_2 are the individual remaining belief values unassigned for $M^m{}_1$ and $M^m{}_2$ ($m = 1, 2, 3, 4$). Then, H_1 and H_2 can be expressed as follows (Yang and Xu, 2002):

$$H_1 = \overline{H}_1 + \widetilde{H}_1$$
$$H_2 = \overline{H}_2 + \widetilde{H}_2$$

where $\overline{H}_n$ ($n = 1$ or 2) representing the degree to which the other assessor can play a role in the assessment, and $\widetilde{H}_n$ ($n = 1$ or 2) caused by the possible incompleteness in the subsets S_1 and S_2, can be described as follows respectively:

$$\overline{H}_1 = 1 - \omega_1 = \omega_2$$

$$\overline{H}_2 = 1 - \omega_2 = \omega_1$$

$$\widetilde{H}_1 = \omega_1 (1 - \sum_{m=1}^{4} \beta_1^m) = \omega_1 [1 - (\beta_1^1 + \beta_1^2 + \beta_1^3 + \beta_1^4)]$$

$$\widetilde{H}_2 = \omega_2 (1 - \sum_{m=1}^{4} \beta_2^m) = \omega_2 [1 - (\beta_2^1 + \beta_2^2 + \beta_2^3 + \beta_2^4)]$$

Suppose $\beta^{m'}$ ($m = 1, 2, 3$ or 4) represents the non-normalised degree to which the safety evaluation is confirmed to the four safety expressions as a result of the synthesis of the judgments produced by assessors 1 and 2. Suppose H_U' represents the non-normalised remaining belief unassigned after the commitment of belief to the four safety expressions because of the synthesis of the judgments produced by assessors 1 and 2. The *ER* algorithm can be stated as follows (Yang and Xu, 2002):

$$\beta^{m'} = K\ (M^m{}_1 M^m{}_2 + M^m{}_1 H_2 + H_1 M^m{}_2)$$

$$\overline{H}_U' = K\ (\overline{H}_1 \overline{H}_2)$$

$$\widetilde{H}_U' = K\ (\widetilde{H}_1 \widetilde{H}_2 + \widetilde{H}_1 \overline{H}_2 + \overline{H}_1 \widetilde{H}_2)$$

$$K = [1 - \sum_{T=1}^{4} \sum_{\substack{R=1 \\ R \neq T}}^{4} M_1^T M_2^R]^{-1}$$

After the above aggregation, the combined degrees of belief are generated by assigning $\overline{H}_U'$ back to the four safety expressions using the following normalization process:

$$\beta^m = \beta^{m'} / 1 - \overline{H}_U' \quad (m = 1, 2, 3, 4)$$

$$H_U = \widetilde{H}_U' / 1 - \overline{H}_U'$$

where H_U is the unassigned degree of belief representing the extent of incompleteness in the overall assessment.

The above gives the pr ocess of combining two fuzzy sets. If three fuzzy sets are required to be combined, the result obtained from the combination of any two sets can be further synthesized with the third one using the above algorithm. In a similar way, multiple fuzzy sets from the judgements of multiple assessors or the safety evaluations of lower level risks in the chain systems (i.e. components or subsystems) can also be combined.

2.11.10. Hybrid Multiple Criteria Decision Making

MCDM problems with both qualitative and quantitative attributes are sometimes called hybrid *MCDM* problems (Sonmez, 2002). When faced with a hybrid *MCDM* problem, the first thing to tackle is how to measure the qualitative criteria (Yang and Sen, 1994).

An *ER* based decision-making approach for *MCDM* problems with both qualitative and quantitative criteria under uncertainty was developed in the early 1990's (Yang and Singh, 1994; Yang and Sen, 1994). When conflicting evidence exists in *MCDM* problems, the *ER* approach by using a distributed evaluation framework has conquered the inability of the *D-S* theory. The *ER* approach can be described as a hierarchical evaluation process in which all decision criteria are aggregated into the goal of the problem. Consequently, the process of applying the *ER* approach to *MCDM* can be briefly described in a stepwise manner as follows (Sonmez, 2002):

- Display a decision problem in a hierarchical structure.
- Assign weights to each criterion and to their sub-criteria.
- Choose a method for assessing a criterion either quantitatively or qualitatively.
- Transform assessments between a main criterion and its associated sub-criteria if they are assessed using different methods (i.e. qualitative and quantitative).
- Evaluate each alternative based on the lowest level criteria in the hierarchical structure.
- Quantify qualitative assessments at the top level if necessary and determine an aggregated value for each alternative.
- Rank alternatives and choose the one with the highest average value.

2.12. Conclusion and Discussions

Within this chapter, a careful analysis of some typical historical failure data concerning the containership accidents clearly elucidates that container cargo damage, machinery failure, collision, grounding, fire/explosion, and contact are the most significant accident categories with high percentages of occurrence. Another important finding is that the most significant basic event contributing to the supply chains' vulnerability is human error. Thus, to create a model for the safety of container supply chain systems, firstly, a methodology for measuring human reliability has to be developed.

The operational process of container supply chain systems including physical cargo flow, information flow and custody flow has been reviewed. Container supply chains include dozens of stakeholders who can physically come into contact with containers and their contents and are potentially related with the container trade and transportation. Security-based disruptions can occur at various points along the supply chain. The literature review in the context of container supply chains from a security point of view clearly elucidates that the best methodology to secure the chain is to use better shipment data for enhanced container targeting capability. Experience has shown that even a limited percentage of inspection, coupled with a targeted approach based on risk analysis, can provide an acceptable security level. Thus, in order not to hamper the logistical process in an intolerable manner, the number of physical checks should be carefully chosen. Furthermore, the container supply chain can be assumed as a series network and for a series network the reliability of a system can be calculated through the reliability of its components (i.e. importers, exporters, manufacturers, manufacturing sites, inland carriers, warehouses, ports, containerships, container consolidation and deconsolidation facilities, etc.). Thus to create a model for the security of container supply chain systems, firstly, methodologies for evaluating and aggregating the reliability of different commercial operators and premises have to be developed; secondly, the strength of the supply chain's weakest link via the components' reliability has to be determined.

Chapter Three

Ergonomics Contribution to the Safety and Reliability of Containerships

Summary

Ergonomics has been recognised to be essential for improving safety and productivity. The focus of ergonomics is the design of human-system interface. This includes interfaces between personnel and hardware, software and physical environments associated with systems. The difference between high and low system performances is highly dependent on human reliability. In this chapter for evaluating seafarers' reliability a generic model with a hierarchical structure, based on the ergonomics model, literature review, historical failure data and statistical analysis, is constructed. Subsequently assessment grades are assigned to all the criteria in the hierarchical structure, those assessment grades could be either qualitative or quantitative. Each quantitative criterion is transformed to a qualitative criterion by using the membership functions of continuous fuzzy sets. Each lower level qualitative criterion is converted into an associated upper level qualitative criterion by formulating a mapping process. An analytic hierarchy process (AHP) methodology is used for assigning the weights to each criterion and also to their sub-criteria. The evidential reasoning (ER) algorithm is used to synthesise the generic seafarer's reliability criteria. The concept of expected utility is used to obtain a single crisp value for a seafarer's reliability. Finally, based on an engineering viewpoint a frame of reference is constructed and employed for assessing the distance of any seafarer's reliability value from an ideal one. Accordingly, the control options to enhance the seafarer's reliability value are suggested. The proposed methodology enables and facilitates the decision makers to evaluate the reliability of a person before his/her designation to any kind of activities and to nominate a correct person for a specific task. Moreover, the decision makers should realise that a seafarer's reliability value depends upon many variables. Therefore, in order to correct any deviation on time, it has to be measured appropriately and regularly.

3.1. Introduction

The number of container ships and their size has increased rapidly over the last 40 years. Due to the increase of customer demand and the lowering of total cost, by the beginning of 2010, the number of container carriers is estimated to be 5240 ships with the total slot capacity of 14.23 million TEU (Vernimmen *et al.*, 2007). Accordingly, the number of container carriers with the capacity of more than 7500 TEU is estimated to be 291 ships with the total slot capacity of 2.6 million TEU (Vernimmen *et al.*, 2007). As a result, the reliability of container vessels will have significant effects on the container supply chains reliability.

A schedule reliability survey was conducted by the maritime analyst Drewry Shipping Consultants (2006), based on 5410 container vessel arrivals on 23 different trade routes. It revealed that more than 40% of vessels deployed on worldwide liner services arrived one or more days behind schedule. The factors causing liner schedule unreliability are found to be bad weather at sea, congestion or labour strikes at different ports of call, as well as knock-on effects of delay suffered at previous ports. More serious liner delays, leading to significant time losses for the cargoes involved or even the loss of cargo altogether are found to be fire, collision and grounding (Vernimmen *et al.*, 2007). Therefore, a reliable container industry not only has to be schedule driven but also has to be safe; its reliability is highly dependent on its container shipments and its safe operation. Consequently, the application of good seamanship and prudent operational practice is highly required.

Container supply chains are vulnerable to many risks. In a supply chain context, logistics internal and external risks together endanger the continuity and reliability of the chains. Therefore, vulnerability can be defined as an exposure to serious disturbances arising from the risks within supply chains as well as the risks external to the supply chain (Yang *et al.*, 2005). By analyzing the nature of results, vulnerability can also be defined as exposure to serious disturbances arising from a hazard or a threat (Yang *et al.*, 2005).

The conducted HAZID concerning the containership accidents (in Chapter 2) clearly elucidated that the container cargo damage, machinery failure, collision, grounding, fire/explosion, and contact are the most significant accident categories with high percentages of occurrence. Another important finding is that the most significant basic event contributing to the supply chains' vulnerability is human error.

The supply chain flow can be segregated into two groups, which are described as links and nodes. The links are trucks, trains, containerships, information transmission facilities and their infrastructures, roads, rails, inland waterways, liner shipping lanes and cables/satellites. The nodes are warehouses, LCL premises, rail termini/stations and ports. No links or nodes will function without the people who understand how to operate and maintain them. Therefore, any activity deviation coming from such persons may lead to a severe disruption in the chains (Yang *et al.*, 2005).

The UK Marine Accident Investigation Branch (MAIB) stated that one factor, human error still dominates the majority of marine accidents (MAIB, 2000). The most common human factor causes were error of judgement and improper look out or watch keeping, followed by failure to comply with regulations (Hetherington *et al.*, 2006).

Risk factors in maritime transportation were analysed and researched by Psarafits *et al.* (2008). After analysing many accident reports (7,553 records) and by taking the vessels' flag, ownership, type, age, type of cargo, and location of accident into account the human factors were found to be the prevalent causes.

Based on expert opinion, the large amount of downtime in container terminals and ports concern the error of gantry crane operators, which is the main cause of physical damage to a vessel's cell guides, railings, container cargoes, and tank tops. The investigation conducted by CellStack (2008) clearly indicated that the large amount of downtime in modern container ports or container terminals is caused by the motion sickness (human fatigue) of crane operators.

In marine operations, the officers and crews are usually designated by a manning and crewing agent or a fleet personnel department; masters and chief engineers usually have limited influence on selection of designated persons. In certain circumstances especially on board a container vessel due to short port stay, the newly incoming officers may relieve the outgoing officers in a matter of hours without properly following the handing and taking over pro cedures. The proposed methodology enables and facilitates the decision makers to evaluate the reliability of a person before his/her designation to any activities and to nominate a correct person for a specific task.

If the aim of managers is to have a safer and more profitable industry (e.g. shipping lines, container terminals, stevedores and packaging companies), they should not only calculate their employees' reliability value but also enhance their reliability value.

Choosing the correct personnel for a job or a task is critical to the overall safety and business performance. Selection of personnel who do not have the requisite skills, training, or tools can adversely affect vessel safety by reducing personnel efficiency and increasing the potential for error (ABS, 2003).

3.2. Literature Review

Measurement of reliability of human behaviour in a human-machine system has been a source of interest since 1963. Swain (1963), Meister (1964) and Askren (1967) have conducted research in this area. Adams (1982) has used Monte Carlo simulations for calculation of human reliability. Due to lack of consideration of the factors that influence human error, precise prediction of human behaviour in complex environments may not be possible. Furthermore, given that human reliability is normally expressed in both quantitative and qualitative terms, decision makers may often carry out their judgments based on both quantitative data and experiential subjective assessments. Therefore, measuring the human reliability by means of probability theory cannot be a precise measurement.

Wagenaar and Groeneweg (1987) stated that "accidents do not occur because people gamble and lose, they occur because people do not believe that the accident that is about to occur, is at all possible". Therefore, for a safe operation, operators should be trained to seek for the causes and the consequences. They should pay attention to any incoming alarm (e.g. fire, oil mist in crankcase, boiler water level) and acknowledge it as a genuine alarm. However, it was elucidated as a false alarm in so many occasions.

3.3. Ergonomics Model

"Ergonomics is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimise human well-being and overall system performance" (International Ergonomics Association, 2000).

The focus of ergonomics is the design of human-system interface. This includes interfaces between personnel and hardware, software and physical environments associated with the systems. The most important elements that affect safety and efficiency in job performance are listed as follows (ABS, 2003):

- Design and layout considerations.
- Ambient environmental considerations.
- Management and organisational considerations.
- Considerations related to people.

3.3.1. Design and Layout Considerations (Human-System Interface)

Design and layout considers the integration of personnel with equipment, systems, and interfaces. It is important for designers and engineers, during the design stage, to consider the following factors that may influence work performance and the likelihood of human error (ABS, 2003):

1. Personnel's social, psychological, and physiological capabilities, limitation and needs.
2. Hardware and software design, arrangement, and orientation.
3. Workplace design includes the physical design and arrangements of the workplace and its effect on safety and performance of personnel.
4. The cultural and regional influences on personnel's behavioural patterns and expectations.

Human-system interface can be evaluated by aggregation of the following seven criteria that directly relate to equipment and system performance in the context of reducing the potential for human error (ABS, 2003):

1. Controls.
2. Displays.
3. Alarms.
4. Integration of controls, displays, and alarms.
5. Video-display units and workstation.
6. Manual valve operation, access, location, and orientation.
7. Labelling, sign, graphics, and symbols.

For further inquiry, kindly refer to the guidance notes for the application of ergonomics to marine systems (ABS, 2003).

3.3.2. Ambient Environmental Considerations (Design & Habitability)

The ambient environmental aspect of the ABS (2003) ergonomics model addresses the habitability and occupational health characteristics related to human whole-body vibration, noise, indoor climate, and lighting. Substandard physical working conditions undermine effective performance of duties, causing stress and fatigue. Ambient environmental considerations also include appropriate design of living spaces that assist in recovery from fatigue. The ambient environmental conditions can be evaluated by aggregation of the workplace and the living space environmental conditions. The workplace environmental conditions can be evaluated by aggregation of the following seven elements:

1. Location (e.g. in the engine room, in the control room, on an open deck, inside a tank).
2. Time and duration (e.g. inside a tank at night for six hours).
3. Ventilation (i.e. cubic meters of ventilation air per minute per person).
4. Climate (i.e. air temperature, air velocity, humidity, and mean air temperature).
5. Vibration level (i.e. vibration velocity and acceleration at a working area).
6. Noise level.

7. Lighting.

The living space environmental conditions can be evaluated by aggregation of the following five elements:

1. Vibration level (i.e. vibration velocity and acceleration at a living area)
2. Noise level.
3. Indoor climate (i.e. air temperature, air velocity, humidity, and mean air temperature).
4. Lighting.
5. Accommodation's design (i.e. location, arrangement, and outfitting of accommodation spaces).

For further inquiry, kindly refer to the ABS guide for crew habitability on ships.

3.3.2.1. Vibration

Developments in the global economy during the last two decades have changed the traditions of shipbuilding. Accordingly, ship design is advanced, vessels' speed is increased, the safety factor is reduced, the construction is optimized, and the tendency for vibration problems is pronounced. One of the factors that can significantly influence human error and fatigue is vibration. Short-term exposure leads to headaches, stress, and fatigue. Long-term exposure leads to hearing loss and causes constant body agitation (Calhoun, 2006). In 1977, the International Labour Organization (ILO) listed vibration as an occupational hazard and recommended that measures have to be taken to protect employees from vibration (ILO, 1977). Vibration level at living spaces and workplaces can be evaluated by the ISO 6954-2000 guideline. The ISO 6954-2000 guideline for the workplaces and the living spaces on boards a ship is presented in Table 3.1.

3.3.3. Management and Organisational Considerations

An atmosphere for error can be segregated into two groups that are described as preventable (e.g. a ship's design & habitability, a ship's design & layout) and inevitable (e.g. sea conditions). Preventable factors, during the preparation of a specification for new building of a vessel and throughout its lifetime, should be considered and determined by a ship's owner. The seafarers' motivations, fatigue, and hours of rest are highly dependent on the manager's strategies. The effective implementation of a well-designed safety policy that includes ergonomics creates an environment that minimises risks (ABS, 2003).

3.3.4. Consideration Related to People

The difference between high and low system performances is highly dependent on human reliability. Choosing the correct personnel for a duty is essential for overall safety. The following factors should be considered when selecting personnel for a task (ABS, 2003):

1. Knowledge, skills, and abilities that stem from an individual's basic knowledge, general training and experience.
2. Maritime-specific training and abilities (certificate and licences), and vessel or offshore installation specific skills and abilities.
3. Bodily dimension and characteristics of personnel such as stature, shoulder breadth, eye height, functional reach, overhead reach, and weight.
4. Physical stamina; capabilities, and limitation, such as resistance to and freedom from fatigue; visual activity; physical fitness and endurance; acute or chronic illness; and substance dependency.
5. Psychological characteristics, such as individual tendencies for risk taking, risk tolerance and resistance to psychological stress.

3.4. Technical Proficiency

The standards for training certification and watch-keeping (STCW, 1995) prescribes the mandatory requirements for certification of deck and engineer officer and watch ratings including requirements relating to age, medical fitness, seagoing service and standards of competence. To satisfy the requirements candidates for the UK certificates of competency have to meet certain medical standards; satisfactorily complete a minimum period of seagoing service; reach the required vocational and academic standard; undertake ancillary technical training. Moreover, in the case of officer candidates, on completion of programmes of education and training approved by the Maritime and Coastguard Agency (MCA), they should pass an oral examination conducted by an MCA examiner (MCA, 2002).

As a result, a seafarer's technical proficiency can be evaluated by aggregation of the following criteria:

- A seafarer's qualification.
- A seafarer's experience.
- A seafarer's specific training.

3.4.1. Qualification

In 1993, the International Maritime organization (IMO) embarked on a comprehensive revision of the Standards for Training Certification and Watch-keeping (STCW 78) to establish the highest practical standards of competence for mariners and to reduce human error as a major cause of marine causalities. On 7 July 1995, a conference of parties to STCW adopted a package of amendments to the convention, which establishes requirements for qualification of masters, officers, watch-keeping and other crew personnel on seagoing merchant vessels operating outside the boundary line and the responsibilities of companies. The abilities specified in the standards of competence are grouped as appropriated under the following seven functions (STCW, 1995):

1. Navigation.
2. Cargo handling and stowage.
3. Controlling the operation of the ship and care for persons on board.
4. Marine engineering.
5. Electrical, electronic and control engineering.
6. Maintenance and repair.
7. Radio communications.

Each deck/navigational officer must qualify in functions 1, 2 and 3 (deck). A deck/navigational officer may then qualify in the additional functions of 3 (engineer), 4, 5, 6, and 7. Each engineer officer must qualify in functions 3 (engineer), 4, 5, and 6. An engineer officer may then qualify in the additional functions of 1, 2, and 3 (deck). A radio operator must qualify in function 7.

The levels of responsibility under STCW (95) are categorised as follows:

1. M stands for management level.
2. O stands for operational level.
3. S stands for support level.

3.4.2. Specific Training

The compulsory and additional courses for deck and engineering officers under STCW (95) are listed as follows:

- Advanced Fire Fighting- Every candidate for a master or mate's certificate or an engineer officer's certificate for service on vessel over 750 kW propulsion power must complete an advanced marine fire-fighting course.
- Radar Simulation Training – Every candidate for a master or mate's certificate must complete a marine radar simulation course.
- GMDSS Certification- Every candidate for a third mate/ second mate/mate's

certificate must hold GMDSS certification.

- First Aid Training- Every candidate for a second mate/ third mate's certificate on vessels over 500 gross tons, every candidate for a master/mate's certificate on vessels less than 500 gross tons and every candidate for an engineer officer's certificate serving on vessels of over 750 kW propulsion must complete first aid training.
- Survival Craft/ Rescue Boat Training- Every candidate for a master, chief mate, second mate, third mate or mate's certificate and every candidate for an engineer officer's certificate on vessels of over 750 kW propulsion power must complete proficiency in survival craft/rescue boats training.
- Automatic Radar Plotting Aids (ARPA) Training- Every candidate for a master, chief mate, second mate, third mate or mate's certificate must complete ARPA training.
- Advanced Medical Training- Effective 1 August 1998, every candidate for a master or chief mate's certificate on vessels over 500 gross tons must complete advanced medical training.
- Bridge Team/ Resource Management- all deck officers must attend the BRM course and obtain a certificate.

All ocean going mariners are required to demonstrate the basic safety training (BST) proficiency by completing an approved course. Basic safety training consists of the following four elements:

1. Personal survival.
2. Elementary first aid.
3. Elementary fire fighting and fire prevention.
4. Personal safety and social responsibility.

3.5. Human Fatigue

The IMO (2001) has formulated a definition of fatigue in which fatigue is conceptualised as a "reduction in physical and/or mental capacity as the result of physical, mental, or emotional extension which may impair nearly all physical abilities including: strength, speed, reaction time, coordination, decision making or balance".

Global concern with the extent of seafarer fatigue and its potential environmental cost is widely evident across the shipping industry. Maritime regulators, ship owners, trade union and P & I clubs are all alert to the fact that with certain ship types a combination of minimal manning, sequences of rapid turnarounds, adverse weather conditions and high level of traffic may find seafarers working long hours and with insufficient recuperative rest (Smith *et al.*, 2006). Despite the rest hours, additional issues such as rolling, pitching, vibration, and noise are also contributing to human fatigue (McNamara *et al.*, 2000).

MAIB (2004) conducted a safety study, during 1994-2004, in which the results conclusively showed poor manning levels and human fatigue as the major causal factors in collisions and groundings.

As a result, a seafarer can be subjected to the variable amounts of fatigue due to aggregation of the following criteria:

- Environmental states.
- Rest hours.
- Design & Habitability (Section 3.3.2).

3.5.1. Environmental States

Slow frequency vibrations that are created by various environmental states (e.g. sea conditions, wind actions, vessel's speed, and heading) result in motion sickness, unsteadiness and motion induced muscle fatigue. The consistent application of labour legislation rules and higher demand for living comfort underlines the need to minimise the vibration level and the simplest way to avoid vibration is to prevent resonance conditions. This procedure is successful as long as natural frequencies and excitation frequencies can be regarded as being independent on environmental conditions. In the question of ship technology, this prerequisite frequently remains unfulfilled. For instance, for different filling stages the natural frequency of a tank structure changes. For different loading conditions due to a change of draught, the overall hull of the ship takes on a different natural mode and natural frequency. Moreover, there might be variable excitation frequencies for propulsion plants having a variable speed.

Parametric rolling due to rough sea conditions and improper choice of speed and heading can be a particular problem on ships (e.g. P&O Nedlloyd Genoa) designed with a flat transom and with a large bow flare. This is a common design, found on many modern container ships, which maximises deck cargo capacity while minimising water resistance with fine hull lines (MIAB, 2006).

Springing can be defined as steady state resonance vibration of hull girder due to linear and non-linear wave excitation. The effect of springing seems to increase as the ships become faster, larger, lighter and wider. For reduction of springing, the following suggestions are listed (Strohaung *et al.*, 2007):

- Springing can be reduced by reducing the speed.
- Springing can be reduced by increasing the heading angle.

Some container vessels are designed with a large metacentric height at partially loaded conditions. A large metacentric height can cause vessels to be too stiff. A stiff vessel rolls with a short period and high amplitude, resulting in high angular acceleration. The stiff vessel quickly responds to the sea as it attempts to assume the slope of a wave and is uncomfortable for the seafarers.

As a result, the influences of environmental states on human fatigue can be evaluated by one or aggregation of the following criteria:

- Sea conditions.
- Vessel's speed.
- Vessel's heading.
- Vessel's stability.

3.5.2. Rest Hours

The maximum seafarers' hours of work and the minimum seafarers' hours of rest are listed as follows (ILO 180, 1996):

(a) Maximum hours of work shall not exceed:

i. 14 hours in any 24-hours period; and
ii. 72 hours in any seven-day period;

or

(b) Minimum hours of rest shall not be less than:

i. 10 hours in any 24-hours period; and
ii. 77 hours in any seven-day period.

Hours of rest may be divided into no more than two periods, one of which shall be at least six hours in length, and the interval between consecutive periods of rest shall not exceed 14 hours.

Due to short manning scales, seafarers are increasingly expected to take on heavier workloads with less crew support, and to work longer hours with less time off. The following results are elucidated by comprehensive research, published in 2006, on seafarer fatigue (ITF, 2009):

- One in four seafarers said that they had fallen asleep while on watch.
- Almost 50% of seafarers reported working weeks of 85 hours or more.
- Around 50% of seafarers reported that their working hours had increased over the past 10 years, despite new regulation intended to combat fatigue.

- Almost 50% of seafarers surveyed considered that their working hours presented a danger to their personal safety.
- Some 37% said that their working hours sometimes posed a danger to the safe operations of their ship.

The symptoms of fatigue due to less duration of rest hours are listed as follows (ITF, 2009):

- Inability to stay awake.
- Clumsiness.
- Headaches and giddiness.
- Loss of appetite.
- Insomnia.
- Moodiness and needless worrying.
- Poor judgement of distance, speed, time and risk.
- Slow response.
- Difficulty of concentrating.

3.6. Personal Issues (Non-Technical Skills)

Hetherington *et al.* (2006) have subdivided the factors, which contribute to organizational accidents in shipping and influencing the human error, to three different issues:

1. Design issues.
2. Personal issues.
3. Organisational and management issues.

Personal issues deal with human performance factors or behaviour that may contribute to marine incidents or accidents. Non-technical skills are an additional set of competencies that are used integrally with the technical shipping skills or the technical proficiencies, such as those to manoeuvre the vessel, or set down the anchor. They encompass both interpersonal (i.e. mental and communicative algorithms applied during social communications and interactions) and cognitive skills (i.e. mental skills that are used in the process of acquiring knowledge) such as situation awareness, communication, team working, and leadership (Hetherington *et al.*, 2006). The following is a review of research that has focused on non-technical skills within the maritime domain.

3.6.1. Situation Awareness

Situation awareness (SA) is especially important in working domains where the information flow can be quite high and poor decisions may lead to serious consequences. Situation awareness is the ability of an individual to process a mental model of what is going on at any one time and to make projections as to how the situation will develop (Hetherington *et al.*, 2006).

Endsley (1988) has categorised the situation awareness to three levels:

1. Individuals must have the correct perception of elements in the situation in order to form an accurate picture.
2. The acquired information has to be combined, interpreted, and stored to form a picture of the situation, whereby the significance of particular objects and events can be understood.
3. Acquired information in levels one and two has to be combined to obtain a projection.

For instance, let us assume that a boiler feed water pump (out of two) on board a container carrier has failed. The consequences of failure of the second pump will be the breakdown of the boiler, stopping of the main engine and delay. However, the failure possibility of the second pump is low but the current situation should warn the engineers to repair the failed pump at once.

3.6.2 Communication and Language Skill

Misunderstanding is a term that contributes to accidents or near misses. It potentially reflects lack of situation awareness and poor team working as well as inadequate communication and language problem (Hetherington *et al.*, 2006).

The Canadian Transportation and Safety Board (CTSB, 1995) questionnaire regarding pilot, master and officer on watch relationship has revealed that 81% of bridge officers sometimes and 12% of bridge officers were always reluctant to question a pilot's decision. These communication issues can often result in error and accident (Hetherington *et al.*, 2006). Perrow (1999) stated that it is not unusual for a deck officer to remain aghast and silent while his captain grounds the ship or collides with another vessel.

The aim of the IMO Standard Marine Communication Phrases (SMCP) is to get round the problem of language barriers at sea and avoid those misunderstandings which can cause accidents (Alert, 2007). Communication was one of the main factors that contributed to breakdown and subsequent fire onboard Maersk Doha (Subsection 2.5.5).

"The key to improved verbal communication is in the recruitment of seafarers who have an understanding of the English language; in education in the art of effective communication and in the correct use of the English language in the maritime environment; and in a programme of regular testing in their knowledge of the English language" (Alert, 2007).

3.6.3. Teamwork

Working as a team is an important factor for the marine industry. The system reliability and performance is directly proportional to each individual attitude towards teamwork.

The maritime equivalent of Crew Resources Management (CRM) is termed Bridge Resources Management (BRM) or Bridge Team Management (BTM) and has been used in the maritime industry for the last decade. Engine Room Resource Management (ERM) was introduced in the 1980s and has been used to train teams in skills of systems resource and crisis management (Barnett *et al.*, 2003). However, the teamwork has been recognised as an important factor by the maritime organisations but resources management has not been implemented internationally (Hetherington *et al.*, 2006).

3.6.4. Decision Making and Cognitive Demands

In nautical environments, both the physical environment (wind, currents, and sandbanks) and the navigation behaviour of other vessels affect uncertainty. Woods (1988) defined uncertainty as an intrinsic feature of complex systems, associated with unavailability or ambiguity of data and reduced predictability of future states. Thus, uncertainty can be considered to push the operator toward the use of knowledge based processing rather than rule based behaviour associated with the standard to prevent or avoid the collision.

An experimental study regarding cognitive demands of collision avoidance in simulated ship control, demonstrated that high mental workloads create a detriment in performance on a secondary task, when operator has to monitor numerous pieces of equipment concurrently (Hockey *et al.*, 2003).

For clarification of human-environment interface, let us assume that in a city, driving is based on knowledge rather than the rules and regulations. Therefore, nobody can be confident about the others' decision or action and has to presume their behaviour of driving. Consequently, due to uncertainty, mental workload will be increased and primary task (i.e. safe driving) will be sacrificed for prophecy of others' behaviour of driving (i.e. secondary task). Thus, the number of accidents (frequency) will be increased.

3.7. Fitness & Strength

The fundamental purpose of the seafarer fitness assessment is to ensure that the individual seafarer is fit for the work for which he or she is to be employed, taking into account the particular risk associated with working at sea (MCA, 2002).

Fitness to undertake the full range of tasks on board ship and to cope with living conditions at sea has long been a requirement. More recently, the focus of medical assessment has been on (MCA, 2002):

- Fitness to navigate a ship safely.
- Fitness in both physical and psychological terms to deal with an emergency at sea.
- Freedom from foreseeable risk of disease while at sea, especially where this might spread to others on board, require emergency treatment or lead to evacuation or diversion.
- Recognition that seafaring careers can be terminated prematurely by conditions, which can be prevented, such as ischemic vascular disease and lung cancer.

However, a seafarer's medical fitness certificate is a good indication of a seafarer's fitness and strength but due to influences of external and ambient environmental conditions, it is not sufficient. As a result, in addition to holding a valid medical fitness certificate, a seafarer's fitness and strength at different environmental conditions may be evaluated by aggregating the following criteria:

- Health (i.e. due to influences of alcohol or due to sleep deprivation).
- Stress (i.e. due to workload).
- Nutrition (i.e. the quality and quantity of foods, which are served on board a ship due to manager's strategies).
- Age (i.e. muscle's strength).

3.7.1. Health

The health of seafarers is not only a major concern of seafarers themselves but also a primary concern of a ship's owner/manager. Approximately 80% of maritime accidents are caused by human error. Sickness and injury benefit represents a growing proportion of the shipping industry's third party liability insurance claims (ILO, 2001).

Substance abuse (Drugs & Alcohol) undoubtedly contributes to lower performance and productivity. Regretfully, no procedure is available for measuring the officers or the engineers' blood alcohol concentration before their designation to any kind of activity. Therefore, a medical fitness certificate anyway is a good indication of seafarer's health but it is not sufficient. Around a third of seafarers (32%) out of a selected seafaring sample in Australia exceeded the safe limit of alcohol consumption (Parker *et al.*, 2002; Hetherington *et al.*, 2006). A study conducted in the US showed that when airline pilots had to perform routine tasks in a simulator under three-alcohol test conditions, the following results were obtained (ILO, 2001):

1. First test: before any alcohol ingestion, 10% could not perform all tasks correctly.
2. Second test: after reaching a blood alcohol concentration of 0.1g / 100ml, 89% could not perform all tasks correctly.
3. Third test: fourteen hours later, after all alcohol has left their systems, 68% could not perform all tasks correctly.

3.7.2. Stress

A containership is a unique type of vessel. The existing high level of stresses on board the container carriers as well as the ship management is unique. The consequences of such a highly stressful environment will be poor health and diminished performance.

Stress is identified as a contributory factor to the productivity and strength costs of an organization as well as to the personal health. Exposure to elevated stress levels for an extended period of time leads to negative mental and physical health outcome

(Hetherington *et al.*, 2006; Cooper *et al.*, 2001; Quick *et al.*, 1997).

The survey results regarding the frequency and level of stresses at sea are listed as follows (Quick *et al.*, 1997):

1. Eighty percent of seafarers had the frequency of stresses as occasional to frequent at sea.
2. Over 65% of engineers, 60% of crew, and over 60% of masters had the level of stresses as moderate to high at sea.
3. The significant sources of stress that are reported by seafarers had work pressure or workload at sea.

3.7.3. Nutrition

Good nutrition, like other vital occupational safety and health issues, is the foundation of workplace productivity and safety. It is well documented that unhealthy foods can lead to obesity and chronic disease, while macro-and micronutrient can cause malnutrition (Wanjek, 2005). A seafarer's fitness and strength is directly proportional to the foods' quality, quantity, frequency and timing. Moreover, fresh fruits and drinking waters' quality and quantity also play a great role in seafarer's fitness and strength.

The contributing factor concerning the grounding of Aqua-boy is listed as follows (MAIB, 2007f):

The master ate very sparingly on the day before the accident, having had breakfast consisting mainly of coffee, a light meal at lunchtime, and then despite offers from the mate to bring him food, nothing to eat in the evening. This would have lowered the master's blood sugar level that, in turn, would have adversely affected his ability to concentrate.

3.7.4. Age

A muscle's strength has a strong relationship to its cross-sectional area in both men and women. Men and women reach peak strength around 20 to 25 years of age. After age 25, strength generally decreases with the rate of about 1% per year. Individuals who are more active, or those who continue to strength training, can considerably decrease this tendency for declining muscular strength (Welle, 1996). Thus if a ship is equipped with a gymnasium and fitness facilities, a seafarer is able to maintain his/her fitness and strength.

The aging process is characterised by a reduction of the physical capacities and coordination, flexibility, strength, and power. Strength generally remains relatively high until 50 years of age when decreases of about 10% per year begin to result in a loss of function and independence. However, little is known about whether neuromuscular power declines in a similar manner or at the same rate as strength (Bemben and McCalip, 1999).

3.8. Motivation

For years, managers, psychologists and academics have been interested in theories about motivation and one of the theories, which have gained prominence, was Hertzberg's dual factor theory. He identified two separate groups of factors that had a strong bearing on motivation. He called the first group hygiene factors because they strongly influenced feelings of dissatisfaction amongst employees. Hygiene factors include working conditions, pay, and job security. According to Hertzberg, they do not motivate employees as such, but if they are not there, they can adversely affect job performance. He referred to the other group as motivation factors because they had a role in positively influencing performance such as achievement, career progression and learning. Hertzberg states that managers can forget about their workforce motivation if they do not get the hygiene factors right first (Herzberg, 1968).

The author's experience of more than twenty years at sea and as a technical superintendent has given him the opportunity to talk with many seafarers from different cultures and nationalities. The outcome clearly indicates that motivation factors, which have been elucidated by Mitroussi (2008), are valuable. Mitroussi (2008) examined twenty motivation factors in the shipping context; the six most important factors from employees' viewpoint are listed as follows:

1. Opportunity to learn new skill.
2. Higher pay.
3. Friendly working atmosphere.
4. Cash bonuses.
5. Personal growth/development.
6. Chance for promotion.

The results do not show great differences among the different contingencies such as age, gender and position in a company.

3.9. Methodology

For conducting the research, a combination of different decision-making techniques, such as fuzzy logic and an evidential reasoning approach (FER) can be used. Fuzzy logic and evidential reasoning techniques and their mathematical backgrounds were presented in Chapter 2. The proposed methodology in stepwise order is described as follows:

Firstly, the seafarers' reliability is displayed in a hierarchical structure (Figure 3.1). Assessment grades are assigned to all the criteria in the hierarchical structure. Those assessment grades could be either qualitative or quantitative.

Secondly, each quantitative criterion is transformed to a qualitative criterion by using membership functions of continuous fuzzy sets.

Thirdly, a fuzzy rule base is developed to demonstrate the mapping process. By formulating a mapping process, each lower level qualitative criterion is converted into an associated upper level qualitative criterion.

Fourthly, a weight is assigned to each criterion by using an analytic hierarchy process (AHP) method.

Fifthly, the evidential reasoning (ER) algorithm is used to synthesise the generic seafarers' reliability criteria. The *ER* can be described as a hierarchical evaluation process in which all the decision criteria are aggregated to one (the goal). Synthesis may be achieved through manual calculation (Sub-subsection 2.11.9) or through use of mathematical software by coding. In this study, the intelligent decision system software (IDS) is used for synthesis of the basic criteria in the hierarchical structure (Yang and Xu, 2002). Selection of IDS is attributable to its ease of use and its accessibility to other industries and academia. It is noteworthy to mention that, the software is tested prior to the commencement of calculations.

Sixthly, the concept of expected utility is used to obtain a single crisp value for a seafarer's reliability.

Finally, the sensitivity of the model will be analysed.

3.9.1. Generic Model for Seafarers' Reliability *(First Step)*

Decision makers should understand and have a clear picture of the whole problem before attempting to solve it especially when there are many criteria to be considered, which in turn may comprise sub-criteria and even sub-sub-criteria. For this reason, it is useful to display the problem in a form of a hierarchical structure. In a hierarchical order as a first level, the goal of problem is stated. In the second level, there are several criteria, each of which has different contribution to measuring, and helping achieve the overall goal. Then, some of these criteria may be broken down further. The process continues up to the level where decision makers are able to make practical assessments (Sonmez, 2002).

A generic model with a hierarchical structure, as shown in Figure 3.1, based on the ergonomics model, the literature review, historical failure data and statistical analysis (in Chapter 2), is constructed. It is noteworthy to mention that for constructing a hierarchical structure and to avoid unnecessary extension of the model's size, only those criteria that were significant are considered and those insignificant criteria were omitted from the model.

Based on the above discussions the main, sub, sub-sub, and sub-sub-sub-criteria that are contributing to a seafarer's reliability (i.e. goal) are presented in Figure 3.1.

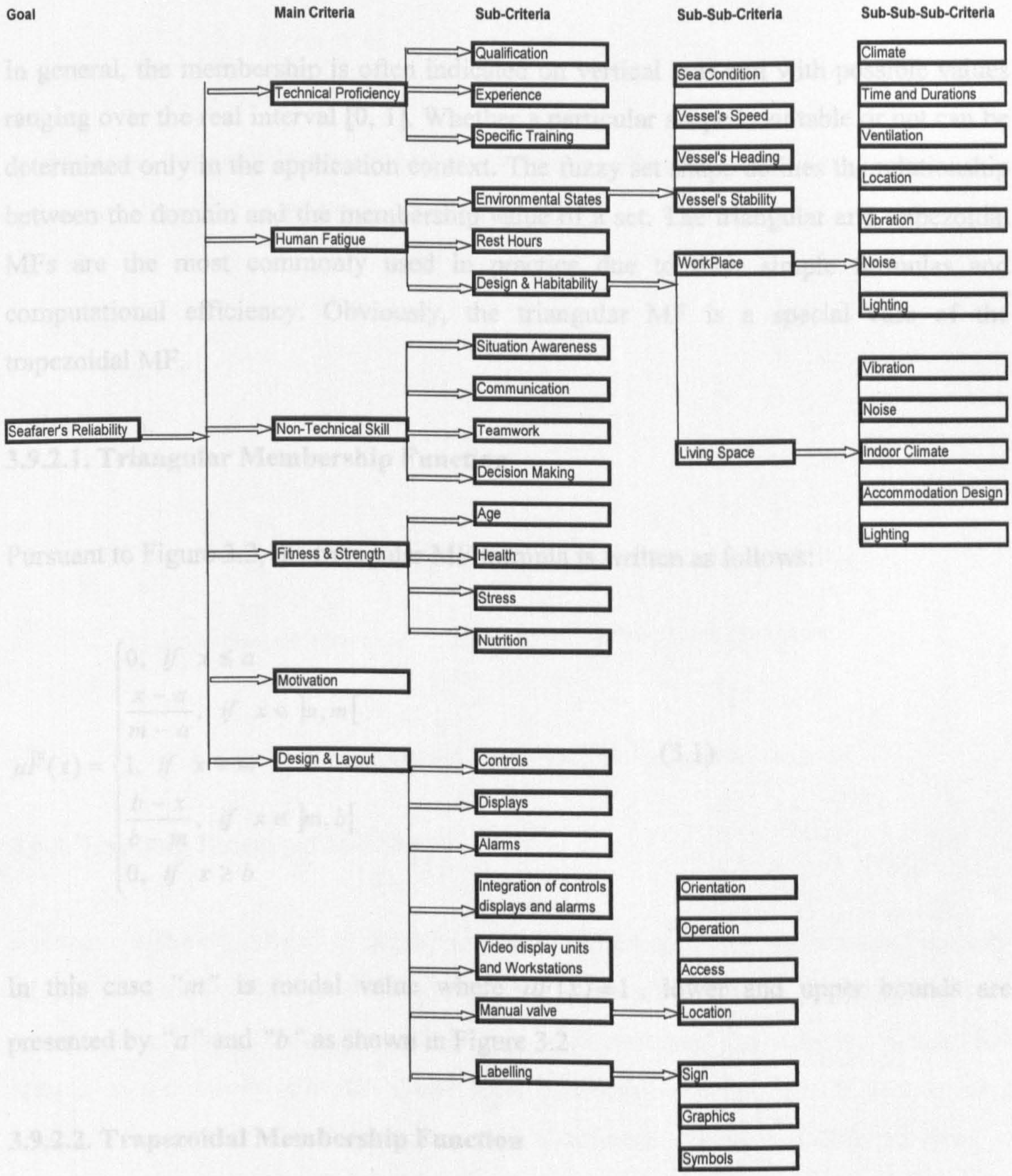

Figure 3.1: Generic Model for Seafarers' Reliability

3.9.2. Quantitative Data Transformation *(Second Step)*

A quantitative criterion can be transformed to a qualitative criterion by using membership functions of continuous fuzzy sets. Membership functions (MFs) are found in different shapes, namely triangular, trapezoidal, S curves, π curves, bell curves and Gaussian curves (Yen and Langari, 1999).

In general, the membership is often indicated on vertical axis and with possible values ranging over the real interval [0, 1]. Whether a particular shape is suitable or not can be determined only in the application context. The fuzzy set shape defines the relationship between the domain and the membership value of a set. The triangular and trapezoidal MFs are the most commonly used in practice due to their simple formulas and computational efficiency. Obviously, the triangular MF is a special case of the trapezoidal MF.

3.9.2.1. Triangular Membership Function

Pursuant to Figure 3.2, the triangular MF formula is written as follows:

$$\mu\tilde{F}(x) = \begin{cases} 0, & if \ x \le a \\ \dfrac{x-a}{m-a}, & if \ x \in \left]a, m\right[\\ 1, & if \ x = m \\ \dfrac{b-x}{b-m}, & if \ x \in \left]m, b\right[\\ 0, & if \ x \ge b \end{cases} \qquad (3.1)$$

In this case "m" is modal value where $\mu\tilde{F}(x) = 1$, lower and upper bounds are presented by "a" and "b" as shown in Figure 3.2.

3.9.2.2. Trapezoidal Membership Function

Pursuant to Figure 3.2, the trapezoidal MF formula is written as follows:

$$\mu\widetilde{F}(x)=\begin{cases}0, & if\ \ x\le a\\ \dfrac{x-a}{m-a}, & if\ \ x\in\,]a,m[\\ 1, & if\ \ x\in[m,n]\\ \dfrac{b-x}{b-n}, & if\ \ x\in\,]n,b[\\ 0, & if\ \ x\ge b\end{cases} \tag{3.2}$$

In this case *"m"* and *"n"* are modal value where $\mu\widetilde{F}(x)=1$, lower and upper bounds are presented by *"a"* and *"b"* as shown in Figure 3.2.

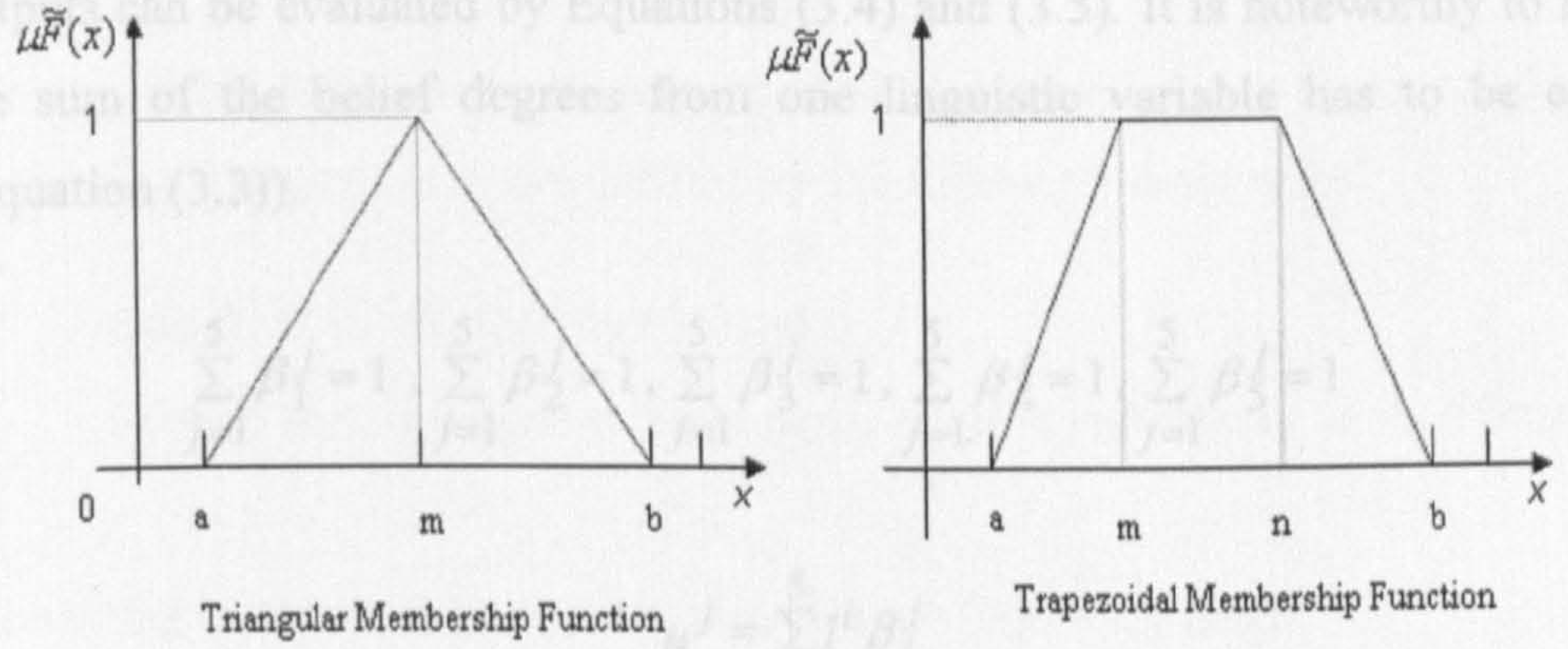

Figure 3.2: Triangular and Trapezoidal Membership Functions

3.9.3. Mapping Process *(Third Step)*

Because a different number of grades are used for the upper level criterion and the sub-criteria, the decision makers have to establish appropriate rules to propagate the sub-criterion assessments to the associated upper level criterion. The mapping process has been used for transforming the lower level qualitative criterion into the upper level criterion. In nature, there are situations with a different amount and different types of linguistic terms in the lower level criteria and the associated upper level criterion. To apply the evidential reasoning approach, it is necessary to have all the data and information on the same universe. Therefore, the information and data need to be transformed before being aggregated. The fuzzy rule base is most suited to transform fuzzy input to fuzzy output.

Let "I" (e.g. qualification) be a lower level qualitative criterion and "J" (e.g. technical proficiency) be an upper level qualitative criterion. As shown in Figure 3.3, "L_i" stands for the lower level linguistic term (e.g. L_1 stands for excellent, L_2 stands for very good, etc.) and "l^i" represents the fuzzy inputs of "L_i". As shown in Figure 3.3 "U_j" stands for the upper level linguistic term (e.g. U_1 stands for very good, U_2 stands for good, etc.) and "u^j" represents the fuzzy outputs. As shown in Figure 3.3, β_i^j stands for the belief degrees that are assigned by experts and they signify the relationship between linguistic variables of different levels. The relationship between fuzzy inputs and fuzzy outputs can be evaluated by Equations (3.4) and (3.5). It is noteworthy to mention that the sum of the belief degrees from one linguistic variable has to be equal to one (Equation (3.3)).

$$\sum_{j=1}^{5} \beta_1^j = 1 \ , \sum_{j=1}^{5} \beta_2^j = 1, \sum_{j=1}^{5} \beta_3^j = 1, \sum_{j=1}^{5} \beta_4^j = 1, \sum_{j=1}^{5} \beta_5^j = 1 \qquad (3.3)$$

$$u^j = \sum_{i=1}^{5} l^i \beta_i^j \qquad (3.4)$$

$$\sum_{i=1}^{5} l^i \leq 1 \qquad (3.5)$$

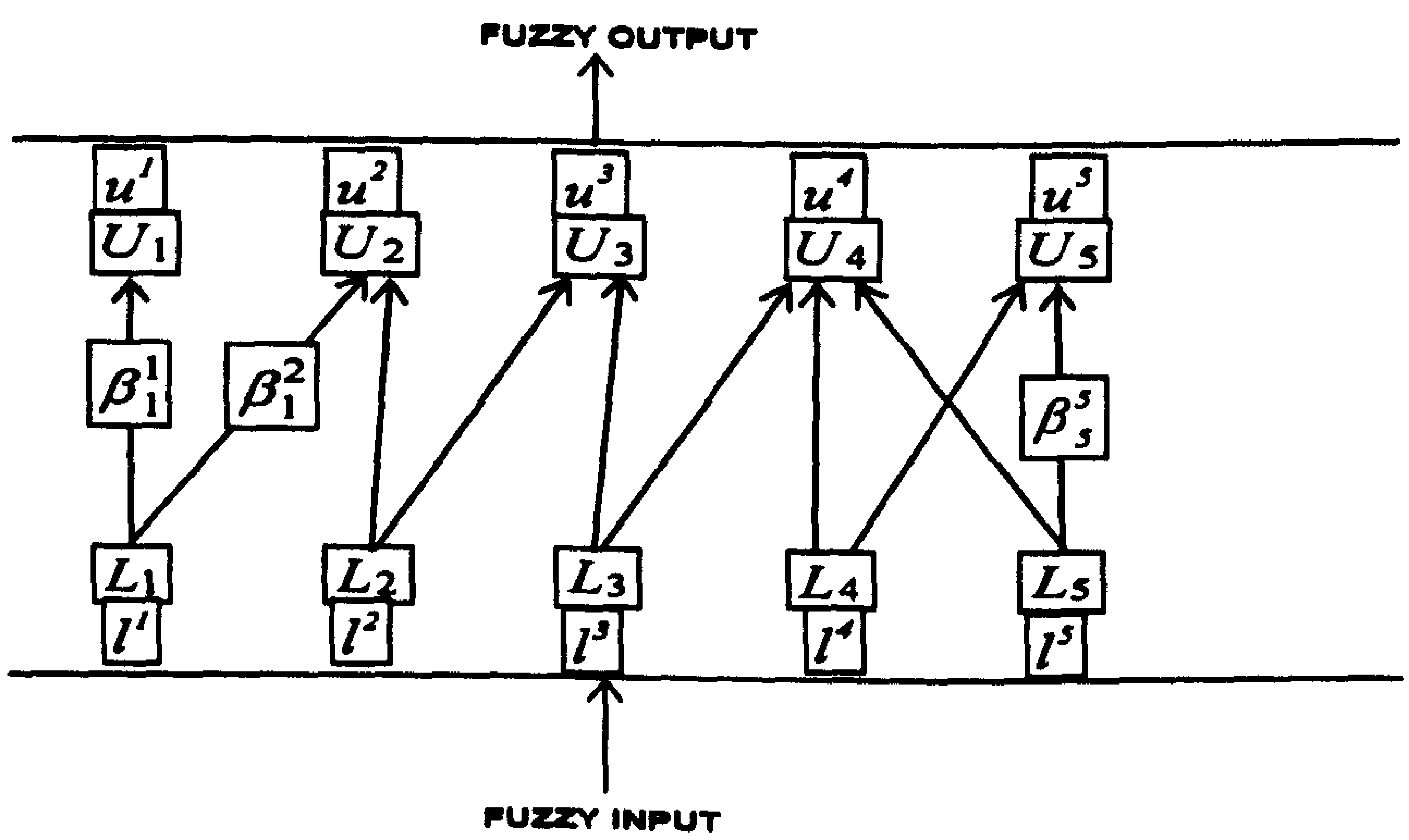

Figure 3.3: Mapping Process

3.9.4. Analytic Hierarchy Process *(Fourth Step)*

Using an Analytic Hierarchy Process *(AHP)* technique to calculate the relative importance of each attribute requires a careful review of its principles and background (Saaty, 1987). When considering a group of attributes for evaluation, the main objectives of the technique are to provide judgements on the relative importance of these attributes and to ensure that the judgements are quantified to an extent, which permits a quantitative interpretation of the judgement among these attributes (Pillay and Wang, 2003).

The quantified judgements on pairs of attributes A_i and A_j are represented by an n-by-n matrix (D). The entries a_{ij} are defined by the following entry rules:

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

According to above rules the matrix D has the following form:

$$D = a_{ij} = \begin{bmatrix} 1 & a_{12} & \cdots\cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots\cdots & a_{2n} \\ \cdot & \cdot & \cdots\cdots & \cdot \\ 1/a_{1n} & 1/a_{2n} & \cdots\cdots & 1 \end{bmatrix} \qquad (3.6)$$

where, $i, j = 1, 2, 3 \ldots, n$ and each a_{ij} is the relative importance of attribute A_i to attribute A_j.

Having recorded the quantified judgements of comparisons on pair (A_i, A_j) as numerical entry a_{ij} in the matrix D, what is left is to assign to the "n" contingencies $A_1, A_2, \ldots\ldots, A_n$ a set of numerical weights $w_1, w_2, \ldots\ldots, w_n$ that should reflect the recorded judgements. In general, weights $w_1, w_2, \ldots., w_n$ can be calculated by using the following equation (Pillary and Wang, 2003):

$$w_k = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{a_{kj}}{\sum_{i=1}^{n} a_{ij}}\right) \quad (k = 1, 2, 3 \ldots n) \tag{3.7}$$

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

The weight vector of the comparison matrix provides the priority ordering. However, it cannot ensure the consistency of the pairwise judgements. Thus, *AHP* provides a measure of the consistency for the pairwise comparisons by computing a consistency ratio (*CR*). *CR* is designed in such a way that a value greater than 0.10 indicates an inconsistency in the pairwise judgements and the decision maker should review the pairwise judgements before proceeding. Thus, if *CR* is 0.10 or less, the consistency of the pairwise comparisons is considered reasonable, and the *AHP* can continue with the computations of the weight vectors. The *CR* value is computed according to the following equations (Andersen *et al.*, 2003).

$$CR = \frac{CI}{RI} \tag{3.8}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3.9}$$

$$\lambda_{max} = \frac{\sum_{j=1}^{n} \frac{\sum_{k=1}^{n} w_k \, a_{jk}}{w_j}}{n} \tag{3.10}$$

where *CI* stands for consistency index, *RI* stands for average random index (Table 3.2), "*n*" stands for matrix order, and $\lambda_{\max}$ stands for maximum weight value of the "*n-by-n*" comparison matrix *D*.

Table 3.2: Value of RI versus Matrix Order (Saaty, 1990)

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

Since decision makers or experts often feel more confident to give imprecise judgment by using qualitative descriptors, in this study linguistic variables with belief degrees are used to describe the relative importance of attribute A_i to attribute A_j. Saaty (2004) has recommended equivalent scores from 1 to 9 as shown in Table 3.3. A preference of 1 indicates equality between two attributes while a preference of 9 indicates that one attribute is 9 times larger or more important that the one to which it is being compared with.

Table 3.3: Comparison Scale (Saaty, 1990)

Relative Importance of Attribute (Scale)	**Definition**
1	Equal importance. (EQ)
3	Moderate importance of one over another. (MO)
5	Essential or strong importance. (ST)
7	Very strong importance. (VS)
9	Extreme importance. (EX)
2,4,6,8	Intermediate values between the two adjacent judgments. (Inta,Intb,intc,intd)

Therefore, a single crisp number for the k^{th} expert's judgment can be obtained as follows:

$$e_{ij}^{k}=\beta_{ij}^{EQk}\times 1+\beta_{ij}^{Intak}\times 2+\beta_{ij}^{MOk}\times 3+\beta_{ij}^{Intbk}\times 4+\beta_{ij}^{ST,k}\times 5+\beta_{ij}^{Intck}\times 6$$
$$+\beta_{ij}^{VS,k}\times 7+\beta_{ij}^{Intdk}\times 8+\beta_{ij}^{EX,k}\times 9 \qquad (3.11)$$

$$\beta_{ij}^{EQk}+\beta_{ij}^{Intak}+\beta_{ij}^{MOk}+\beta_{ij}^{Intbk}+\beta_{ij}^{ST,k}+\beta_{ij}^{Intck}+\beta_{ij}^{VS,k}+\beta_{ij}^{Intdk}+\beta_{ij}^{EX,k}=1 \qquad (3.12)$$

where $\beta_{ij}^{EQ,k}$ stands for the k^{th} expert's belief degree concerning equal importance of attribute A_i over attribute A_j and $\beta_{ij}^{ST,k}$ stands for the k^{th} expert's belief degree concerning strong importance of attribute A_i over attribute A_j. Subsequently the other belief degrees are defined accordingly.

If "*m*" decision makers with an equal weight have judged the relative importance of attribute A_i over attribute A_j, then the values of "a_{ij}" can be calculated as follows:

$$a_{ij} = \frac{\sum_{m=1}^{m} e_{ij}^{m}}{m} \qquad (3.13)$$

3.9.5. Evidential Reasoning Algorithm *(Fifth Step)*

IDS incorporating the *ER* algorithm can be employed for a synthesis of criteria in a hierarchical structure. The evidential reasoning algorithm and its background were described in Chapter 2. For further information, kindly refer to (Yang and Xu, 2002).

3.9.6. Expected Utility *(Sixth Step)*

An expected utility approach was developed by Yang (2001). The main aim of using a utility approach is to obtain a single crisp number for the top-level criterion (final-result or the goal) of each alternative in order to rank them.

Let the utility of an evaluation grade H_n be denoted by $u(H_n)$ and $u(H_{n+1}) > u(H_n)$ if H_{n+1} is preferred to H_n (Yang, 2001). $u(H_n)$ stands for the utility values of each linguistic term and can be estimated using the decision maker's preferences. If no preference information is available, it could be assumed that the utilities of evaluation grades are equidistantly distributed in a normalised utility space, so that "$u(H_n) = (n-1)/(N-1)$" ($n = 1,...,N$). Otherwise, a probability assignment approach could be employed for utility estimation (Keeney and Raiffa, 1976; Farguhar, 1984; Winston, 1994). Therefore, the utilities of evaluation grades that are equidistantly distributed in a normalised utility space can be calculated as follows:

$$u(H_n) = \frac{V_n - V_{min}}{V_{max} - V_{min}} \qquad (3.14)$$

where V_n is the ranking value of the linguistic term that has been considered (H_n), V_{max} is the ranking value of the most preferred linguistic term (H_N), and V_{min} is the ranking value of the least preferred linguistic term (H_1).

$$\beta_H = 1 - \sum_{n=1}^{N} \beta_n \tag{3.15}$$

The utility of the top level or general criterion *S(E)* is denoted by *u(S(E))*. If $\beta_H \neq 0$ (the assessment is incomplete) there is a belief interval $[\beta_n, (\beta_n + \beta_H)]$, which provides the likelihood that *S(E)* is assessed to H_n. Without loss of generality, suppose the least preferred linguistic term having the lowest utility is denoted by $u(H_1)$ and the most preferred linguistic term having the highest utility is denoted by $u(H_N)$. Then the minimum, maximum and average utilities of *S(E)* are defined as follows (Yang , 2001):

$$u_{min}(S(E)) = \sum_{n=2}^{N} \beta_n u(H_n) + (\beta_1 + \beta_H) u(H_1) \tag{3.16}$$

$$u_{max}(S(E)) = \sum_{n=1}^{N-1} \beta_n u(H_n) + (\beta_N + \beta_H) u(H_N) \tag{3.17}$$

$$u_{average}(S(E)) = \frac{u_{min}(S(E)) + u_{max}(S(E))}{2} \tag{3.18}$$

Obviously if all the assessments are complete, then $\beta_H = 0$ and the maximum, minimum and average utilities of *S(E)* will be the same. Therefore, *u(S(E))* can be calculated as follows:

$$u(S(E)) = \sum_{n=1}^{N} \beta_n u(H_n) \tag{3.19}$$

It has to be made clear that the above utilities are only used for characterising an assessment, and not for criteria aggregation.

3.9.7. Sensitivity Analysis (*Final Step)*

The objective of sensitivity analysis is to test the sensitivity of the FER model. Sensitivity analysis in FER refers to analysing how sensitive the conclusions (i.e. model outputs) are to minor change in inputs. The change may be variation of the parameters of the model or may be changes of the belief degrees assigned to the linguistic variables used to describe the parameters. If the methodology is sound and its inference reasoning is logical, then the sensitivity analysis must at least pursue the following three axioms (Yang, *et al.*, 2009).

Axiom 1: A slight increment/decrement in the degree of belief associated with any linguistic variables of the lowest level criteria will certainly result in the effect of a relative increment / decrement in the degree of belief of the linguistic variable and preference degrees of the model output.

Axiom 2: If the degree of belief associated with the highest preference linguistic variable of a lowest level criterion is decreased by m and n (i.e. simultaneously the degree of belief associated with its lowest preference linguistic variable is increased by m and n ($1 > n > m$)) and accordingly the utility value of the model output is evaluated as U_m and U_n respectively, then U_m should be greater than U_n.

Axiom 3: If "N" and "K" ($K < N$) criteria from all the lowest level criteria are selected and the degree of belief associated with the highest preference linguistic variables of each of such "N" and "K" criteria is decreased by the same amount (i.e. simultaneously the degree of belief associated with the lowest preference linguistic variables of each of such "N" and "K" criteria is increased by the same amount) and accordingly the utility value of the model output is evaluated as U_K and U_N respectively, then U_K should be greater than U_N.

The reasons for selection of above-mentioned axioms are, firstly, to use a sensitivity test to measure the effect of one criterion over another. Axiom 1, for example, states a slight increase in the belief associated with a linguistic variable should result in a slight increase in the output result. Secondly, to validate the methodology used for synthesis of the basic criteria (i.e. Axioms 2 and 3). Finally, to rank the criteria based on their effects on the model output. It is noteworthy to mention that, it is possible to define other axioms for further research, for instance, to distribute the dissimilar weights to the criteria.

3.10. Test Case

By help of the proposed methodology (Section 3.9) and the following information, the Master of a container vessel can assess the reliability of a Third Officer under his command and evaluate the variation of the Third Officer's reliability value by alteration of each criterion's value.

3.10.1. Information

- The Third Officer is 30 years old.
- He holds an approved "officer in charge of navigational watch" certificate of competency (STCW 95) with the level of competency as a second mate and does not hold a BSc degree in nautical science.
- He has a valid medical fitness certificate, and 31.2 months of qualifying sea service.
- He holds the following approved certificates:

  1. Ethic and leadership certificate.
  2. Basic safety training (BST) certificate.
  3. Advanced fire prevention & fire fighting certificate.
  4. Radar simulation training certificate.
  5. Global maritime distress safety system (GMDSS) certificate.
  6. First aid training certificate.
  7. Survival craft and rescue boat training certificate.
  8. Automated radar plotting aids (ARPA) training certificate.
  9. ISM attendance course certificate.
  10. Bridge resource management (BRM) attendance course certificates.

- Pursuant to his statements, the quality of the foods, which are served on board, is "not bad".
- He had 8 hours rest in the previous night.

- Based on his statements, the level of his stress is "moderate" and he is "healthy".
- The values of Beaufort number for the last two days are indicated as 4 and 5 respectively.
- The vessel is partially loaded and the value of metacentric height (GM) is 3 meters.
- Based on the available data (during design and construction) and pursuant to ABS guidance notes for the application of ergonomics to marine systems, the design & layout grade is estimated as 100% very good.
- The design & habitability grade for the last two days is estimated as 100% good.
- Based on the Master's observation, he is punctual, needs supervision occasionally, and is enthusiastic.
- Based on the Master's judgement, the grade of his communication and language skill is medium, his teamwork is good, and the grade of his decision-making is medium.
- To estimate his situation awareness, the Master has demonstrated a scenario. The Master asked him to elucidate his actions regarding the presented scenario. Accordingly, the grade of his situation awareness is evaluated as good.

3.10.2. Third Officer's Reliability Modelling

Based on the generic model for the seafarers' reliability (Figure 3.1) and available information a specific model for the third officer's reliability can be constructed (Figure 3.4). Assessment grades are assigned to all the criteria in the hierarchical structure and the quantitative and qualitative criteria are segregated (Tables 3.4-3.5). The linguistic terms for each qualitative criterion are defined and presented in Tables 3.4 and 3.5.

Miller (1956) showed a number of remarkable coincidences between the channel capacity of a number of human cognitive and perceptual tasks. In each case, the effective channel capacity is between 5 and 9 equally-weighted error-less choices. With respect to Miller's investigation, it is "often recommended" that the number of categories be restricted to not more than nine (Karwowski and Mital, 1986). In this study, five categories of linguistic representation are employed.

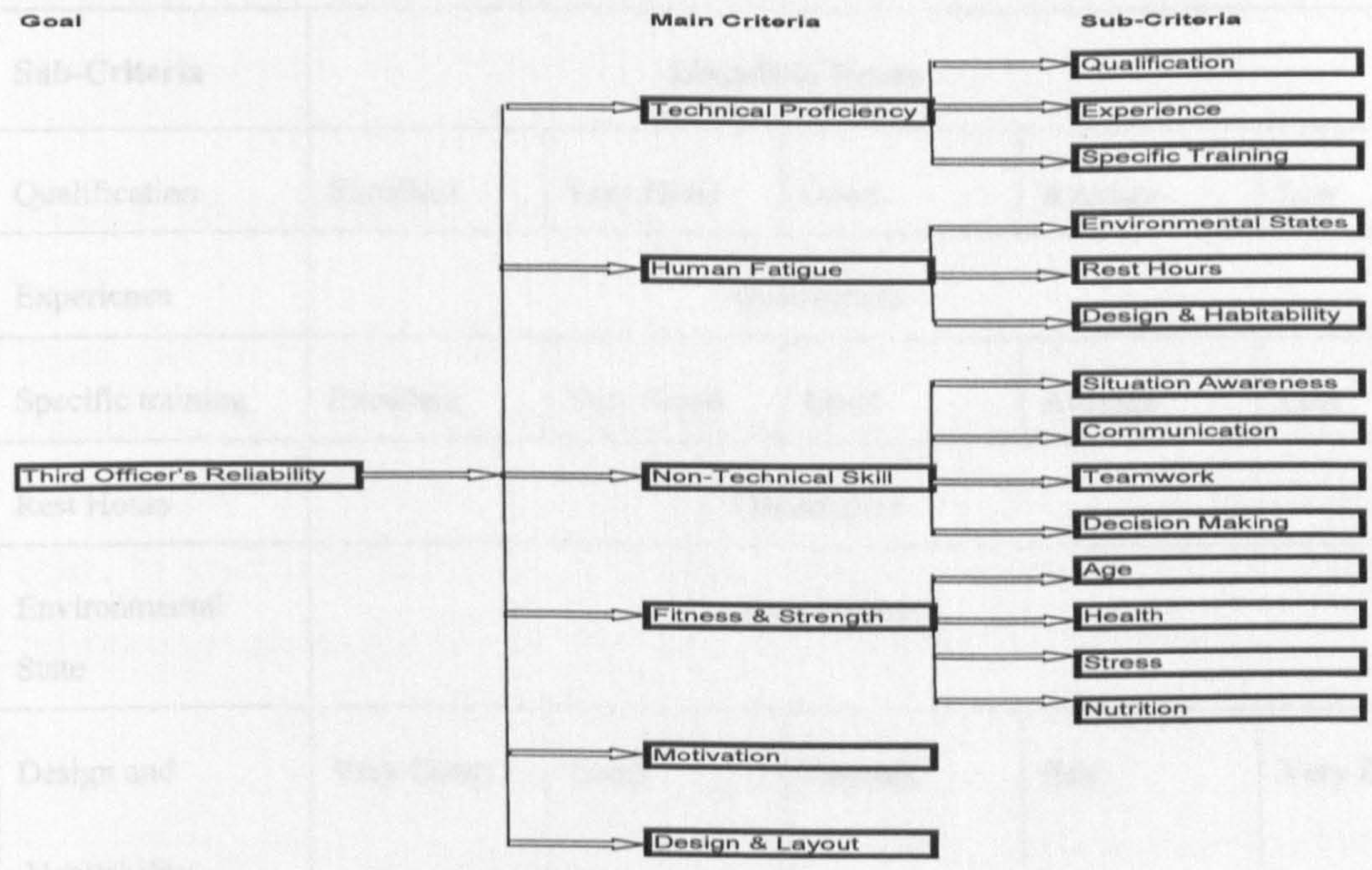

Figure 3.4: Specific Model for Third Officer's Reliability

Table 3.4: Linguistic Terms for Main Criteria

Goal	Linguistic Terms				
Seafarer's Reliability	High	Fairly High	Medium	Fairly Low	Low
Main Criteria	**Linguistic Terms**				
Technical Proficiency	Very Good	Good	Average	Fairly Low	Low
Human Fatigue	Very Low	Low	Medium	High	Very High
Non-Technical Skill	Very Good	Good	Average	Fairly Low	Low
Fitness & Strength	Very High	High	Medium	Low	Very Low
Motivation	Very High	High	Medium	Low	Very Low
Design & Layout	Very Good	Good	Average	Bad	Very Bad

Table 3.5: Linguistic Terms for Sub-Criteria

Sub-Criteria	**Linguistic Terms**				
Qualification	Excellent	Very Good	Good	Average	Low
Experience	Quantitative				
Specific training	Excellent	Very Good	Good	Average	Low
Rest Hours	Quantitative				
Environmental State	Quantitative				
Design and Habitability	Very Good	Good	Average	Bad	Very Bad
Situation Awareness	Very Good	Good	Medium	Low	Very Low
Communication & Language Skill	Very Good	Good	Medium	Low	Very Low
Teamwork	Very Good	Good	Medium	Low	Very Low
Decision Making	Very Good	Good	Medium	Low	Very Low
Age	Qualitative				
Health	Very Healthy	Healthy	Mol. Healthy	Unhealthy	
Stress	Very High	High	Moderate	Low	
Nutrition	Very good	Good	Average	Bad	Very Bad

Note: Mol. stands for more or less.

3.10.3. Quantitative Data Transformation

Based on the available information and the previous discussion (Section 3.9.2), the quantitative criteria can be modelled as follows:

3.10.3.1. Environmental States

Based on the available information and the previous discussion (Section 3.5.1), by considering the correlation between the vessel's stability (GM = 3m) and the sea conditions on the vessel's response (period, amplitude, and angular acceleration), the effect of environmental states on human fatigue can be evaluated. The correlation between the sea conditions and Beaufort number is presented in Table 3.6.

Table 3.6: Beaufort Number versus Sea Conditions

Beaufort Number	Sea Conditions
0	Flat.
1	Ripples without crests.
2	Small wavelets.
3	Large wavelets.
4	Small wave.
5	Moderate (1.2m) longer waves. Some foam and spray.
6	Large wave with foam crests and some spray.
7	Sea heaps up and foam begins to be blown in steaks in wind direction.
8	Moderately high waves with breaking crests forming spindrift.
9	High waves (6-7m) with dense foam.
10	Very high waves.

Source: [Beaufort scale, 2009]

Based on Table 3.6 and the previous discussion (Section 3.9.2), the membership functions of sea conditions can be constructed (Figure 3.5). The horizontal axis shows the quantitative number, and vertical axis shows the degree of belief (membership value). If any quantitative number (e.g. h_i) is found in the range of $h_{n+1,i}$ (with a grade H_{n+1}) and $h_{n,i}$ (with a grade H_n), its belief degrees can be evaluated as follows:

If $h_{n,i} < h_i < h_{n+1,i}$ then $\beta_{n,i} = \frac{h_{n+1,i} - h_i}{h_{n+1,i} - h_{n,i}}$, $\beta_{n+1,i} = 1 - \beta_{n,i}$ (3.20)

where, $\beta_{n,i}$ stands for the degree of belief of the concerned quantitative number with the grade H_n and $\beta_{n+1,i}$ stands for the degree of belief of the concerned quantitative number with the grade H_{n+1}. Based on the given information, the values of Beaufort Number for the last two days are indicated as 4 and 5 respectively. Thus, the average value of Beaufort Number is evaluated as 4.5 (i.e. $\frac{(4+5)}{2}$). Based on Figure 3.5 and Equation (3.20), the belief degrees are calculated as follows:

- H_{n+1} stands for Moderate.
- H_n stands for Calm.
- $h_i = 4.5$, $h_{n,i} = 4$, and $h_{n+1,i} = 5$.

Thus, $\beta_{n,i} = (5-4.5)/(5-4) = 0.5$ with the Calm grade and $\beta_{n+1,i} = 1-0.5 = 0.5$ with the Moderate grade. Therefore, the sea condition's set is assessed:

{(Very Calm, 0), (Calm, 0.5), (Moderate, 0.5), (Rough, 0), (Very Rough, 0)}

If Beaufort Number is 3.5, then the sea condition's set is assessed:

{(Very Calm, 0), (Calm, 1), (Moderate, 0), (Rough, 0), (Very Rough, 0)}

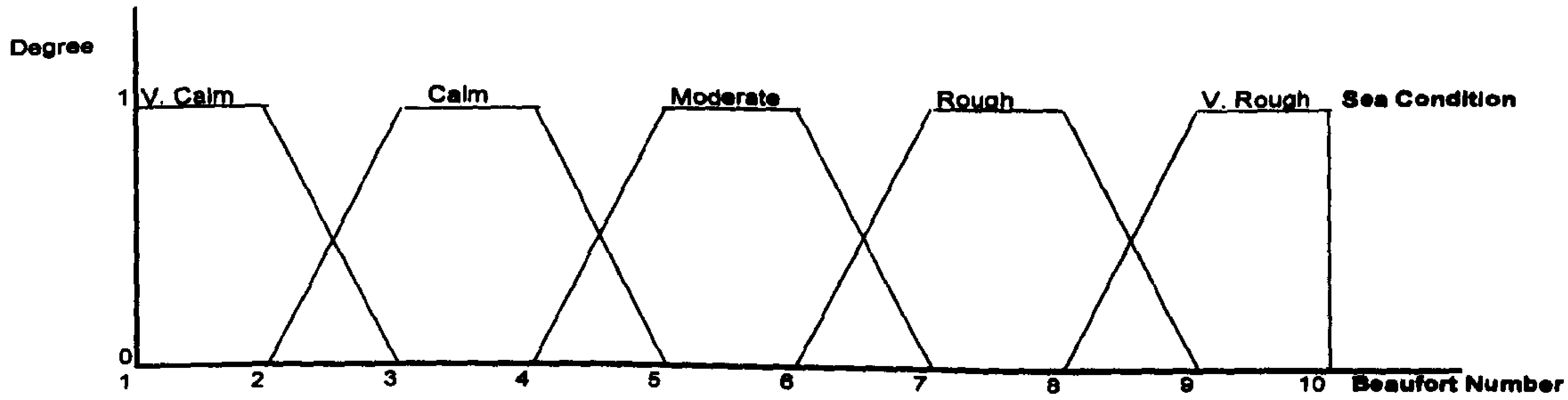

Figure 3.5: Membership Functions of Sea Condition

3.10.3.2. Experience (Qualifying Sea Service)

Based on a seafarer's qualifying sea service a seafarer's experience can be modelled.

Qualifying sea service should be accounted from the commencement of a ship's voyage to the termination of such voyage. For instance, where a ship is laid up in a port for an unreasonably long period, such a period should not be accounted towards qualifying sea service. In addition, during reliability assessment, the consistency of sea service has to be accounted (i.e. ship's tonnage, type, route, mode of propulsion, and main engine's power). Thus, a promotion can be granted to a deck or an engineer officer by considering his/her qualifying sea service, confidential reports, oral examination's result, qualifications, and certificate of competency. A deck or an engineer officer is eligible for promotion after completion of the following months of qualifying sea service:

- Third Officer is eligible for promotion to Second Officer's rank after completing 18-24 months of sea service.
- Second Officer is eligible for promotion to Chief Officer's rank after completing 36-42 months of sea service (i.e. at least sailing for 18 months as a second mate).
- Chief Officer is eligible for promotion to Master's rank after completing 60-66 months of sea service (i.e. at least sailing for 24 months as a chief mate).

Based on the stated rules and by looking at a deck officer's experience as an independent criterion, a deck officer after completing 60-66 months of sea service is eligible for promotion to Master's rank. Thus, 60-66 months of sea service can be categorised as Very Good and accordingly the membership functions of experience, as shown in Figure 3.6, can be constructed. The horizontal axis shows the quantitative number, and vertical axis shows the degree of belief (membership value).

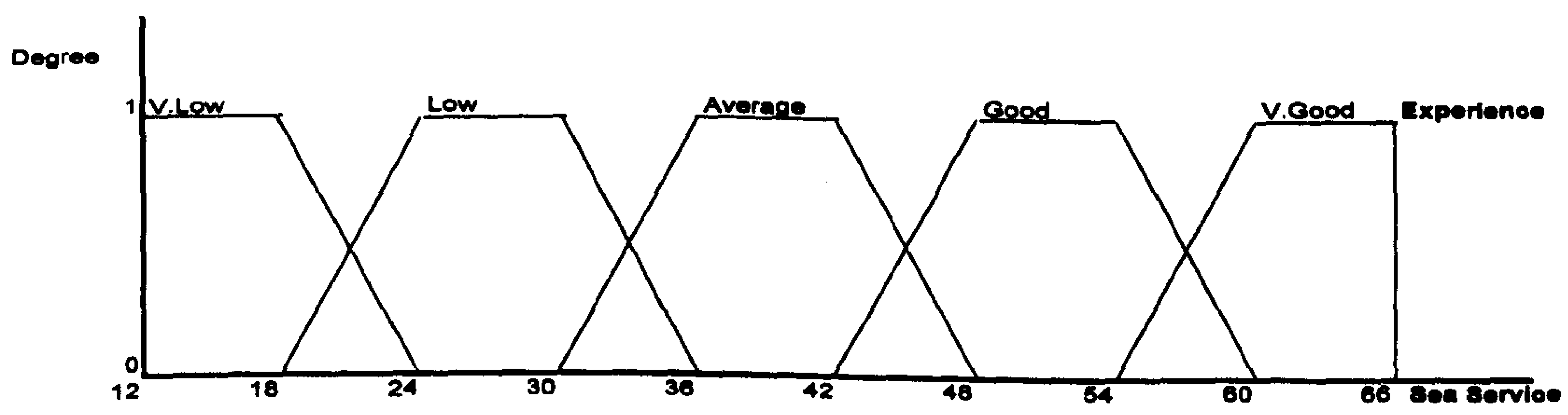

Figure 3.6: Membership Functions of Experience

3.10.3.3. Age

Based on the previous discussion (Section 3.7.4), a seafarer's age can be modelled. In this study, 0.33% declining of a seafarer's strength per year is considered (based on eight months working and four months leave). Thus, the membership function of age, as shown in Figure 3.7, can be constructed. The horizontal axis shows the quantitative number, and vertical axis shows the degree of belief (membership value).

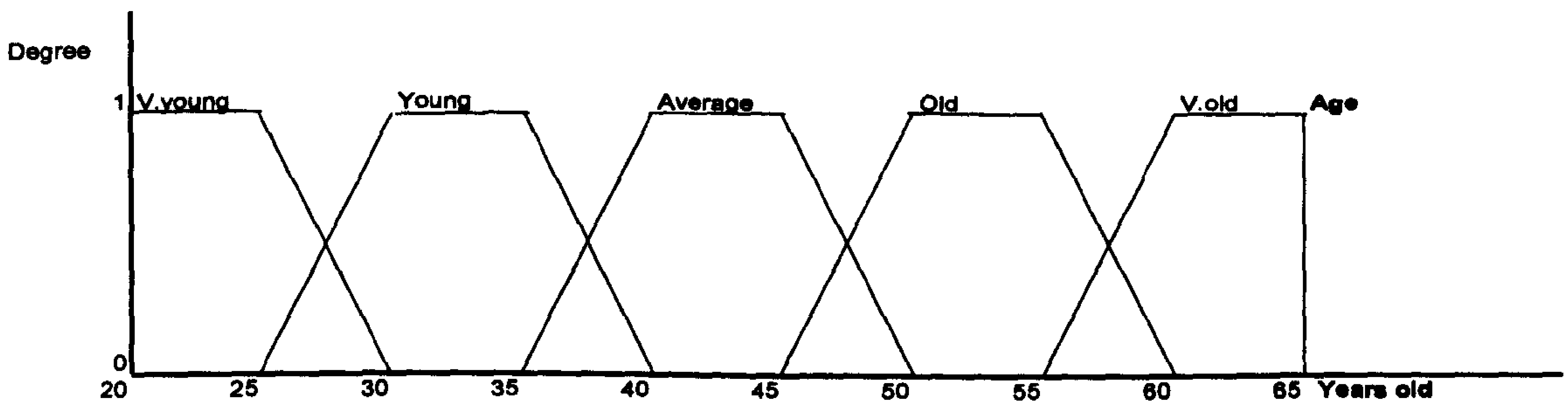

Figure 3.7: Membership Functions of Age

3.10.3.4. Rest Hours

Based on the ILO (180) convention (Section 3.5.2) and human psychology (most adults need approximately 8 to 9 hours of sleep each night to do their best), a seafarer's hours of rest can be modelled (Figure 3.8). The horizontal axis shows the quantitative number, and vertical axis shows the degree of belief (membership value).

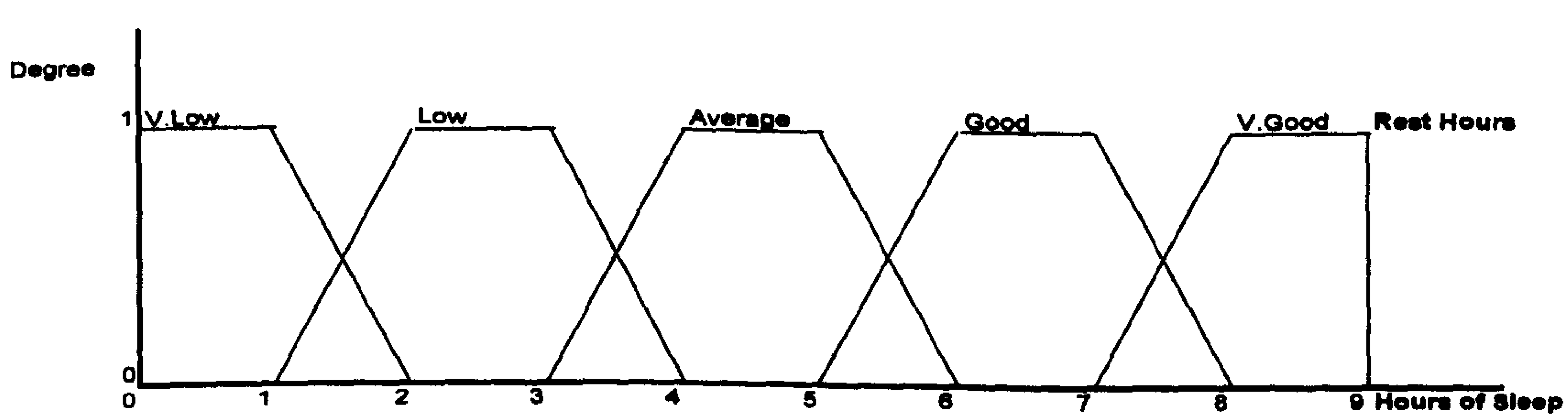

Figure 3.8: Membership Functions of Rest Hours

3.10.4. Weight Assignment

To show the relative importance of each sub-criterion for its associated upper level criterion, it is necessary to assign the weight to each sub-criterion. In order to conduct the assessment a group of experts, which is composed of three experts is used. To avoid prejudgment, all experts utilized in the assessments are containing both academia and industrial related experience and they are assigned with equal weight.

1. A professor of marine technology who has been involved in the marine and offshore safety research for 20 years.
2. A lecturer and head of maritime studies who has been involved in the maritime and marine industry for more than 20 years.
3. A researcher who has been involved in the marine industry for more than 20 years.

Let A_1, A_2 and A_3 respectively stand for qualification, experience and specific training. Three experts with equal weight have judged and evaluated the relative importance of specific training, experience and qualification for their associated upper level criterion (i.e. technical proficiency) as shown in Table 3.7. Based on Equations (3.6-3.13), the a_{ij} values can be evaluated:

$$e_{12}^{1} = 1 \quad e_{12}^{2} = 0.8 + 0.2 \times 2 = 1.2 \quad e_{12}^{3} = 0.7 + 0.3 \times 2 = 1.3$$

$$a_{12} = \frac{(1 + 1.2 + 1.3)}{3} = 1.16 \quad a_{21} = \frac{1}{a_{12}} = 0.86$$

$$e_{13}^{1} = 1.2 \quad e_{13}^{2} = 1.1 \quad e_{13}^{3} = 1.3 \quad a_{13} = 1.2 \quad a_{31} = \frac{1}{1.2} = 0.83$$

$$e_{23}^{1} = 1 \quad e_{23}^{2} = 1.3 \quad e_{23}^{3} = 1.5 \quad a_{23} = 1.26 \quad a_{32} = \frac{1}{1.26} = 0.79$$

The matrix D is obtained as follows:

$$D = \begin{bmatrix} 1 & 1.16 & 1.2 \\ 0.86 & 1 & 1.26 \\ 0.83 & 0.79 & 1 \end{bmatrix}$$

Based on Equations (3.6)-(3.13), the consistency ratio is calculated as 0.0042 and the weights of the three attributes, as shown in Table 3.8, are assessed.

Table 3.7: Relative Importance of Qualification, Experience and Specific Training

	A_2		A_3	
A_1	1, EQ		0.8, EQ	0.2, Inta
	0.8, EQ	0.2, Inta	0.9, EQ	0.1, Inta
	0.7, EQ	0.3, Inta	0.7, EQ	0.3, Inta
	A_3			
A_2	1, EQ			
	0.7, EQ	0.3, Inta		
	0.5, EQ	0.5, Inta		

Table 3.8: Calculated Weights (i.e. Qualification, Experience, and Specific Training)

Description	Weight
Qualification	0.3708
Experience	0.3408
Specific Training	0.2884

Table 3.9: Relative Importance of Rest Hours, Environmental State and Design & Habitability

	A_2		A_3	
A_1	0.6,EQ	0.4, Inta	0.4, EQ	0.6, Inta
	0.4,EQ	0.6, Inta	0.3, EQ	0.7, Inta
	0.3,EQ	0.7, Inta	0.2, EQ	0.8, Inta
	A_3			
A_2	1, EQ			
	0.9, EQ	0.1, Inta		
	0.8, EQ	0.2, Inta		

Let A_1, A_2 and A_3 respectively stand for rest hours, environmental states, and design & habitability. Three experts with equal weight have judged and evaluated the relative importance of d esign & habitability, environmental states, and rest hours for their associated upper level criterion (i.e. human fatigue) as shown in Table 3.9. Based on Equations (3.6-3.13), the consistency ratio was calculated as 1.78×10^{-5} and the weights of the three attributes, as shown in Table 3.10, are obtained.

Table 3.10: Calculated Weights (i.e. Rest Hours, Environmental State, and Design & Habitability)

Description	Weight
Rest Hours	0.4491
Environmental State	0.2880
Design & Habitability	0.2629

Let A_1, A_2, A_3 and A_4 respectively stand for stress, health, nutrition, and age. Three experts with equal weight have judged and evaluated the relative importance of age, nutrition, health, and stress for their associated upper level criterion (i.e. fitness and strength) as shown in Table 3.11.

Table 3.11: Relative Importance of Stress, Health, Age, and Nutrition

	A_2		A_3		A_4	
A_1	0.6,EQ	0.4,Inta	1, Inta		0.7, Inta	0.3,MO
	0.5,EQ	0.5,Inta	0.8, Inta	0.2,MO	O.6, Inta	0.4,MO
	0.4,EQ	0.6, Inta	O.8, Inta	0.2,MO	0.5, Inta	0.5,MO
	A_3		A_4			
A_2	0.2, Inta	0.8,MO	1, Inta			
	0.3, Inta	0.7,MO	0.9, Inta	0.1,MO		
	O.3, Inta	0.7, MO	0.8, Inta	0.2, MO		
	A_4					
A_3	1,EQ					
	0.9, EQ	0.1, Inta				
	O.8,EQ	0.2, Inta				

Based on Equations (3.6-3.13), the consistency ratio is calculated as 0.0147 and the weights of the four attributes, as shown in Table 3.12, are obtained.

Table 3.12: Calculated Weights (i.e. Stress, Health, Nutrition and Age)

Description	Weight
Stress	0.3798
Health	0.3205
Nutrition	0.1518
Age	0.1479

Based on the experts' judgment, the situation awareness, communication and language skill, teamwork, and decision-making are equally important. Therefore, all the criteria are assigned with an equal weight (i.e. 0.25). Based on the experts' judgment, the main criteria are equally important. Therefore, the weights are distributed evenly between them (i.e. 1/6).

3.10.5. Qualification

Based on the previous discussion (Section 3.4.1) the decision makers have assigned the following fuzzy rules for a deck officer's qualification:

- If a person holds a BSc degree in nautical science and an approved chief mate/master certificate of competency "STCW (95)" with the level of competency as a master, then his qualification is 100% excellent.
- If a person holds an approved chief mate/master certificate of competency "STCW (95)" with the level of competency as a master, then his qualification is 20% excellent and 80% very good.
- If a person holds a BSc degree in nautical science and an approved chief mate/master certificate of competency "STCW (95)" with the level of competency as a chief mate, then his qualification is 100% very good.
- If a person holds an approved chief mate/master certificate of competency "STCW (95)" with the level of competency as a chief mate, then his qualification is 20% very good and 80% good.

- If a person holds a BSc degree in nautical science and an approved officer in charge of a navigational watch certificate of competency "STCW (95)" with the level of competency as a third or second mate, then his qualification is 100% good.
- If a person holds an approved officer in charge of a navigational watch certificate of competency "STCW (95)" with the level of competency as a third or second mate, then his qualification is 20% good and 80% average.
- If a person does not hold any certificate of competency, then his qualification is 100% low.

Based on the given information and the stated rules, the Third Officer's qualification set is assessed as follows:

$$\tilde{Q} = \{(\text{Excellent}, 0), (\text{Very good}, 0), (\text{Good}, 0.2), (\text{Average}, 0.8), (\text{Low}, 0)\}$$

The decision makers have assigned the following fuzzy rules for mapping from qualification to technical proficiency (Figure 3.9):

- If a person qualification is excellent, then his/her technical proficiency is 100% very good.
- If a person's qualification is very good, then his/her technical proficiency is 20% very good and 80% good.
- If a person's qualification is good, then his/her technical proficiency is 10% good and 90% average.
- If a person's qualification is average, then his/her technical proficiency is 20% average and 80% fairly low.
- If a person's qualification is low, then his/her technical proficiency is 100% low.

Based on Equations (3.3-3.5), the following is obtained:

$$u^2 = 0.2 \times 0.1 = 0.02 \text{ , } u^3 = 0.2 \times 0.9 + 0.8 \times 0.2 = 0.34 \text{ , } u^4 = 0.8 \times 0.8 = 0.64$$

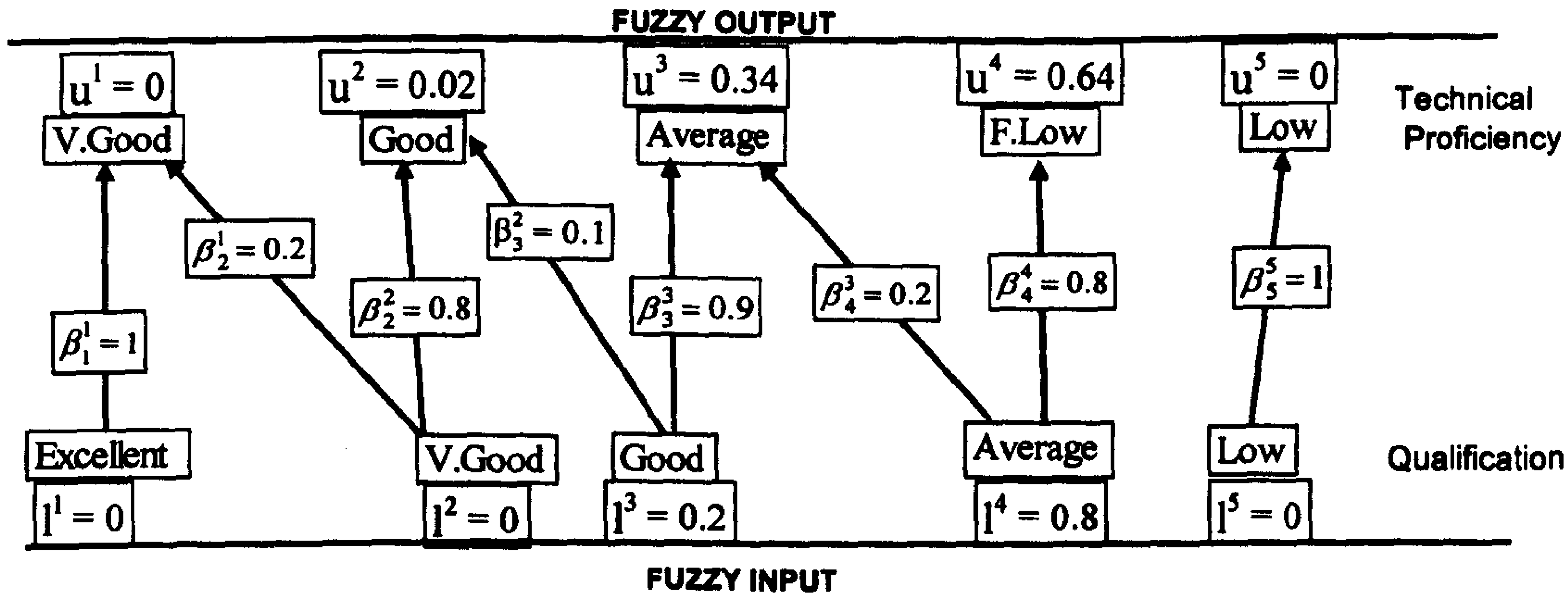

Figure 3.9: Mapping from Qualification to Technical Proficiency

The fuzzy output set is assessed as follows:

$$\tilde{T}_Q = \{(\text{Very Good}, 0), (\text{Good}, 0.02), (\text{Average}, 0.34), (\text{Fairly Low}, 0.64), (\text{Low}, 0)\}$$

3.10.6. Experience

Based on the given information, the Third Officer has 31.2 months of qualifying sea service. Based on Figure 3.6 and Equation (3.20), the belief degrees are calculated as follows:

- H_{n+1} stands for Average grade.
- H_n stands for Low grade.
- $h_i = 31.2$, $h_{n,i} = 30$, and $h_{n+1,i} = 36$.

Thus, $\beta_{n,i} = (36 - 31.2)/(36 - 30) = 0.8$ with the Low grade and $\beta_{n+1,i} = 1 - 0.8 = 0.2$ with the Average grade. Therefore, the Third Officer's experience set is assessed:

$$\tilde{E} = \{(\text{Very Low}, 0), (\text{Low}, 0.8), (\text{Average}, 0.2), (\text{Good}, 0), (\text{Very Good}, 0)\}$$

The mapping process, as shown in Figure 3.10, is elucidated and elaborated. Accordingly, the fuzzy output set is evaluated as follows:

$$\tilde{T}_E = \{(\text{Very Good}, 0), (\text{Good}, 0), (\text{Average}, 0.28), (\text{Fairly Low}, 0.72), (\text{Low}, 0)\}$$

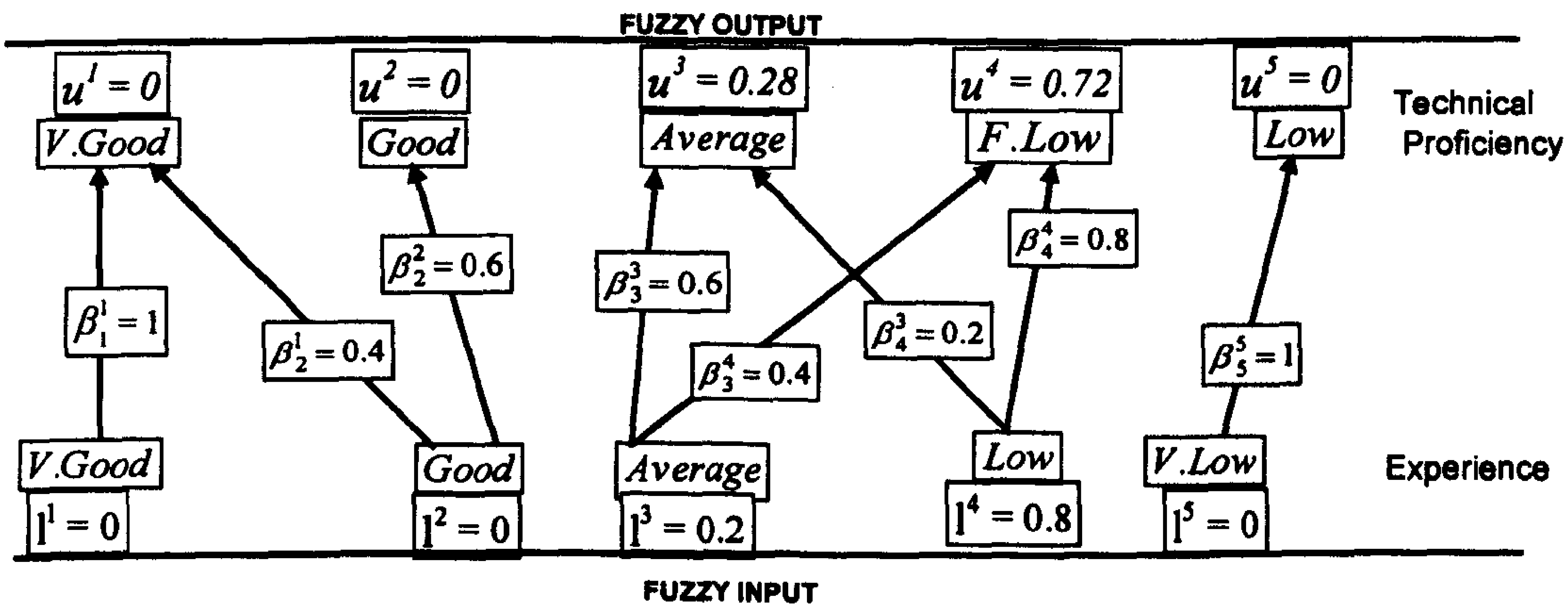

Figure 3.10: Mapping from Experience to Technical Proficiency

3.10.7. Specific Training

Based on the previous discussion (Section 3.4.2) the decision makers have assigned the following fuzzy rules for a deck officer's specific training. It is noteworthy to mention that for special vessels (i.e. LNG, Tanker, RORO, passenger, etc) additional requirements have to be considered.

- If a person holds following certificates, then his/her specific training is 100% excellent.

  1. Ethic and leadership certificate.
  2. Advanced medical training certificate.
  3. Basic safety training (BST) certificate.
  4. Advanced fire prevention & fire fighting certificate.
  5. Radar simulation training certificate.
  6. Global maritime distress safety system (GMDSS) certificate.
  7. First aid training certificate.
  8. Survival craft and rescue boat training certificate.
  9. Automated radar plotting aids (ARPA) training certificate.
  10. ISM attendance course certificate.
  11. Bridge resource management (BRM) attendance course certificates.

- If a person holds the following certificates, then his/her specific training is 20% excellent and 80% very good.

  1. Ethic and leadership certificate.
  2. BST certificate.
  3. Advanced fire prevention & fire fighting certificate.
  4. Radar simulation training certificate.
  5. GMDSS certificate.

6. First aid training certificate.
7. Survival craft and rescue boat training certificate.
8. ARPA training certificate.
9. ISM attendance course certificate.
10. BRM attendance course certificates.

- If a person holds the following certificates, then his/her specific training is 100% good.

1. BST certificate.
2. Advanced fire prevention & fire fighting certificate.
3. Radar simulation training certificate.
4. GMDSS certificate.
5. First aid training certificate.
6. Survival craft and rescue boat training certificate.
7. ARPA training certificate.
8. ISM attendance course certificate.
9. BRM attendance course certificates.

- If a person holds the following certificates, then his/her specific training is 20% good and 80% average.

1. BST certificate.
2. Advanced fire prevention & fire fighting certificate.
3. Radar simulation training certificate.
4. GMDSS certificate.
5. First aid training certificate.
6. Survival craft and rescue boat training certificate.
7. ARPA training certificate.
8. ISM attendance course certificate.

- If a person does not hold any certificate, then his/her specific training is 100% low.

Based on the stated rules and the information, the Third Officer's specific training set is assessed as follows:

$$\tilde{S} = \{(\text{Excellent}, 0.2), (\text{Very good}, 0.8), (\text{Good}, 0), (\text{Average}, 0), (\text{Low}, 0)\}$$

The mapping process is elucidated as shown in Figure 3.11, and the fuzzy output set is evaluated as follows:

$$\tilde{T}_S = \{(\text{Very Good}, 0.2), (\text{Good}, 0.64), (\text{Average}, 0.16), (\text{Fairly Low}, 0), (\text{Low}, 0)\}$$

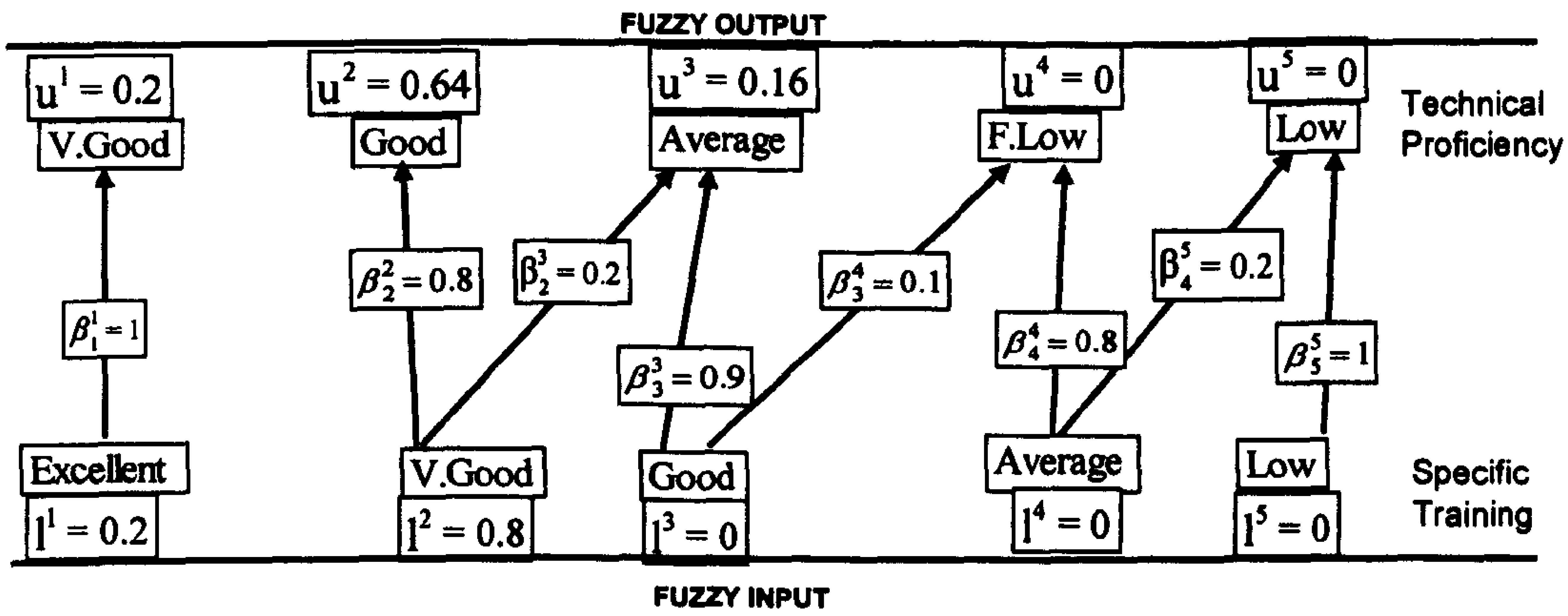

Figure 3.11: Mapping from Specific Training to Technical Proficiency

3.10.8. Aggregation of Sub-Criteria

The weight of each sub-criterion can be extracted from Table 3.8. Moreover, by help of the IDS software, $\widetilde{T}_Q$, $\widetilde{T}_E$ and $\widetilde{T}_S$ are aggregated and the result is presented in Table 3.13.

Table 3.13: Aggregation of Sub-Criteria (Technical Proficiency)

Technical Proficiency	Very Good	Good	Average	Fairly Low	Low	Weight
$\widetilde{T}_Q$	0	0.02	0.34	0.64	0	0.3708
$\widetilde{T}_E$	0	0	0.28	0.72	0	0.3408
$\widetilde{T}_S$	0.2	0.64	0.16	0	0	0.2884
Aggregation Result	0.0474 ≈ 0.05	0.1605 ≈ 0.16	0.2712 ≈ 0.27	0.5209 ≈ 0.52	0 $= 0$	

3.10.9. Mapping from Main Criterion (Technical proficiency) to Goal

The main criterion (i.e. technical proficiency) can be transformed to the goal (i.e. Third

Officer's reliability) by formulating a mapping process. Based on Table 3.13, the fuzzy set for the Third Officer's technical proficiency can be written as follows:

$\tilde{T}$ = {(Very Good, 0.05), (Good, 0.16), (Average, 0.27), (Fairly Low, 0.52), (Low, 0)}

The mapping process, as shown in Figure 3.12, is elaborated and elucidated. The fuzzy output set is evaluated as follows:

$\tilde{G}_T$ = {(High, 0.08), (Fairly High, 0.16), (Medium, 0.34), (Fairly Low, 0.42), (Low, 0)}

where $\tilde{G}_T$ stands for fuzzy output set that is evaluated by mapping from technical proficiency to the Third Officer's reliability.

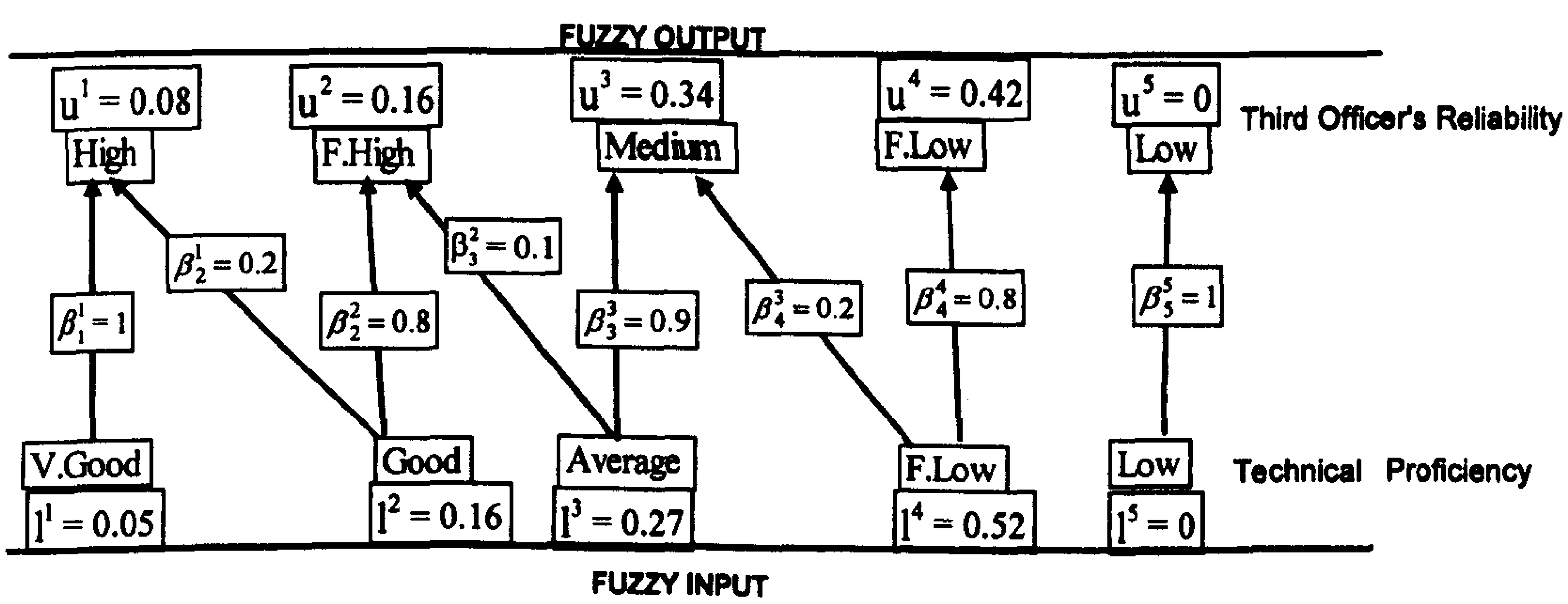

Figure 3.12: Mapping from Technical Proficiency to the Third Officer's Reliability

3.10.10. Aggregation of Main Criteria

Using the same technique with which $\tilde{G}_T$ has been calculated, the other fuzzy output sets (i.e. $\tilde{G}_H$, $\tilde{G}_{NT}$, $\tilde{G}_{FS}$, $\tilde{G}_M$ and $\tilde{G}_{DL}$) can also be evaluated where

- $\tilde{G}_H$ stands for fuzzy output set that is evaluated by mapping from human fatigue to the Third Officer's reliability.
- $\tilde{G}_{NT}$ stands for fuzzy output set that is evaluated by mapping from non-technical skills to the Third Officer's reliability.

- $\tilde{G}_{FS}$ stands for fuzzy output set that is evaluated by mapping from fitness and strength to the Third Officer's reliability.
- $\tilde{G}_{M}$ stands for fuzzy output set that is evaluated by mapping from motivation to the Third Officer's reliability.
- $\tilde{G}_{DL}$ stands for fuzzy output set that is evaluated by mapping from design & layout to the Third Officer's reliability.

For complete calculations, please refer to Appendix 2. Based on the experts' judgment, the main criteria are equally important. Therefore, the weights are distributed evenly between them (i.e. 1/6). Moreover, by help of the IDS software, $\tilde{G}_{T}$, $\tilde{G}_{H}$, $\tilde{G}_{NT}$, $\tilde{G}_{FS}$, $\tilde{G}_{M}$ and $\tilde{G}_{DL}$ are aggregated and the result is presented in Table 3.14.

Table 3.14: Aggregation of Main Criteria (Goal)

Ship-Staff Reliability	High	Fairly High	Medium	Fairly Low	Low	Weight
$\tilde{G}_{T}$	0.08	0.16	0.34	0.42	0	1/6
$\tilde{G}_{H}$	0.656	0.224	0.1	0.016	0.004	1/6
$\tilde{G}_{NT}$	0.18	0.32	0.4	0.08	0.02	1/6
$\tilde{G}_{FS}$	0.53	0.36	0.04	0.042	0.028	1/6
$\tilde{G}_{M}$	0.09	0.21	0.7	0	0	1/6
$\tilde{G}_{DL}$	1	0	0	0	0	1/6
Goal Result	0.4449	0.2060	0.2581	0.0834	0.0076	

3.10.11. Utility Value

Evidently, the assessment based on a single value is much easier and more intuitive as a practical tool for a professional decision maker for ranking the alternatives. Therefore, to obtain a single crisp number for the goal, the utility value associated with each linguistic term has to be calculated. Based on Table 3.14, the fuzzy set for the Third Officer's reliability (Goal) can be written as follows:

$\widetilde{G}$ = {(High, 0.4449), (Fairly High, 0.2060), (Medium, 0.2581), (Fairly Low, 0.0834), (Low, 0.0076)}

In view of the fact that the fuzzy set for the goal has been characterised by five linguistic terms, the highest preference is given to the "High" linguistic term and the lowest preference is given to the "Low" linguistic term. Thus, the ranking value is designated from five (i.e. highest preference) to one (i.e. lowest preference). The goal's assessments, as shown in Table 3.15, are complete. Based on Equations (3.14) and (3.19) the goal's utility value can be calculated as shown in Table 3.15.

Table 3.15: Utility Value

H_n	High	Fairly High	Medium	Fairly Low	Low
V_n	5	4	3	2	1
$u(H_n)$	$\frac{5-1}{5-1}=1$	$\frac{4-1}{5-1}=0.75$	$\frac{3-1}{5-1}=0.5$	$\frac{2-1}{5-1}=0.25$	$\frac{1-1}{5-1}=0$
β_n	0.4449	0.2060	0.2581	0.0834	0.0076
$\sum_{n=1}^{5}\beta_n = 0.4449+0.2060+0.2581+0.0834+0.0076=1 \rightarrow \beta_H = 0$					
$\beta_n \times u(H_n)$	0.4449	0.1545	0.12905	0.02085	0
$R_T = \sum_{n=1}^{5}\beta_n \times u(H_n) = 0.7493 \approx 0.75$					

R_Γ represents the goal's utility value and elucidates the Third Officer's reliability value. The same methodology, for computing all engineers and officers' reliability values, can be employed. Moreover, by comparing the results, the most eligible person can eventually be selected. It is noteworthy to mention that the comparison is only valid for the personnel at the same rank.

3.10.12. Sensitivity Analysis

The sensitive analysis is used to test the logicality of the delivery of the analysis result. Three Axioms introduced in Section 3.9.7 are used. To carry out the study the degrees of belief associated with the highest preference linguistic variables of all the sub-criteria (Table 3.16) as shown in Tables 3.17-3.19 are decreased by 0.1, 0.2 and 0.3 (i.e. simultaneously the degrees of belief associated with the lowest preference linguistic variables of corresponding sub-criteria are increased by 0.1, 0.2 and 0.3). It is noteworthy to mention that for decreasing the belief degree of the highest preference linguistic variable (β_H) of a criterion by "*m*", simultaneously the belief degree of its lowest preference linguistic variable has to be increased by "*m*". However if "β_H" is less than "*m*", then the remaining belief degree (i.e. $m - \beta_H$) can be taken from the next linguistic variable. This process continues until "*m*" is consumed. Accordingly, the results (the goal's utility value) as shown in Tables 3.17-3.19 are obtained. Based on the obtained results (Tables 3.17-3.19) Figure 3.13 (Data 1, 2 and 3 for 0.1, 0.2 and 0.3 respectively) is drawn. All the results obtained keep harmony with Axioms 1 and 2. From Figure 3.13 it is obvious that the model output is more sensitive to the rest hours that the other sub-criteria.

If the degrees of belief associated with the highest linguistic variables of all the sub-criteria are decreased by 0.3 the utility value of the model output (i.e. reliability of the Third Officer) is evaluated as "0.5888". By selection of ten sub-criteria (i.e. Qualification, Experience, Specific Training, Environmental States, Design and Habitability, Rest Hours, Nutrition, Age, Stress and Health) from 14 sub-criteria and by decreasing the degrees of belief associated with the highest preference linguistic variables of those selected sub-criteria (i.e. ten sub-criteria) by 0.3 the utility value of the model output (i.e. reliability of the Third Officer) is evaluated as "0.6263". In view of the fact that "0.5888" is smaller than "0.6263", the result is aligned with Axiom 3.

Table 3.16: Fuzzy Input Sets

Sub-Criteria Description	Fuzzy Input Set (Based on Information)
Qualification	{(Excellent, 0), (Very good, 0), (Good, 0.2), (Average, 0.8), (Low, 0)}
Experience	{(Very Good, 0), (Good, 0), (Average, 0.2), (Low, 0.8), (Very Low, 0)}
Specific Training	{(Excellent, 0.2), (Very good, 0.8), (Good, 0), (Average, 0), (Low, 0)}
Environmental States	{(Very Calm, 0), (Calm, 0.5), (Moderate, 0.5), (Rough, 0), (Very Rough, 0)}
Design and Habitability	{(Very Good, 0), (Good, 1.0), (Average, 0), (Bad, 0), (Very Bad, 0)}
Rest Hours	{(Very Good, 1), (Good, 0), (Average, 0), (Low, 0), (Very Low, 0)}
Nutrition	{(Very Good, 0), (Good, 0), (Average, 0.4), (Bad, 0.6), (Very Bad, 0)}
Age	{(Very Young, 0), (Young, 1.0), (Average, 0), (Old, 0), (Very old, 0)}
Stress	{(Low, 0), (Moderate, 1), (High, 0), (Very High, 0)}
Health	{(Very Healthy, 0.5), (Healthy, 0.5), (Mol. Fit, 0), (Unhealthy, 0)}
Communication and Language skills	{(Very Good, 0), (Good, 0), (Medium, 1.0), (Low, 0), (Very Low, 0)}
Decision Making	{(Very Good, 0), (Good, 0), (Medium, 1.0), (Low, 0), (Very Low, 0)}
Teamwork	{(Very Good, 0), (Good, 1.0), (Medium, 0), (Low, 0), (Very Low, 0)}
Situation Awareness	{(Very Good, 0), (Good, 1.0), (Medium, 0), (Low, 0), (Very Low, 0)}

Table 3.17: Decrement of Sub-Criteria by 0.1

Sub-Criteria Description	The degree of belief associated with the highest preference linguistic variable is decreased and simultaneously the degree of belief associated with the lowest preference linguistic variable is increased by 0.1.	Goal's utility value (R_Γ)
Qualification	{(Excellent, 0), (Very good, 0), (Good, 0.1), (Average, 0.8), (Low, 0.1)}	0.7464
Experience	{(Very Good, 0), (Good, 0), (Average, 0.1), (Low, 0.8), (Very Low, 0.1)}	0.7475
Specific Training	{(Excellent, 0.1), (Very good, 0.8), (Good, 0), (Average, 0), (Low, 0.1)}	0.7448
Environmental States	{(Very Calm, 0), (Calm, 0.4), (Moderate, 0.5), (Rough, 0), (Very Rough, 0.1)}	0.7450
Design and Habitability	{(Very Good, 0), (Good, 0.9), (Average, 0), (Bad, 0), (Very Bad, 0.1)}	0.7454
Rest Hours	{(Very Good, 0.9), (Good, 0), (Average, 0), (Low, 0), (Very Low, 0.1)}	0.7411
Nutrition	{(Very Good, 0), (Good, 0), (Average, 0.3), (Bad, 0.6), (Very Bad, 0.1)}	0.7492
Age	{(Very Young, 0), (Young, 0.9), (Average, 0), (Old, 0), (Very Old, 0.1)}	0.7481
Stress	{(Low, 0), (Moderate, 0.9), (High, 0), (Very High, 0.1)}	0.7445
Health	{(Very Healthy, 0.4), (Healthy, 0.5), (Mol. Fit, 0), (Unhealthy, 0.1)}	0.7447
Communication and Language Skills	{(Very Good, 0), (Good, 0), (Medium, 0.9), (Low, 0), (Very Low, 0.1)}	0.7480
Decision Making	{(Very Good, 0), (Good, 0), (Medium, 0.9), (Low, 0), (Very Low, 0.1)}	0.7480
Teamwork	{(Very Good, 0), (Good, 0.9), (Medium, 0), (Low, 0), (Very Low, 0.1)}	0.7461
Situation Awareness	{(Very Good, 0), (Good, 0.9), (Medium, 0), (Low, 0), (Very Low, 0.1)}	0.7461

Table 3.18: Decrement of Sub-Criteria by 0.2

Sub-Criteria Description	The degree of belief associated with the highest preference linguistic variable is decreased and simultaneously the degree of belief associated with the lowest preference linguistic variable is increased by 0.2.	Goal's utility value (R_{Γ})
Qualification	{(Excellent, 0), (Very good, 0), (Good, 0), (Average, 0.8), (Low, 0.2)}	0.7438
Experience	{(Very Good, 0), (Good, 0), (Average, 0), (Low, 0.8), (Very Low, 0.2)}	0.7458
Specific Training	{(Excellent, 0), (Very good, 0.8), (Good, 0), (Average, 0), (Low, 0.2)}	0.7411
Environmental States	{(Very Calm, 0), (Calm, 0.3), (Moderate, 0.5), (Rough, 0), (Very Rough, 0.2)}	0.7428
Design and Habitability	{(Very Good, 0), (Good, 0.8), (Average, 0), (Bad, 0), (Very Bad, 0.2)}	0.7435
Rest Hours	{(Very Good, 0.8), (Good, 0), (Average, 0), (Low, 0), (Very Low, 0.2)}	0.7330
Nutrition	{(Very Good, 0), (Good, 0), (Average, 0.2), (Bad, 0.6), (Very Bad, 0.2)}	0.7487
Age	{(Very Young, 0), (Young, 0.8), (Average, 0), (Old, 0), (Very Old, 0.2)}	0.7466
Stress	{(Low, 0), (Moderate, 0.8), (High, 0), (Very High, 0.2)}	0.7391
Health	{(Very Healthy, 0.3), (Healthy, 0.5), (Mol. Fit, 0), (Unhealthy, 0.2)}	0.7401
Communication and Language Skills	{(Very Good, 0), (Good, 0), (Medium, 0.8), (Low, 0), (Very Low, 0.2)}	0.7470
Decision Making	{(Very Good, 0), (Good, 0), (Medium, 0.8), (Low, 0), (Very Low, 0.2)}	0.7470
Teamwork	{(Very Good, 0), (Good, 0.8), (Medium, 0), (Low, 0), (Very Low, 0.2)}	0.7429
Situation Awareness	{(Very Good, 0), (Good, 0.8), (Medium, 0), (Low, 0), (Very Low, 0.2)}	0.7429

Table 3.19: Decrement of Sub-Criteria by 0.3

Sub-Criteria Description	The degree of belief associated with the highest preference linguistic variable is decreased and simultaneously the degree of belief associated with the lowest preference linguistic variable is increased by 0.3.	Goal's utility value (R_Γ)
Qualification	{(Excellent, 0), (Very good, 0), (Good, 0), (Average, 0.7), (Low, 0.3)}	0.7423
Experience	{(Very Good, 0), (Good, 0), (Average, 0), (Low, 0.7), (Very Low, 0.3)}	0.7445
Specific Training	{(Excellent, 0), (Very good, 0.7), (Good, 0), (Average, 0), (Low, 0.3)}	0.7384
Environmental States	{(Very Calm, 0), (Calm, 0.2), (Moderate, 0.5), (Rough, 0), (Very Rough, 0.3)}	0.7395
Design and Habitability	{(Very Good, 0), (Good, 0.7), (Average, 0), (Bad, 0), (Very Bad, 0.3)}	0.7414
Rest Hours	{(Very Good, 0.7), (Good, 0), (Average, 0), (Low, 0), (Very Low, 0.3)}	0.7249
Nutrition	{(Very Good, 0), (Good, 0), (Average, 0.1), (Bad, 0.6), (Very Bad, 0.3)}	0.7483
Age	{(Very Young, 0), (Young, 0.7), (Average, 0), (Old, 0), (Very Old, 0.3)}	0.7451
Stress	{(Low, 0), (Moderate, 0.7), (High, 0), (Very High, 0.3)}	0.7337
Health	{(Very Healthy, 0.2), (Healthy, 0.5), (Mol. Fit, 0), (Unhealthy, 0.3)}	0.7353
Communication and Language Skills	{(Very Good, 0), (Good, 0), (Medium, 0.7), (Low, 0), (Very Low, 0.3)}	0.7458
Decision Making	{(Very Good, 0), (Good, 0), (Medium, 0.7), (Low, 0), (Very Low, 0.3}	0.7458
Teamwork	{(Very Good, 0), (Good, 0.7), (Medium, 0), (Low, 0), (Very Low, 0.3)}	0.7398
Situation Awareness	{(Very Good, 0), (Good, 0.7), (Medium, 0), (Low, 0), (Very Low, 0.3)}	0.7398

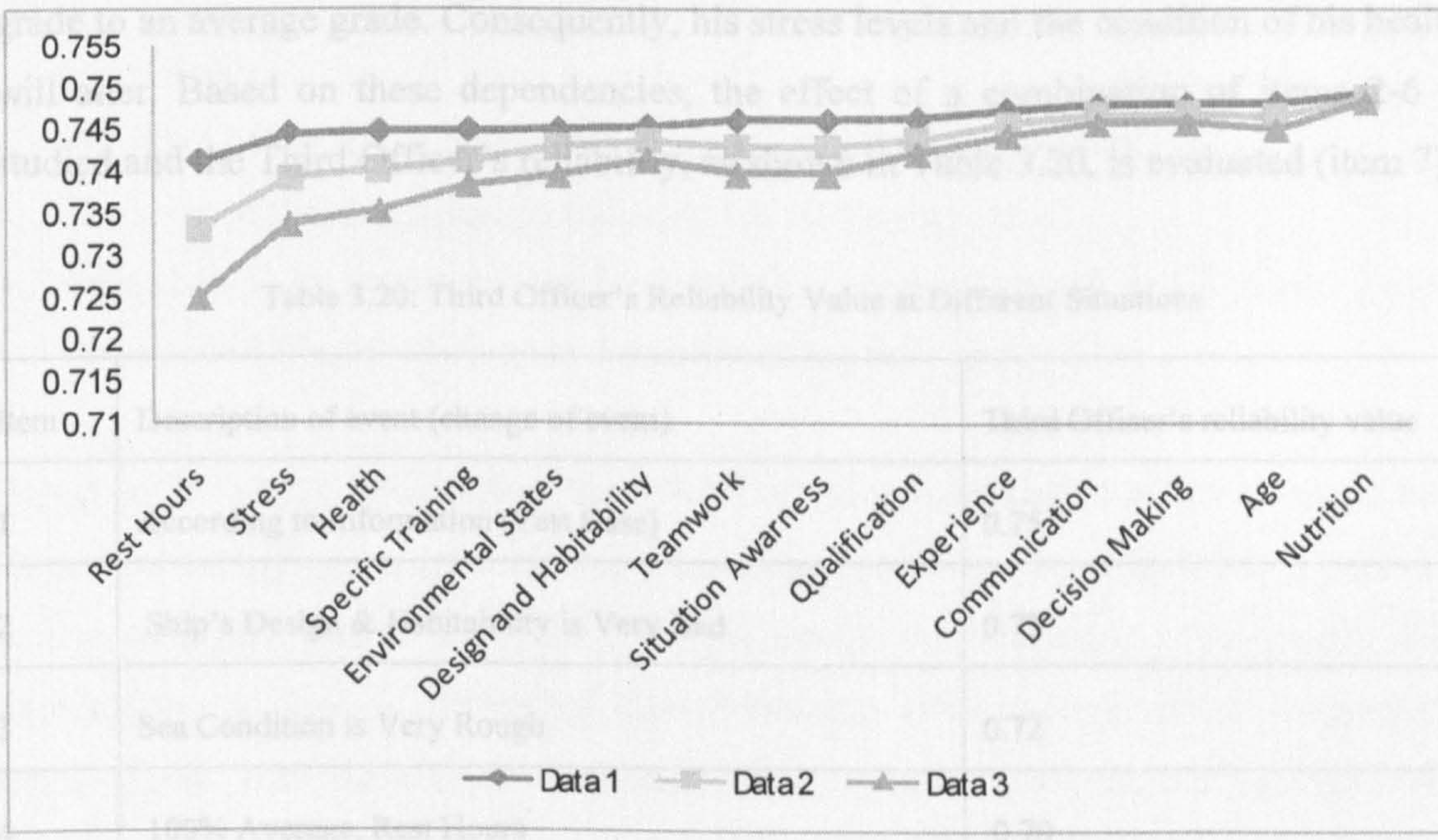

Figure 3.13: Sensitivity of the Model Output to the Same Variation of Each Sub-Criterion

3.11. Results and Discussion

The seafarers' reliability depends upon many variables. Alteration of a criterion's value will ultimately alter such reliability. From the above the reliability value of the Third Officer, sailing on board a ship with good design & habitability, at calm to moderate sea conditions, having sufficient number of rest hours, was evaluated as 0.75. However, his reliability value is not fixed and by alteration of a criterion's value, it will alter. To clarify these statements deviation of his reliability from 0.75 due to alteration of each of the following criteria as an independent variable (items 2-6), as shown in Table 3.20, is evaluated:

- Sailing in other ships with different design & habitability.
- Different sea conditions.
- Alteration of hours of his rest.
- Alteration of his level of stresses due to workloads.
- Alteration of his health's conditions due to acute sleep loss or sea conditions.

If the grade of a ship's design & habitability is very bad and the grade of the sea condition is very rough, then due to noise and vibration, the Third Officer will not be able to sleep appropriately. Therefore, his rest hour's grade will descend from a good grade to an average grade. Consequently, his stress levels and the condition of his health will alter. Based on these dependencies, the effect of a combination of items 2-6 is studied and the Third Officer's reliability, as shown in Table 3.20, is evaluated (item 7).

Table 3.20: Third Officer's Reliability Value at Different Situations

Item	Description of event (change of event)	Third Officer's reliability value
1	According to Information (Test Case)	0.75
2	Ship's Design & Habitability is Very Bad	0.72
3	Sea Condition is Very Rough	0.72
4	100% Average, Rest Hours	0.70
5	100%, High, Stress level	0.71
6	100%, Mol. Healthy	0.71
7	Influencing factors -combination of items 2-6	0.56

3.11.1. Seafarers' Selection

Based on an engineering viewpoint, a comparison can only be made relative to a frame of reference. Therefore, to define the membership functions for the seafarers' selection, the following scenarios are prepared. It is noteworthy to mention that in these scenarios an ideal seafarer, who is sailing on board an ideal vessel at perfect environmental states, is called an ideal seafarer.

- An ideal master of a container vessel is 45 years old.
- The grade of his technical proficiency and his non-technical skills are 100% very good.
- He is an expert.
- The grade of his motivation is 100% very high.
- According to his statements and his medical fitness certificate, he is 100% very healthy and his stress level is 100% low.

- The values of Beaufort number for the last two days are indicated as 1 and 2 respectively.
- The level of the ship's design and habitability is 100% very good.
- The level of the ship's design and layout is 100% very good.
- According to his statements the food, which is served on board, is 100% very good.
- He obtained 8 hours of sleep in the previous night.

Based on the above information, his reliability value is evaluated as 0.99. People who do not get enough sleep are subjected to moodiness and mood swing. When a person is exhausted from a lack of sleep, his emotions can get out of control. Occasionally sleep deprivation can lead to feeling of drowsiness and even nodding off at inopportune times. Those with significant sleep deprivation sometimes experience hallucinations. People who are sleep deprived often experience a decrease in hand eye coordination, their ability to balance, and their reaction time. Living in a state of sleep deprivation can have serious health implications. The human body needs sleep to sustain optimal immune system functioning. The immune system can become weakened very quickly in individuals who do not get enough sleep. Additionally, the inability to sleep leads to a physiological stress response, which can further weaken immune system functioning (APA, 2009).

Suppose the above seafarer's rest hours' grade is reduced from 100% very good to 100% very low. Consequently, based on the previous discussion (i.e. sleep deprivation) the grade of his non-technical skills and his fitness & strength is reduced to very low. Accordingly, his reliability value is assessed as 0.55. It is obvious that at this point (i.e. 0.55 for his reliability value) an ideal seafarer is not able to perform his duty appropriately. Thus, the grade of his performance can be evaluated as 100% Low.

During a seafarer's selection, his resistance to and freedom from fatigue and resistance to psychological stresses have to be considered (ABS, 2003). Thus, an ideal seafarer as a part of his duty and due to the nature of his job should be able to sustain his reliability, for a short time period, under any circumstances. The reliability value of an ideal seafarer due to alteration of a criterion's value for a short time period (i.e. the criterion being taken as an independent variable with limited or without side effects) and a long time period (i.e. the criterion being taken as a dependent variable with side effects), as shown in Table 3.21, is assessed.

Table 3.21: An Ideal Seafarer's Reliability Value at Different Circumstances

Description	Time period	Side Effect	Reliability value	Grade of his Performance
Ideal seafarer, based on the information	-	-	0.99	High
100% Very Low, Rest Hours	-	NTS, Fitness and Strength	0.55	Low
Very rough sea conditions	Short		0.95	High
Very rough sea conditions	Long	Rest hours, Fitness and Strength	0.7	Fairly Low
Average rest hours	Short	-	0.95	High
Average rest hours	Long	Fitness and Strength	0.78	Average
Medium fatigue	Short	-	0.9	Fairly High
Medium fatigue	Long	Fitness and Strength	0.6	Low
Very high Stress level	Short	-	0.9	Fairly High
Very high stress level	Long	Rest hours, Fitness and Strength	0.58	Low
High fatigue	Short	-	0.86	Fairly High

Note: NTS stands for Non-Technical Skills.

Based on the previous discussion and Table 3.21, the membership functions that are suitable for the seafarers' selection, as shown in Figure 3.14, can be constructed. It is noteworthy to mention that Figure 3.14 presents a frame of reference. In other words, by exploiting the frame of reference the performance of any seafarer can be compared with an ideal seafarer. A frame of reference can be employed for converting a reliability value to a grade (grades) of performance.

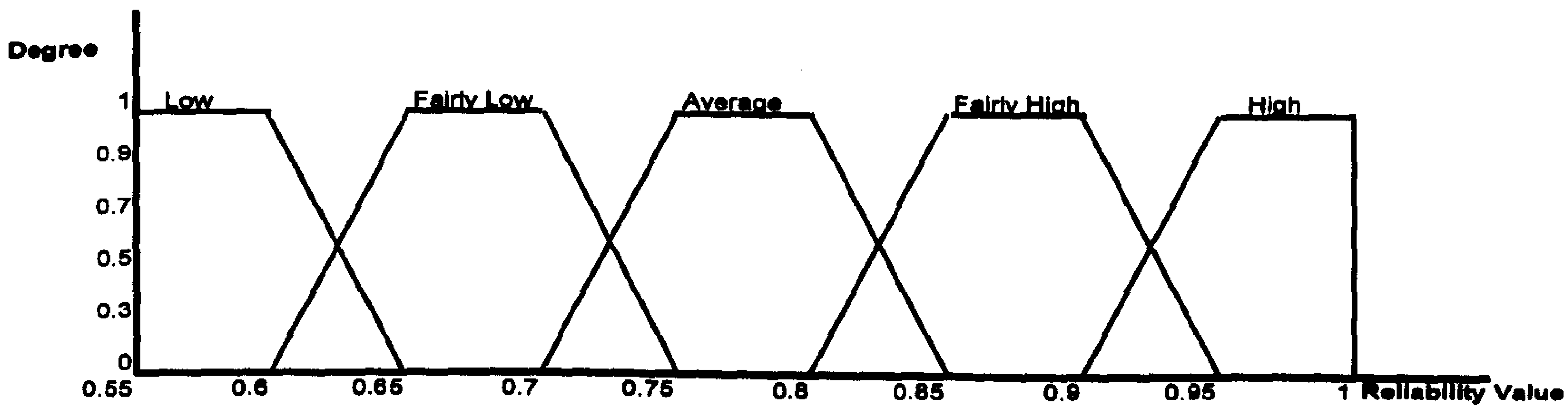

Figure 3.14: Frame of Reference

3.11.2. Control Options

Based on the frame of reference (Figure 3.14) and the Third Officer's reliability value (i.e. 0.75) the grade of his performance can be assessed as 100% average. Therefore, if he is appointed for any kind of activity, his performance is expected to be 100% average. For improving his reliability the control options, as shown in Table 3.22, are suggested.

Based on Table 3.22 and Figure 3.14, by improving the quality of the ship's provisions, his motivations and non-technical skills the grade of his performance can be enhanced from 100% average (i.e. 0.75 for his reliability value) to 100% fairly high (i.e. 0.9 for his reliability value). Pursuant to the previous discussion (Section 3.8), the hygiene factors include the quality of the foods and motivation factors include opportunity to learn a new skill, personal growth and development. Thus, one of the factors that can significantly influence personal performance is motivation. However, many in marine industries, regretfully, hardly consider and pay limited attention to the seafarers' motivation.

Table 3.22: Control Options

Item	Control option	Description	Reliability Value
1	Improving his qualification.	According to the information, his qualification is sufficient for his rank.	0.75
2	Improving his specific training.	According to the information, his specific training is sufficient for his rank.	0.75
3	Improving the ship's design & habitability.	According to the information, the grade of the ship's design and habitability is good.	0.75
4	Improving the number of his rest hours.	According to the information, the grade of his rest hours is very good.	0.75
5	Improving his non-technical skills.	It can be improved to a very good grade.	0.82
6	Improving his motivation.	It can be improved to a very high grade.	0.83
7	Improving the quality of the ship's provisions.	It can be improved to a very good grade.	0.78
8	CO5+CO6+CO7	Improving the quality of the ship's provisions, his motivation and his non-technical skills.	0.9

Note: CO stands for Control Option

3.12. Conclusion

Within the previous chapter and based on the formal safety assessment of containerships it was found that the most significant basic event contributing to the containerships' accident is ship staff error. Furthermore, it has been revealed that the container supply chain is a series network and for a series network, the reliability of a system can only be calculated via evaluating the reliability of its components. Containership is one of the container supply chain' components, and its reliability can be evaluated via the reliability of its personnel, its facilities and their interfaces.

Within this chapter and based on literature reviews on seafarers' reliability, those significant criteria that are influencing the seafarers' reliability are found and methodology for evaluating the seafarers' reliability, by using fuzzy logic and *ER* approach, is revealed. Based on the analysis, firstly, it has been revealed that a seafarer's reliability is dependent on many variables and alteration of a criterion's value will ultimately alter his/her reliability. Secondly, it has been revealed that, during design and fabrication of a new vessel, if the integration of personnel with equipments, system, and interfaces (i.e. design and layout) of a vessel is not considered, then the reliability of a seafarer is 23% lower than the same person living on board a vessel with very good grade of design and layout. Thirdly, during design and fabrication of a new vessel, if design and habitability is not considered, then the reliability of a seafarer is 25% lower than the same person living on board a vessel with very good grade of design and habitability. Therefore, during the preparation of a specification for new building of a vessel and throughout its life cycle, ergonomics should be considered and determined by ship owners. Furthermore, based on the analysis, it has been revealed that, if a seafarer's motivation grade is very high, then his/her reliability value is 21% more than a same person with very low motivation, however, many in marine industries, regretfully, hardly consider and pay limited attention to the seafarers' motivation. Based on the analysis, a frame of reference (i.e. benchmark) for selection of seafarers based on their performance is developed. The seafarers' motivation, fatigue, and hours of rest are highly dependent on strategies of ship owners. It is revealed that the frequency of accidents and the severity of consequences can be reduced by improving seafarers' performance through ship owners' appropriate strategies.

As it is revealed within this chapter, the seafarers' reliability depends upon many variables and alteration of a criterion value will ultimately alter their reliability. Although the developed *FER* methodology does provide a comprehensive view for assessment of seafarers' reliability, but it cannot deal with dependencies between criteria. Graphs have proven to be very intuitive language for communication and discussing dependence and independence relations among problem-domain variables. Therefore, it is essential to develop a *FBN* model for evaluating the seafarers' reliability within the next chapter.

Chapter Four

A Proposed Fuzzy Bayesian Network (FBN) Model for Evaluating the Seafarers' Reliability

Summary

This chapter makes full use of the Bayesian network's advantages and further develops and extends Fuzzy Bayesian Network (FBNs) and a new "symmetric method" by exploiting a conceptual and sound methodology for the assessment of seafarers' reliability. In this chapter for evaluating the seafarers' reliability an initial graph, based on the ergonomics model, literature reviews, historical failure data and statistical analysis, is constructed. In the first stage, to produce the initial graph, all root causes that are not directly influenced by any other variables are found. All root causes are then assigned a node each. Because the variables are identified in an almost hierarchical way, from a higher level of sub-chains to the component level, the graphical structure will unavoidably have a hierarchical feature. As a result the nodes associated with the root causes at the first stage can be defined as level-1 nodes at the first stage. All the variables that are directly influenced by the variables in the level-1 nodes can be discovered and the nodes associated with them can be defined as level-2 nodes at the second stage. A given node at level-2 has as its parents all those nodes in level-1 that directly influence this particular node. This hierarchical process continues until all the variables have a place in the graph and all the parent-child links are accounted by the edges of the graph. Because the parents are identified through the subjective judgements of the individuals constructing the graph, the whole process is subjective. The procedure is, however, consistent because in the BN formalism, for any node, once the direct influences on it are known, all other potential influences are irrelevant as far as constructing the network is concerned. To calculate the unconditional prior probability of each node in level-1, it is necessary to have all data and information on the same universe (i.e. goal's universe). Thus, each quantitative criterion in level-1 is transformed to a qualitative criterion by using the membership functions of a continuous fuzzy set. Each qualitative criterion in level-1 at the i^{th} stage is converted into its associated qualitative criterion in level-2 at the $(i+1)^{th}$ stage by formulating a mapping process, the mapping process continues up to the goal's stage (leaf node). The concept of expected utility is then used to obtain a single crisp value which presents the unconditional prior probability of the concerned node in level-1. To show the relative importance of each parent node for its associated child node an analytic hierarchy process (AHP) methodology is used. Finally, 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).

4.1. Introduction

The seafarers' reliability depends upon many variables and alteration of a criterion value will ultimately alter their reliability. For instance, if the grade of a ship's design and habitability is very bad and the grade of the sea condition is very rough, then due to noise and vibration, a seafarer will not be able to sleep appropriately. Therefore, his/her rest hour's grade will descend from a good grade to an average grade. Consequently, his/her stress levels and the condition of his/her health will alter. Graphs have proven to be a very intuitive language for representing such dependence and independence statements, and thus provide an excellent language for communication and discussing dependence and independence relations among problem-domain variables. A large and important class of assumptions about dependence and independence relations expressed in factorised representations of joint probability distribution can be represented very compactly in a class of graphs known as directed acyclic graphs (DAGs). Chain graphs are a generalisation of *DAGs*, capable of representing a boarder class of dependence and independence assumption (Fydenberg, 1989; Wermuth and Lauritzen, 1990). A Bayesian network (BN) is a probabilistic graphical model that represents a set of random variables and their conditional dependencies through a *DAG*.

The reasons for choosing *BNs* can be summarised as follows:

- They are graphical models, capable of displaying relationships clearly and intuitively.
- They are directional, thus being capable of representing cause-effect relationships.
- They can be used to represent indirect causation in addition to direct one.

The approach is based on conceptualising a model domain or system of interest as a graph of connected nodes and linkages. In the graph, nodes represent important domain variables and a link from one node to another represents a dependency relationship between the corresponding variables. Given their network structuring, Bayesian networks successfully capture the notation of modularity (i.e. a complex system can be built by combining simpler parts). Due to their Bayesian probability formalism, Bayesian networks provide a rational technique to combine both subjective (e.g. expert opinion) and qualitative (e.g. monitoring data) information (Das, 2000). The flexibility nature of Bayesian networks also means that new information can easily be incorporated as it becomes available. Only the conditional probabilities of the affected variable require redetermination. Moreover Bayesian networks are helpful for challenging experts to articulate what they know about the model domain, and to join those influences into dependency network. The graphical nature of Bayesian networks therefore facilitates the easy transfer of understanding about key linkages. In addition, because subjective expert opinions are made explicit in the formal structure of the network, they can be challenged and revised, and can also be directly evaluated to determine whether the results are robust.

Bayesian networks are a modern inclusion to a family of techniques known as expert systems. A common definition of an expert system is a software system that emulates the problem solving behaviour of human expert over some restricted domain. Other popular examples of expert system include rule based systems, fuzzy logic algorithms, and neural networks. As one kind of expert system, Bayesian networks, like rule based systems, may be developed using expert opinion instead of requiring historical data (Charniak, 1991). This is not always the case for all expert systems. For instance, historical data is required to train neural networks, which means that although data is not required for generic algorithms, the development of generic objective functions needs significant resources (McCabe *et al.*, 1998). The major disadvantage of incorporating expert judgements into *BNs* is the general lack of understanding of probability theory so as to fail to precisely probabilistically estimate subjective fuzziness. Such inaccurate subjective estimates of the certainty of an event have been claimed as an unwanted introduction of bias into *BNs* (Tversky and Kahneman, 1990). The proposed Fuzzy Bayesian network (FBN) model is able to overcome this deficiency by challenging and revising the experts' opinions.

FBN can be seen as compact representation of fuzzy cause-effect rules that, contrary to logical rule based system, are capable of performing deductive and abductive reasoning as well as intercausal reasoning. Deductive reasoning which is known as causal reasoning follows the direction of the causal links between variables of a model. Abductive reasoning which is known as diagnostic reasoning goes against the direction of casual links. Getting evidence that supports solely a single hypothesis or a subset of hypotheses automatically leads to decreasing belief in the unsupported competing hypotheses; this property is often known as intercausal reasoning (Kjaerulff and Madsen, 2008).

4.2. Bayesian Networks

Bayesian Networks (BNs) also known as "Bayesian Belief Networks (BBNs)", "Belief Networks", "Causal Probabilistic Networks", "Causal Nets", "Graphical Probability Networks", and "Probabilistic Cause-Effect" models are an emerging modelling approach of artificial intelligence research that aim to provide a decision-support framework for problems involving uncertainty, complexity and probabilistic reasoning (Neapolitan, 1990). Bayesian networks were first developed at Stanford University in the 1970s (McCabe *et al.*, 1998). The first book on Bayesian network was published by Pearl (1988) and since then several other text books have been published (Neapolitan, 1990; Jensen, 1996; Castillo *et al.*, 1997). The first world application of Bayesian network was Munin (Andreassen *et al.*, 1989). Since then, Bayesian networks have spread quickly and been used extensively to model many real world problems (Oliver and Smith, 1990; Ottonello *et al.*, 1992; Burnell and Horvits, 1995; Szolovits and Pauker, 1993; Russell and Norvig, 1995).

4.2.1. Notation

Throughout this chapter the terms node, variable, criterion, and attribute are considered interchangeably. Similarly the terms edge and arc are considered interchangeably. The symbols are presented in Table 4.1.

Table 4.1: Table of Symbols

$X, Y, Z, \ldots$	One dimensional variables
x, y, z, …	Values of corresponding variables $X, Y, Z, \ldots$
Pa_i	Set of parents of X_i
$\mathfrak{E}$	Set of edges of a BN
$\mathcal{U}$	Universe, set of variables/nodes in the domain: $\{X_1, \ldots, X_n\}$
$\mathfrak{G}$	Directed acyclic graph (DAG) of a BN (i.e. $\mathcal{U}, \mathfrak{E}$)

4.2.2. Bayesian Networks Models

A Bayesian network consists of a set of nodes and a set of directed edges. Each node represents a probability distribution, which may in principle be "continuous" or "discrete". In this chapter, the formulation is restricted to the discrete case in which each node represents a finite set of states where each state is associated with a probability measure. Nodes represent random variables and arcs represent probabilistic correlation between the variables. Arcs indicate conditional probabilistic dependence so that the probability of a dependent variable being in a particular state is given for each combination of the states of the preceding variables. The dependence structure is thus represented by a set of conditional probability distributions. A variable, which is dependent on other variables, is often referred to as a "child node". Likewise, directly preceding variables are called "parents". Nodes, which have no parents, are called "root nodes" and nodes without children are called "leaf nodes". Quantitative probability information is specified in the form of conditional probability tables (CPT). For each node the table specifies the probability of each possible state of node given each possible combination of states of its parents. The table for a root node just contains unconditional probabilities.

In general a Bayesian network is a graphical representation of a probability distribution over a set of variables and it consists of two parts:

1. The directed network structure in the form of a directed acyclic graph (DAG).
2. A set of the joint probability distributions, one for each node, conditional on each value combination of the parents.

The network structure is constrained to be acyclic. Undirected cycles (i.e. cycles along which not all edges are pointed in the same way) are allowed. Such a structure represents alternative paths of possible influences between certain variables in the cycle.

4.2.3. Interference Formulism of Bayesian Networks

The basis of reasoning under uncertainty in *BNs* is called Bayesian interference formulism, which is developed for the task of computing the probability of each value of a node in a *BN* when other variables' values are known (Jensen, 1996). The uncertainty may be due to imperfect understanding of the domain, incomplete knowledge of the state of the domain at the time where a given task is to be performed, randomness in the mechanism governing the behaviour of the domain, or combination of these. One of the main advantages of *BNs* is that they allow interference based on observed evidence. The model can be updated in accordance with observation using Bayesian's rule. For random variables "X_1" and "X_2", as shown in Figure 4.1, Bayesian's rule states:

$$P(X_1 \mid X_2) = \frac{P(X_2 \mid X_1)P(X_1)}{\sum_{all..i} P(X_2 \mid X_1 = x_i)P(X_1 = x_i)} \tag{4.1}$$

Assume for instance that variable "X_2" is observed to be in state x_j. The probability of a parameter value given the observation is referred to as the posterior probability. This distinguishes it from the prior probability held by the analyst prior to collection and analysis of the observation. By applying Equation 4.1 to each state of "X_1" the probability distribution "$P(X_1 \mid X_2 = x_j)$" is computed:

$$P(X_1 \mid X_2 = x_j) = \frac{P(X_2 = x_j \mid X_1)P(X_1)}{\sum_{all..i} P(X_2 = x_j \mid X_1 = x_i)P(X_1 = x_i)} \tag{4.2}$$

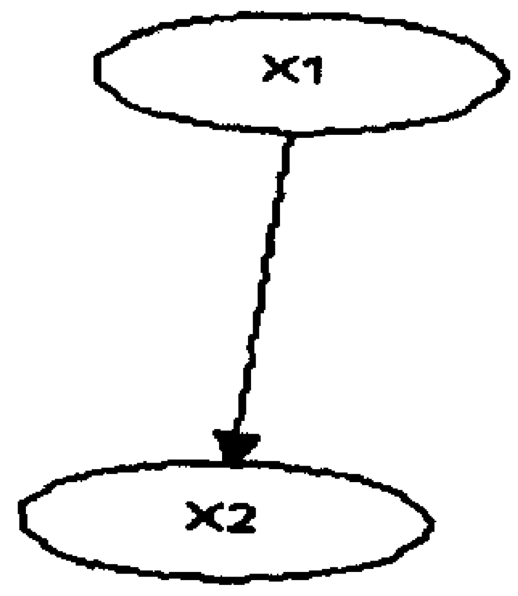

Figure 4.1: BN Consisting of Two Nodes

Similar computations may be performed for large networks, allowing users to investigate different scenarios. Manually updating by this method is practical only if the network is small and each node represents only a few states. However, in the 1980s researchers discovered propagation algorithms that make it possible to break the overall graph down into smaller sub-sets within which information flows are largely self-contained (Lauritzen and Spiegelhalter, 1988). With the introduction of software tools that implement these algorithms it is now possible to use Bayesian networks to solve a complex problem without doing it manually.

4.2.4. Causal Relationship

The parent-child relationships are identified by individuals constructing the graph using very simple semantics, namely causality. However, this does not mean that causality is an easy concept. It may be very difficult to experience causality and philosophically the concept is not fully understood so that many humans cannot sensibly organise casual relationships in a knowledge domain (Jensen, 2001). *BNs* correspond to a very broad class of models, one that can be used to represent nested, acyclic statistical models of virtually any kind of non-pathological joint probability distribution. Their remarkable characteristic is their ability to encode directional relations which can represent a cause-effect relationship, compared to other graphical models that cannot. As an added benefit, they are capable of representing the independence in a domain through their structure, which is a directed acyclic graph. *BNs* contain only random variables, and links represent direct dependences (often, but not necessarily, casual relationships) among the variables (Kjaerulff and Madsen, 2008). To correctly represent the dependence and independence relations that exist among a set of variables of a problem domain it is very useful to have the casual relations among the variables presented in terms of directed links from causes to effects. If done the other way round the model may not properly represent the dependence and independence relations of the problem domain. Generally "a variable "X" is said to be a direct cause of "Y" if setting the value of "X" by force, the value of "Y" may change and there is no other variable "Z" that is a direct cause of "Y" such that "X" is a direct cause of Z" (Kjaerulff and Madsen, 2008).

4.2.5. Joint Probability Distributions (JPDs)

In addition to the *BNs'* ability to represent casual relationships, they can and have been used to represent joint probability distributions (JPDs) compactly. Indeed this is the most common usage of them today. This ability comes from local *JPDs* that are attached to each variable in the network, whose purpose is to quantify the strength of the causal relationships depicted in the *BN* through its structure. These local *JPDs* mathematically describe the behaviour of that variable under every possible value assignment of its parents. The *JPDs* can be obtained using the combination of qualitative and quantitative relationship. Since to specify this behaviour one needs a number of parameters exponential in the number of parents, and since this number is typically smaller than the number of variables in the domain, this results in exponential saving in space and time. To understand this computational saving, let us assume a network, consisting of five variables (X_1, X_2, X_3, X_4, and X_5) is constructed. Firstly, let us assume that all the variables are dependent on (i.e. influence) each other. Based on the chain rule from probability theory the joint probability distribution can be calculated as follows:

$$P(X_1, X_2, X_3, X_4, X_5) = P(X_1 \mid X_2, X_3, X_4, X_5) \times P(X_2 \mid X_3, X_4, X_5) \times P(X_3 \mid X_4, X_5) \times P(X_4 \mid X_5) \times P(X_5) \quad (4.3)$$

Secondly, suppose that the dependencies are explicitly modelled as for the *BN* in Figure 4.2. Then the joint probability distribution can be calculated as follows:

$$P(X_1, X_2, X_3, X_4, X_5) = P(X_1 \mid X_2) \times P(X_2 \mid X_3, X_4) \times P(X_3 \mid X_5) \times P(X_4) \times P(X_5) \quad (4.4)$$

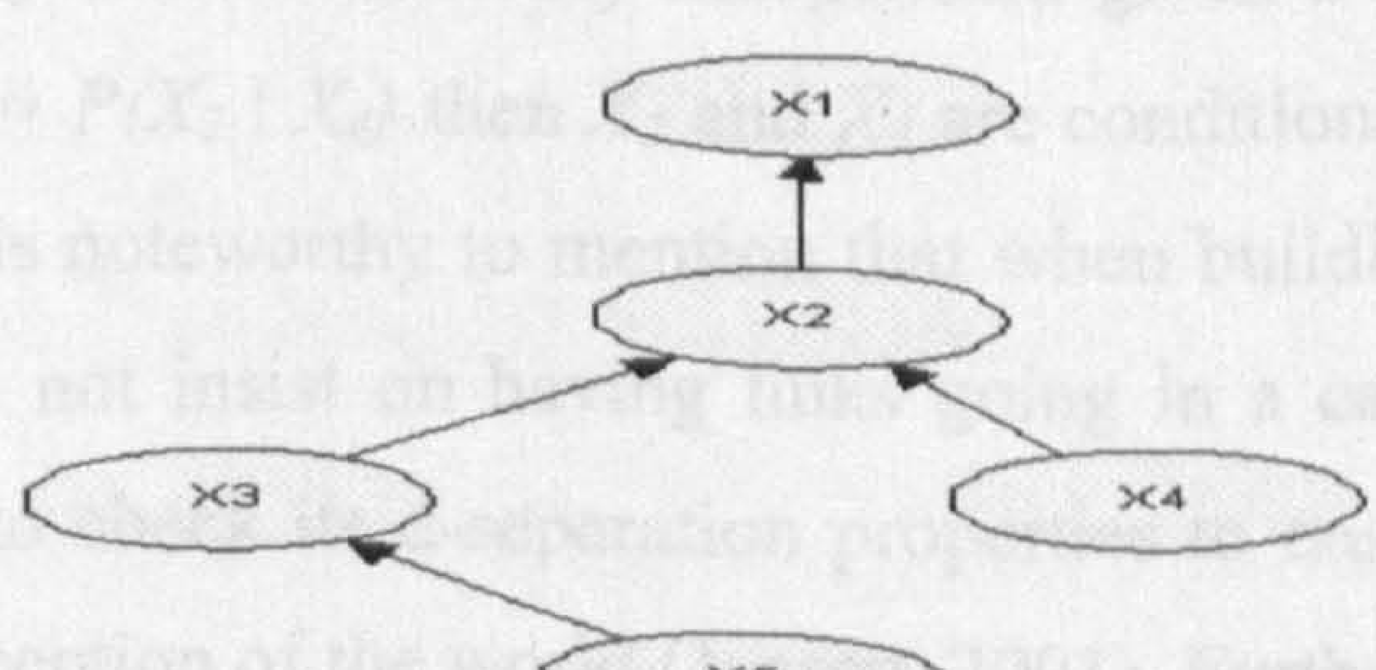

Figure 4.2: BN Consisting of Five Nodes

More concretely, given the structure and the local joint probability distribution of a *BN*, the joint probability distribution of the domain of "n" variables can be calculated as follows:

$$P(X_1, X_2, \ldots\ldots, X_n) = \prod_{i=1}^{n} P(X_i \mid Pa_i) \qquad (4.5)$$

where Pa_i denotes the set of direct parents of variable X_i in the Bayesian network whose structure is $\mathfrak{G}$. The conditional probabilities $P(X_i \mid Pa_i)$ can be specified by $2^{|Pa_i|}$ rather than 2^n parameters, resulting in the exponential space savings mentioned above. As a result for each node the conditional probability of that node taking a certain value given the value of its parents is required. For discrete networks this amounts to defining a conditional probability table (CPT). For consistency with the axioms of probability one has to ensure that these probabilities address the relation associated with the completeness of states.

4.2.6. Directional Separation

Directional separation, or d-separation, is a property of $\mathfrak{G}$ which may be exploited to identify irrelevant and the requisite information for specific queries in a *BN* or an influence diagram. D-separation is a very important concept, because not only does it assist in modifying the initial graphs toward more effective models, but also it provides the basis of inferring the quantitative calculation and combining the probabilities representing uncertainty in *BNs*. The notation of d-separation originates from Pearl (1986) but has been investigated by numerous researchers. Two nodes of a *BN* are said to be d-separated if they are conditionally independent given a specified set of nodes. Thus, If $P(X_2 \mid X_3, X_4) = P(X_2 \mid X_4)$ then X_2 and X_3 are conditionally independent, or d-separated, given X_4. It is noteworthy to mention that when building the structure of *BN* models, assessors need not insist on having links going in a casual direction. On the other hand, they need to check its d-separation properties to ensure that the properties correspond to their perception of the world (Jensen, 2001). Furthermore, some scientists take the point of view that the networks are not causal models, but models for how information may propagate between events (Jensen, 1996).

In principle, only three types of connection in a directed graph exist, namely serial, diverging and converging connections. In a serial network $(X \rightarrow Y \rightarrow Z)$ evidence may transmitted from X to Z only if Y is not observed to be in a specific state, in other words information may flow through $(X \rightarrow Y \rightarrow Z)$ unless the state of Y is known (Kjaerulff and Madsen, 2008). Instantiation blocks the communication between X and Z and they are thus conditionally independent given Y. In a diverging connection $(X \leftarrow Y \rightarrow Z)$ evidence may be transmitted through Y if it is not instantiated, in other words information may flow through $(X \leftarrow Y \rightarrow Z)$ unless the state of Y is known (Kjaerulff and Madsen, 2008). In a converging connection $(X \rightarrow Y \leftarrow Z)$, X and Z are independent if nothing is known about Y, in other words information may flow through $(X \rightarrow Y \leftarrow Z)$ if evidence on Y or one of its descendants is available (Kjaerulff and Madsen, 2008).

4.2.7. Hugin Software

The Hugin software comes with an easy to use graphical user interface (GUI) and provides applicable programmer's interface (API). It can be used as a robust *BN* programming environment for modelling and interference. While Hugin software makes it easy to key the input and read the output of the network by providing a graphical representation of the properties of each node as a bar graph, the general strategy of using a Hugin *BN* model must be obeyed (Wang and Trbojevic, 2007):

1. Firstly, the nodes of *BNs* must be mapped out (enter evidence for some variables).
2. Secondly, the states of the nodes must be defined (observe the effect of the evidence on other variables).
3. Thirdly, the probability of each state must be determined (explain the new probabilities).

4.3. Determining the Conditional Probabilities

As discussed previously (Section 4.2.5) the prior probabilities are only required locally to be assigned to the bunch of $(Pa_i \rightarrow X_i)$ links as conditional probabilities $P(X_i \mid Pa_i)$. However, it is not often straightforward to obtain $P(X_i \mid Pa_i)$. The Bayesian approach requires much information in a form of prior probability. In principle, most values could be acquired through failure database or experiments. However, experiments may be difficult to design and conduct correctly and historical data does not often satisfy the requirements of the Bayesian approach. In practice, it is often necessary and important to rely on subjective probabilities provided by expert judgments as a rational expression of an individual's degree of belief. However, since subjective probabilities are based on informed guesses, serious deviation could happen if they are accurately expressed with precise numbers. Moreover, it has been discovered that linguistic expressions of probabilistic uncertainty were more accurate than numerical values in estimating the likelihood of multiple attributes through experimental studies (Zimmer, 1986). Fuzzy logic has been widely used to model such subjective linguistic variables and deal with discrete problems using fuzzy numbers, which often reflect expert opinion more faithfully.

4.3.1. Noisy-Or Approach

In constructing a *BN*, the converging connections between nodes are always a problem for both Bayesian statisticians and experienced analysts. To understand the mentioned difficulties, let us assume "X_1" and "X_2" be the two children listing all effects of the single parent "X_3". Based on Equation 4.5 the joint probability distribution for the diverging connections can be calculated as follows:

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

Alternatively let us assume "X_1" and "X_2" be the two parent nodes of their single child "X_3". Based on Equation 4.5 the joint probability distribution for the converging connections can be calculated as follows:

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

By comparing the results, because $P(X_3\,|\,X_1,X_2)$ cannot be further decomposed, it is not friendly enough for human knowledge and may be too specific for any expert. Thus the converging connections are more difficult to be appropriately handled compared to the diverging and serial connections in *BNs*. Many pioneers in the research field associated with *BNs* have generated some novel and effective methods to deal with this problem from both quantitative and qualitative viewpoints, such as "Noisy-Or" and "Divorcing" approaches (Jensen, 2001).

Often conditional probability tables (CPTs) fall into one of several common categories or canonical distributions. These canonical forms are based on regularities that permit much more compact representation. The canonical models differ from general Bayesian network models in that they have a certain local structure within the *CPTs*. Canonical models were introduced by Pearl (1988) and successfully used in reliability engineering research (Reed, 1990). In literature they are also called casual independence models or models of independence of casual influence (ICI). "Noisy-Or" models are probably the most popular example of canonical Bayesian network models. "Noisy-Or" is generated with the strong assumption revealed by a deterministic OR gate, where the child will be present given the presence of any parent and child will be absent, if and only if all parents are absent. A standard "Noisy-Or" is correct only if it satisfies the requirement that the possible causes are collectively exhaustive, that is:

$$P(Y = Present \mid X_1, X_2, ..., X_n = Absent) = 0 \qquad (4.6)$$

The "Noisy-Or" gate model is working under the following three assumptions (Neapolitan, 1997):

- Casual inhibition: this assumption entails that there is some mechanism that inhibits a cause from bringing about its effect, and the presence of the cause results in the presence of the effect if and only if this mechanism is disabled.
- Exception independence: this assumption entails that the mechanism that inhibits one cause is independent of the mechanism that inhibits another cause.
- Accountability: This assumption entails that an effect can happen only if at least one of its causes is present and is not being inhibited. Therefore, all causes which are not stated explicitly must be lumped into one unknown cause.

In the situation of "Noisy-Or", the probability of a binary node "Y" conditional upon "n" binary parent nodes, X_r, where $r = 1, 2, \ldots, n$, is estimated as follows:

$$P(Y \mid X_1, X_2, \ldots, X_n) = 1 - \prod_{r=1}^{n} (1 - P(Y \mid X_r)) \qquad (4.7)$$

In Equation 4.7, $P(Y \mid X_1), P(Y \mid X_2), P(Y \mid X_3), \ldots, P(Y \mid X_n)$ are assessed and then used to estimate $P(Y \mid X_1, X_2, \ldots, X_n)$. Its theoretical base is that if any of the parents is present, then the child happens unless an inhibitor prevents it; if all inhibitors are independent, then the combined probability is easy to calculate as one minus the product of the appropriate probabilities for the inhibitor.

4.3.2. Critical Review of "Noisy-Or" Methodology

In order to explain the "Noisy-Or" methodology and for critical appraisal of this methodology, a simplified example (Figure 4.3) is given to represent a scenario for constructing and evaluating a *CPT*. This model represents the casual relationships among the variables, and each variable has only two values. A variable takes its first value if a feature is present and its second value otherwise. Let us assume in a certain province due to uncertainty the likelihood of existence and non-existence of malaria, flu and cold are equal.

$$P(Malaria = Present) = P(Flu = Present) = P(Cold = Present) = 0.5$$
$$P(Malaria = Absent) = P(Flu = Absent) = P(Cold = Absent) = 0.5$$

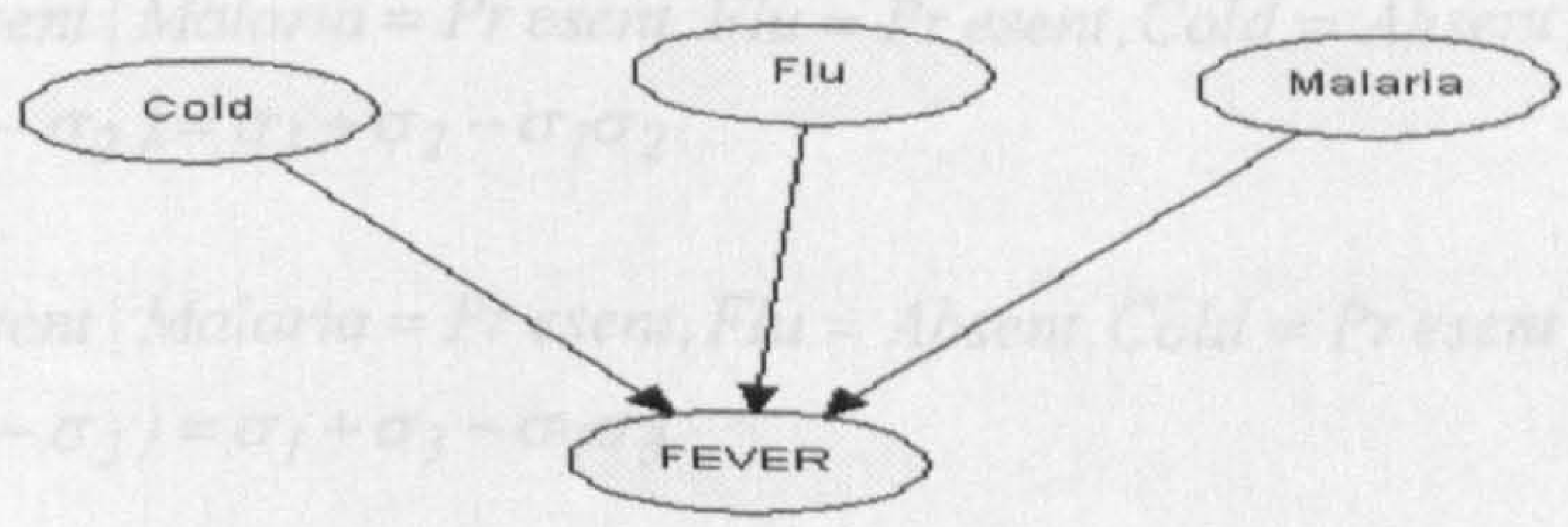

Figure 4.3: The Parent-Child Relationship

An expert (a physician), based on his experience, has assessed the following conditional probabilities:

$$P(Fever = Present \mid Malaria = Present) = \sigma_1 \tag{4.8}$$

$$P(Fever = Present \mid Flu = Present) = \sigma_2 \tag{4.9}$$

$$P(Fever = Present \mid Cold = Present) = \sigma_3 \tag{4.10}$$

Based on Equations (4.7 - 4.10) the following equations can be obtained:

$$\begin{aligned} &P(Fever = Present \mid Malaria = Present, Flu = Absent, Cold = Absent) \\ &= 1-(1-\sigma_1) = \sigma_1 \end{aligned} \tag{4.11}$$

$$\begin{aligned} &P(Fever = Present \mid Flu = Present, Malaria = Absent, Cold = Absent) \\ &= 1-(1-\sigma_2) = \sigma_2 \end{aligned} \tag{4.12}$$

$$\begin{aligned} &P(Fever = Present \mid Cold = Present, Malaria = Absent, Flu = Absent) \\ &= 1-(1-\sigma_3) = \sigma_3 \end{aligned} \tag{4.13}$$

$$\begin{aligned} &P(Fever = Present \mid Malaria = Present, Flu = Present, Cold = Present) \\ &= 1-(1-\sigma_1)(1-\sigma_2)(1-\sigma_3) = \sigma_1+\sigma_2+\sigma_3-\sigma_1\sigma_2-\sigma_2\sigma_3-\sigma_1\sigma_3+\sigma_1\sigma_2\sigma_3 \end{aligned} \tag{4.14}$$

$$\begin{aligned} &P(Fever = Absent \mid Malaria = Present, Flu = Present, Cold = Present) \\ &= (1-\sigma_1)(1-\sigma_2)(1-\sigma_3) \end{aligned} \tag{4.15}$$

$$\begin{aligned} &P(Fever = Present \mid Malaria = Present, Flu = Present, Cold = Absent) \\ &= 1-(1-\sigma_1)(1-\sigma_2) = \sigma_1+\sigma_2-\sigma_1\sigma_2 \end{aligned} \tag{4.16}$$

$$\begin{aligned} &P(Fever = Present \mid Malaria = Present, Flu = Absent, Cold = Present) \\ &= 1-(1-\sigma_1)(1-\sigma_3) = \sigma_1+\sigma_3-\sigma_1\sigma_3 \end{aligned} \tag{4.17}$$

$$\begin{aligned} &P(Fever = Present \mid Malaria = Absent, Flu = Present, Cold = Present) \\ &= 1-(1-\sigma_2)(1-\sigma_3) = \sigma_2+\sigma_3-\sigma_2\sigma_3 \end{aligned} \tag{4.18}$$

Based on the Bayes chain rule the marginal probability of the presence of fever can be calculated as follows:

$$P(Fever = Present) = [4(\sigma_1 + \sigma_2 + \sigma_3) - 2(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_1\sigma_3) + \sigma_1\sigma_2\sigma_3] \times 0.5^3 \quad (4.19)$$

Based on informed or genuine guesses of the expert the values of σ_1, σ_2 and σ_3 can be substituted as $\sigma_1 = 0.9, \sigma_2 = 0.8$ and $\sigma_3 = 0.4$ respectively. Accordingly, based on Equations (4.8-4.18) the conditional probability table (CPT), as shown in the Table 4.2, can be evaluated.

Table 4.2: Conditional Probability Table ("Noisy-Or" methodology)

	Malaria (P)				*Malaria (A)*			
	Flu (P)		*Flu (A)*		*Flu (P)*		*Flu (A)*	
	Cold (P)	*Cold (A)*	*Cold (P)*	*Cold (A)*	*Cold (P)*	*Cold (A)*	*Cold (P)*	*Cold (A)*
Ω (Fever)	0.988	0.98	0.94	0.9	0.88	0.8	0.4	0
Ω (¬ Fever)	0.012	0.02	0.06	0.1	0.12	0.2	0.6	1

where,

Ω (Fever) = P (Fever=Present| Malaria, Flu, Cold)

Ω (¬ Fever) = P (Fever=Absent| Malaria, Flu, Cold)

Based on Equation 4.19 the marginal probability of the presence and the absence of fever can be evaluated as follows:

$$P(Fever = Present) = 0.736$$
$$P(Fever = Absent) = 0.264$$

For constructing and evaluating the *CPT* based on synthesising the "Noisy-Or" methodology and expert's judgement certain application problems that are listed as follows may be revealed.

Firstly, as it is clear from Equation 4.15, if in the province malaria, cold and flu are present, then the likelihood of absence of fever can be estimated as follows:

$$(1-\sigma_1)(1-\sigma_2)(1-\sigma_3)=0.012$$

However, in many real world situations, there are multiple possible causes for presence of a child node, some of which cannot be involved in the model (Jensen, 2001). Henrion (1989) proposed a direct extension of the "Noisy-Or" model which models that an effect Y (child node = Present) can also occur if all the causes are absent. He called this extension "Leaky Noisy-Or" model. This can be modelled by introducing an additional parameter (i.e. $P_{background}$) which is called the leaky probability. The leaky probability represents the phenomenon that an effect occurs spontaneously (i.e. in absence of the causes that are modelled explicitly). Thus, Equation 4.7 can be modified as follows:

$$P(Y \mid X_1,X_2,\ldots,X_n)=1-(1-P_{background})\prod_{r=1}^{n}(1-P(Y \mid X_r)) \qquad (4.20)$$

Secondly, the marginal probability of the presence of fever was evaluated as 0.736. This value indicated that in a certain province, although the likelihood of existence and non-existence of malaria, flu and cold are equal, without observation of any evidence, the likelihood of presence of fever is much more than its absence. In other words if someone is uncertain about existence and non-existence of a child's parents, then he can be persuaded that the likelihood of existence of the child is much more than its non-existence, which is not a logical hypothesis. The "Noisy-Or" model is not responsible for the mentioned deficiency; as a matter of fact the expert's certainty concerning the value of σ_1,σ_2 and σ_3 has introduced a bias into *BN*. In general if someone is uncertain about existence and non-existence of a child's parents, he or she should remain uncertain about the existence and non-existence of their child.

Thirdly, Equation 4.7 is asymmetric, it means it is only true in one direction (i.e. *Y=Present*). This scarcity may result in miscalculation by non-mathematicians for instance:

$$P(Fever=Present \mid Flu=Present, Malaria=Absent, Cold=Absent)$$
$$=1-(1-\sigma_2)=\sigma_2$$

$P(Fever = Present \mid Flu = Present, Malaria = Absent, Cold = Absent)$
$= 1 - P(Fever = Absent \mid Flu = Presnet, Malaria = Absent, Cold = Absent)$

$$\sigma_2 \neq 1-(1-\sigma_1)(1-\sigma_3)$$

To overcome the above mentioned problems a symmetric model is developed.

4.3.3. Symmetric Model

For synthesising the analytic hierarchy process (AHP) methodology with probability theory, a symmetric model is developed. This model, called the symmetric model, concerns the case in which the relationships among variables ordinarily represent casual mechanism, and each variable has only two values. The dissimilarity between this methodology and the "Noisy-Or" methodology 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 nodes for their associated child node. The strength of direct dependence of each child node to its associated parents is indicated by their normalized weights (these weights are normalized to a sum of unity).

To understand the terminology of the symmetric model, let us assume that there are "n" viruses or diseases (parent nodes) with two states (present or absent) and each of them may cause the presence of fever (child node). Thus, $P(Y = Present \mid X_1 = Present) = P(A_1)$ stands for the probability that the effect "Y" will occur, given that only one cause "X_1" is present and all other causes are absent (i.e. the probability of presence of the fever given that the first virus is present). $P(Y = Present \mid X_n = Present) = P(A_n)$ stands for the probability that the effect "Y" will occur, given that only one cause "X_n" is present and all other causes are absent (i.e. the probability of presence of the fever given that the n^{th} virus is present). Based on the "Noisy-Or" methodology, let us assume that in a room which has been occupied by one person, two viruses are present. The probability of presence of fever by the presence of first and the second virus are estimated as 80% and 79% respectively. Based on Equation 4.7 (if the A_1 and A_2 are independent, then $(P(A_1 \cup A_2) = 0.8 + 0.79 - 0.8 \times 0.79 = 0.958)$ by presence of both viruses the likelihood of presence of fever is estimated as 95.8%. By increasing the number of viruses the likelihood of the presence of fever will be increased. For instance, if the probability of the presence of fever by presence of a third virus is estimated as 85%, then based on Equation 4.14 by the presence of all three viruses the likelihood of presence of fever is estimated as 99%. Therefore, by increasing the number of viruses to "$4,5,6,\ldots,n$" the value of $P(A_1 \cup A_2 \cup A_3 \cup \cdots \cup A_n)$ will eventually approach 100% or one. As it is obvious from this example A_1, A_2 and A_3 are not disjoint.

As mentioned earlier, in the symmetric model the expert's opinion is distributed by relative importance of each parent node for their associated child node (the normalised weights). Thus, in normalized space $P(Y = Present \mid X_1 = Present) = P(\hat{A}_1)$ stands for the relative importance of first parent node for its associated child node in absence of all other causes. In general:

$$P(Y = Present \mid X_1 = Present) = P(\hat{A}_1) = \frac{P(A_1)}{\sum_{m=1}^{n} P(A_m)}$$

$$\vdots$$

$$P(Y = Present \mid X_n = Present) = P(\hat{A}_n) = \frac{P(A_n)}{\sum_{m=1}^{n} P(A_m)} \qquad (4.21)$$

$$\therefore$$

$$P(\hat{A}_1) + P(\hat{A}_2) + P(\hat{A}_3) + \cdots + P(\hat{A}_n) = 1$$

Based on the axioms of probability theory:

$$P(\hat{A}_1 \cup \hat{A}_2 \cup \hat{A}_3 \cup \cdots \cup \hat{A}_n)$$
$$= P(\hat{A}_1) + P(\hat{A}_2) + \cdots P(\hat{A}_n) - P(\hat{A}_1 \cap \hat{A}_2) - P((\hat{A}_1 \cap \hat{A}_2) \cup (\hat{A}_2 \cap \hat{A}_3)) - \cdots$$

Owing to normalization and in normalized space $\hat{A}_1, \hat{A}_2, \hat{A}_3, \cdots \& \hat{A}_n$ remain disjoint:

$$(P(\hat{A}_1 \cap \hat{A}_2) = P(\hat{A}_2 \cap \hat{A}_3) = \cdots = 0)$$

$$\therefore \qquad (4.22)$$

$$P(\hat{A}_1 \cup \hat{A}_2 \cup \hat{A}_3 \cup \cdots \cup \hat{A}_n) = P(\hat{A}_1) + P(\hat{A}_2) + P(\hat{A}_3) + \cdots + P(\hat{A}_n)$$

Derived from the former example, the probability of presence of the fever by the first, second and third viruses in the normalized space can be calculated as follows:

$$P(\hat{A}_1)=\frac{0.8}{2.44}=0.328,\ P(\hat{A}_2)=\frac{0.79}{2.44}=0.324 \text{ and } P(\hat{A}_3)=\frac{0.85}{2.44}=0.348$$

$$(P(\hat{A}_1 \cup \hat{A}_2 \cup \hat{A}_3)=P(\hat{A}_1)+P(\hat{A}_2)+P(\hat{A}_3)=0.328+0.324+0.348=1)$$

Thus, by presence of all the parent nodes the probability of the child's presence is equal to one and as a result of normalization the influences of all parent nodes remain disjoint.

The kernel of the symmetric model can be described as follows:

Firstly, to show the relative importance (influence) of each parent node for their associated child node an *AHP* methodology as explained in Section 3.9.4 can be used. In the normalized space, based on the influence of each parent node, the conditional probability of a binary child node Y given each binary parent node, X_r, where $r = 1, 2, \ldots, n,$ can be estimated as follows:

$$\begin{aligned}
&P(Y=Present \mid X_1=Present)=\omega_1\\
&P(Y=Present \mid X_2=Present)=\omega_2\\
&\vdots\\
&P(Y=Present \mid X_n=Present)=\omega_n\\
&\sum_{r=1}^{n}\omega_r=1
\end{aligned} \qquad (4.23)$$

Based on Equation 4.22 in the situation of the symmetry approach (i.e. normalized space) the probability of a binary node "Y" conditional upon "n" binary parent nodes, X_r, where $r = 1, 2, \ldots, n,$ can be estimated as follows:

$$P(Y \mid X_1, X_2, \ldots, X_n)=\sum_{r=1}^{n}\tilde{\omega}_r$$

$$\begin{cases}\tilde{\omega}_r=\omega_r : \text{If the state of the "rth parent node" is identical to the state of its child}\\ \tilde{\omega}_r=0 : \text{If the state of the "rth parent node" is different from the state of its child}\end{cases} \qquad (4.24)$$

Thus, based on Equation 4.24, the following can be obtained:

$$P(Y = Present \mid X_1, X_2, ..., X_n = Absent) = 0$$

$$P(Y = Absent \mid X_1, X_2, ..., X_n = Absent) = 1$$

$$P(Y = Present \mid X_1, X_2, ..., X_n = Present) = 1$$

$$P(Y = Absent \mid X_1, X_2, ..., X_n = Present) = 0$$

To compare the results obtained by evaluating a *CPT* based on synthesising the "Noisy-Or" methodology and expert's judgement (Section 4.3.2, Figure 4.3 and Table 4.2) and results which will be obtained by evaluating a *CPT* based on synthesising the "symmetric" methodology and expert's judgement the illustrated example that presented in Section 4.3.2 (Figure 4.3) is recalculated using the symmetric methodology. Accordingly, the values of ω_1, ω_2 and ω_3 can be estimated as follows:

$$\omega_1 = \frac{\sigma_1}{\sigma_1 + \sigma_2 + \sigma_3} = \frac{0.9}{0.9 + 0.8 + 0.4} \approx 0.43, \omega_2 = \frac{0.8}{0.9 + 0.8 + 0.4} \approx 0.38$$

$$\omega_3 = \frac{0.4}{0.9 + 0.8 + 0.4} \approx 0.19$$

Based on Equation 4.24 the *CPT*, as shown in Table 4.3, can be quantified.

Table 4.3: Conditional Probability Table (Symmetric model)

	Malaria (P)				*Malaria (A)*			
	Flu (P)		*Flu (A)*		*Flu (P)*		*Flu (A)*	
	Cold (P)	*Cold (A)*	*Cold (P)*	*Cold (A)*	*Cold (P)*	*Cold (A)*	*Cold (P)*	*Cold (A)*
Ω (Fever)	1	0.81	0.62	0.43	0.57	0.38	0.19	0
Ω (¬ Fever)	0	0.19	0.38	0.57	0.43	0.62	0.81	1

where,

Ω (Fever) = P (Fever=Present| Malaria, Flu, cold)

Ω (¬ Fever) = P (Fever=Absent| Malaria, Flu, cold)

Based on the Bayes chain rule the marginal probabilities of the presence and absence of fever can be calculated as follows:

$$P(Fever = Present) = 0.5$$
$$P(Fever = Absent) = 0.5$$

It is noteworthy to mention that the above calculation is true not only for the concerned scenario but also for any number of parent nodes. In general as mentioned early, if someone is uncertain about the existence and non-existence of a child's parents, he/she should remain uncertain about the existence and non-existence of their child. However, the most important use of *BNs* is in revising probabilities in the light of actual observation of events.

The objective of using *BNs* is to make the right decision depending on the corresponding posterior probabilities, which can also be explained as the interference of an unobservable situation using observable reality. The state of a variable is assumed to be known with certainty often termed as an instantiation of the variable. Prior to instantiation, the propagation process yields the marginal distributions (pre-posterior analysis), whereas the query posterior probabilities are calculated with the instantiation of evidence. With diagnosis interference which is typical in medical and industrial applications, one may use evidence of an effect to infer the most likely cause.

Assume that the presence of fever is known with 100% certainty (i.e. instantiation of fever), by using the Hugin software the posterior probabilities of malaria, flu and cold by the "symmetric" and "Noisy-Or" methodologies, as shown in Figure 4.4, can be estimated. Based on Figure 4.4, the posterior probabilities of presence of malaria, flu and cold by the symmetric model are estimated as 71.5%, 69% and 59.5% respectively while the posterior probabilities of presence of malaria, flu and cold by the Noisy-Or model are estimated as 64.67%, 61.96% and 54.48% respectively. However, the values are different but the ratios are more or less identical.

$$\frac{71.5}{69} \approx \frac{64.67}{61.96} \approx 1.04$$
$$\frac{71.5}{59.5} \approx \frac{64.67}{54.48} \approx 1.2$$
$$\frac{69}{59.5} \approx \frac{61.96}{54.48} \approx 1.14$$

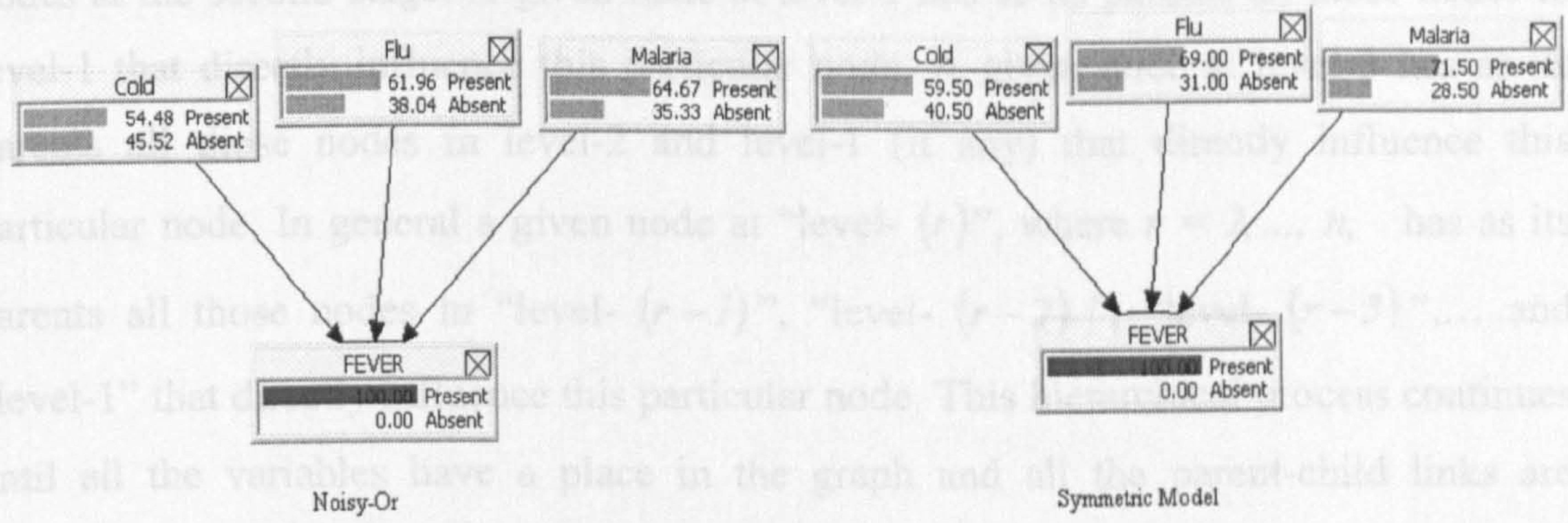

Figure 4.4: Symmetric Model versus Noisy-Or Model

It is noteworthy to mention that whatever the form of interference is utilised, the output for the hypothesis or query variable is a probability distribution representing the degrees of belief in each state rather than a simple scalar or vector.

4.4. Methodology

For conducting the research, a combination of different decision making techniques such as fuzzy logic and *BN* can be used. Fuzzy logic and its mathematical backgrounds were presented in Chapter 2. The methodology in stepwise orders is described as follows:

Firstly, for evaluating the seafarer's reliability based on the ergonomics model (Chapter 3), literature reviews (Chapter 3), historical failure data and statistical analysis (Chapter 2), all the root causes that are not directly influenced by any other variables are found. All the root causes are then assigned a node each. As a result the nodes associated with the root causes at the first stage can be defined as level-1 nodes (or root nodes) at the first stage. The nodes associated with the root causes at the second stage can be defined as level-1 nodes (or root nodes) at the second stage. In similar approach, such a definition can be conducted at higher stages.

Secondly, all the variables that are directly influenced by the level-1 nodes at the first stage can be discovered and the nodes associated with them can be defined as level-2 nodes at the second stage. A given node at level-2 has as its parents all those nodes in level-1 that directly influence this particular node. A given node at level-3 has as its parents all those nodes in level-2 and level-1 (if any) that directly influence this particular node. In general a given node at "level- (r)", where $r = 2, \ldots, n,$ has as its parents all those nodes in "level- $(r-1)$", "level- $(r-2)$ ", "level- $(r-3)$ ",.....and "level-1" that directly influence this particular node. This hierarchical process continues until all the variables have a place in the graph and all the parent-child links are accounted by the edge of the graph (Table 4.4 and Figure 4.5).

Thirdly, assessment grades are assigned to all the level-1 nodes in the graph. Those assessment grades could be either qualitative or quantitative.

Fourthly, each level-1 quantitative criterion is transformed to a qualitative criterion by using a membership function of continuous fuzzy sets (Section 3.9.2).

Fifthly, to have all the data and information on the same universe (i.e. goal's universe) a fuzzy rule base is developed to demonstrate the mapping process (Section 3.9.3). By formulating a mapping process, each level-1 qualitative criterion at the i^{th} stage is converted into an associated level-2 qualitative criterion at the $(i+1)^{th}$ stage. Then the result is converted by another mapping process into an associated level-3 qualitative criterion (if any) at the $(i+2)^{th}$ stage. The mapping process continues up to the goal's stage (leaf node). The concept of expected utility (Section 3.9.6) is then used to obtain a single crisp value which presents the unconditional prior probability of the concerned node in level-1.

Sixthly, to obtain the relative importance (influence) of each parent node for its associated child node an *AHP* methodology is used (Section 3.9.4).

Seventhly, 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 the "symmetric model".

Finally, the sensitivity of the *FBN* model will be analysed.

Table 4.4: Table of Abbreviations

Abbreviation	Description
CL	Communication and Language skills
CTR	Controls
DH	Design & Habitability
DL	Design & Layout
DM	Decision Making
DP	Displays
ES	Environmental States
EXP	Experience
FS	Fitness & Strength
HF	Human Fatigue
ICDA	Integration of Controls, Displays and Alarms
LA	Labelling
MV	Manual Valve
NTS	Non-Technical Skills
QU	Qualification
RH	Rest Hours
SA	Situation Awareness
ST	Specific Training
TP	Technical Proficiency
TW	Teamwork
VDU	Video Display Unit & Workstation

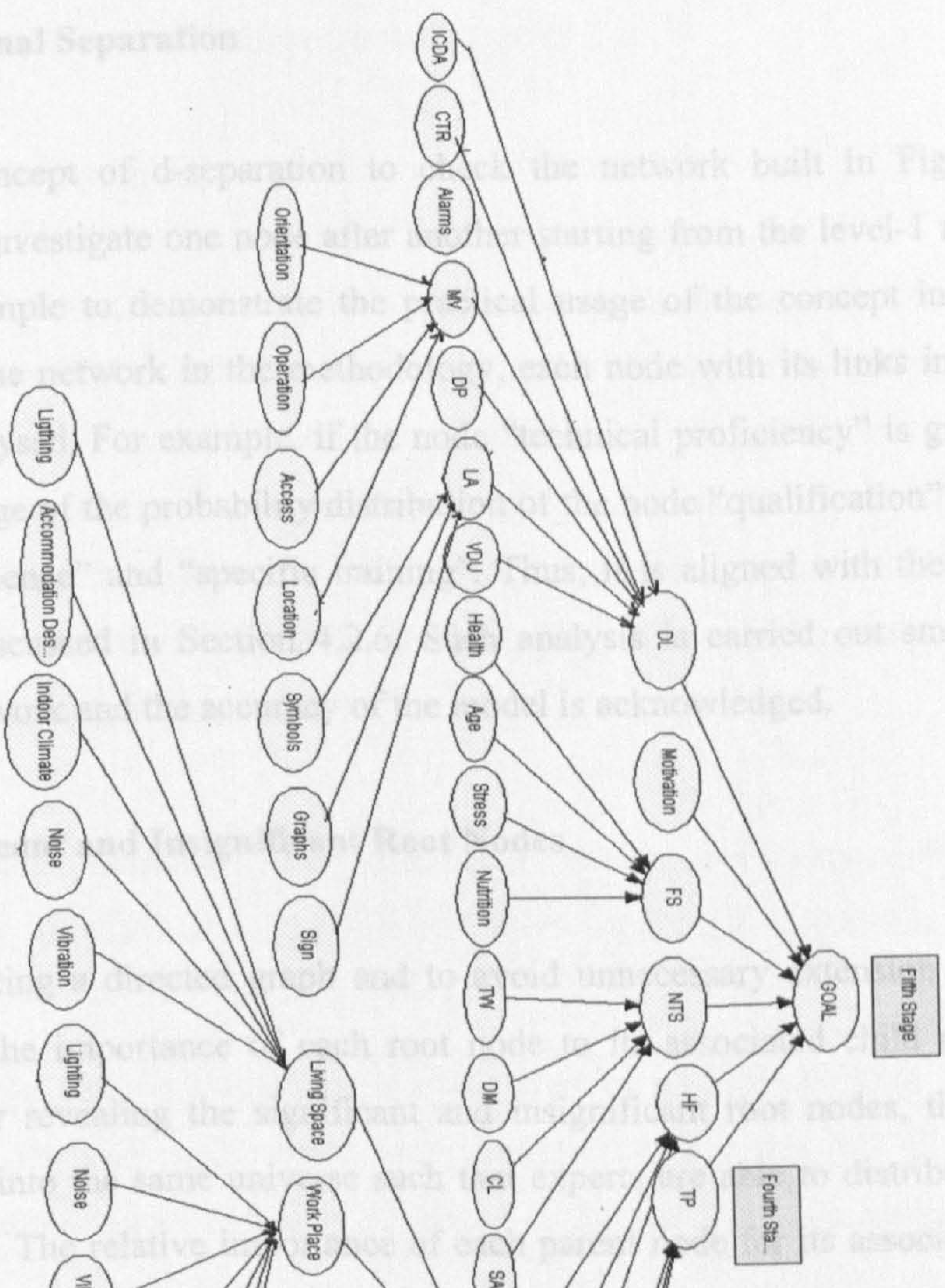

Figure 4.5: Generic Model for Seafarers' Reliability

4.4.1 Directional Separation

Using the concept of d-separation to check the network built in Figure 4.5, it is necessary to investigate one node after another starting from the level-1 nodes. Having given an example to demonstrate the practical usage of the concept in checking the accuracy of the network in the methodology, each node with its links in Figure 4.5 is carefully analysed. For example, if the node "technical proficiency" is given evidence, then the change of the probability distribution of the node "qualification" will affect the nodes "experience" and "specific training". Thus, it is aligned with the concept of d-separation discussed in Section 4.2.6. Such analysis is carried out smoothly for the complete network and the accuracy of the model is acknowledged.

4.4.2. Significant and Insignificant Root Nodes

For constructing a directed graph and to avoid unnecessary extension of the graph's size, firstly the importance of each root node to its associated child node has to be revealed. For revealing the significant and insignificant root nodes, they have to be transformed into the same universe such that experts are able to distribute the weights among them. The relative importance of each parent node for its associated child node may be revealed by their weights and accordingly those nodes with relatively less weight may be eliminated from the graph.

To understand this computational saving, let us assume that a network which indicates the likelihood of a human fatality for the entry into an enclosed space is constructed. Based on the experts' judgement the root nodes are air, food and water. However, a human probably would die after 10 minutes without air, 24 hours (1440 minutes) without water and 7 days (10080 minutes) without food. Thus, by transforming all the root nodes to the same universe (1 minute) and normalizing the result to a sum of unity, the relative importance of air, water and food to their associated child node (human fatality) is calculated as: Air (0.992), Water (0.007) and Food (0.001). Therefore for entry into an enclosed space the significant root node is the air (i.e. before entry the percentage of oxygen has to be checked) and the other two nodes are comparatively insignificant (i.e. may be eliminated from the graph).

4.4.3. Sensitivity Analysis

The objective of sensitivity analysis is to test the sensitivity of a *FBN* model output to the slight probability variation of the input nodes. If the model reflects the realistic situation, then an increment/decrement in the rate or probability at which any of its input nodes may occur would certainly result in the effect of a relative increment/ decrement in the rate or probability of occurrence of its output node. If the methodology is sound and its inference reasoning is logical, then the sensitivity analysis must at least pursue the following three axioms:

Axiom 1: A slight increment / decrement in the rate or probability of occurrence of an input variable should certainly result a relative increment / decrement of the model output.

Axiom 2: If the rate or probability of occurrence of an input variable is decreased by *"I%"* and *"J%"* ($J < I$) respectively and accordingly the rate or probability of occurrence of the model output is evaluated as P_I and P_J respectively, then P_J should be greater than P_I.

Axiom 3: If *"N"* and *"K"* ($K < N$) input variables from all the input variables are selected and the rate or probability of occurrence of each of *"N"* and *"K"* input variables is decreased by the same percentage (e.g. *"I %"*) and accordingly the rate or probability of occurrence of the model output is evaluated as P_K and P_N respectively, then P_K should be greater than P_N.

4.5. Test Case

For calculation of percentage error between the results obtained by the *FER* (Fuzzy Evidential Reasoning) methodology and by a *FBN* methodology, the identical test case illustrated in Section 3.10 is reused here.

4.5.1. Third Officer's Reliability Modelling *(Steps 1, 2 and 3)*

Based on the generic model for the seafarers' reliability (Figure 4.5) and available information (Section 3.10.1) a specific model for the Third Officer's reliability can be constructed (Figure 4.6). It is noteworthy to mention that in the specific model (Figure 4.6) for ease of calculation and due to available information DH (design and habitability), ES (environmental states) and DL (design and layout) are represented as a root node. Assessment grades are assigned to all the criteria in the hierarchical structure and the quantitative and qualitative criteria are segregated (Tables 3.4-3.5).

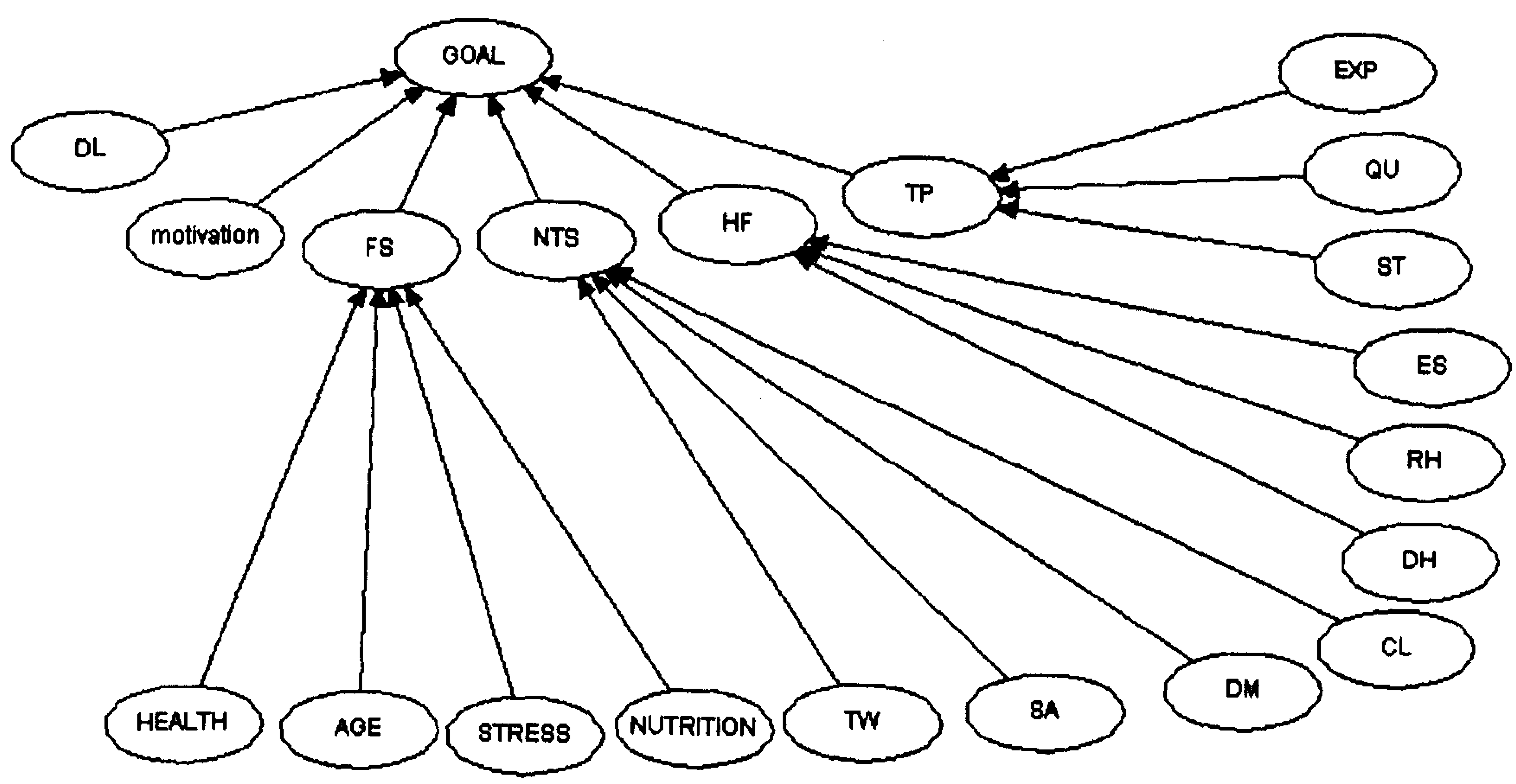

Figure 4.6: Specific Model for the Third officer's Reliability

4.5.2. Quantitative Data Transformation *(Step 4)*

Each level-1 (root node) quantitative criterion (i.e. Environmental states, Experience, Age and Rest hours) is transformed to a qualitative criterion by using a membership function of continuous fuzzy sets (Sections 3.9.2 and 3.10.3).

4.5.3. Mapping Process

As discussed previously in Section 3.9.3, the mapping process can be used for transforming the lower level qualitative criterion into the upper level criterion. By formulating a mapping process, each level-1 qualitative criterion at the i^{th} stage can be converted into an associated level-2 qualitative criterion at the $(i+1)^{th}$ stage and the result can be converted by another mapping process into an associated level-3 qualitative criterion (if any) at the $(i+2)^{th}$ stage. The mapping process continues up to the goal's stage (leaf node). The mathematical equation which governs the two consecutive mapping processes can be written as follows:

$$g^m = \sum_{j=1}^{5} \sum_{i=1}^{5} l^i \beta_i^{j,1} \beta_j^{m,2} \tag{4.25}$$

where g^m represents the fuzzy output (the result), l^i highlights the fuzzy input of a root node and $\beta_i^{j,1}$ & $\beta_j^{m,2}$ stand respectively for the belief degrees that are distributed in the first and second mapping processes by experts for indicating the relationship between linguistic variables of different levels.

4.5.3.1. Unconditional Prior Probability of Root Nodes *(Step 5)*

Based on the previous discussions (Sections 3.4.1 and 3.10.3) the Third Officer's qualification fuzzy set (fuzzy input) was assessed as follows:

$\tilde{Q}$ = {(Excellent, 0), (Very good, 0), (Good, 0.2), (Average, 0.8), (Low, 0)}

Based on Figures 3.9 and 3.12 the belief degrees in the first and second mapping processes, as shown in Table 4.5, are distributed by the experts. Based on Equation 4.25 the fuzzy output (at goal's universe) for the Third Officer's qualification, as shown in Table 4.5, is calculated as follows:

$\tilde{Q}_G$=

{(High, 0.004), (Fairly High, 0.05), (Medium, 0.434), (Fairly Low, 0.512), (Low, 0)}

To obtain a single crisp number for the Third Officer's qualification (at the goal's universe) which represents the unconditional prior probability of the Third Officer's qualification, the utility value of $\widetilde{Q}_G$ must be calculated. Based on Equations 3.14-3.19, as discussed previously in Sections 3.9.6 and 3.10.11, the utility value can be calculated. The corresponding utility value (0.3865) indicates that the Third Officer's qualification is 38.65% reliable and accordingly 61.35% unreliable compared to an ideal seafarer.

Using the same technique, the unconditional prior probabilities of the root nodes can be evaluated. For detailed calculations refer to Appendix 3.

Table 4.5: Unconditional Prior Probability of the Third Officer's Qualification

Fuzzy Input	l^1	l^2	l^3	l^4	l^5			
	0	0	0.2	0.8	0			
Belief degrees in First mapping	$\beta_1^{1,1}$	$\beta_2^{1,1}$	$\beta_2^{2,1}$	$\beta_3^{2,1}$	$\beta_3^{3,1}$	$\beta_4^{3,1}$	$\beta_4^{4,1}$	$\beta_5^{5,1}$
	1	0.2	0.8	0.1	0.9	0.2	0.8	1
Belief degrees in Second mapping	$\beta_1^{1,2}$	$\beta_2^{1,2}$	$\beta_2^{2,2}$	$\beta_3^{2,2}$	$\beta_3^{3,2}$	$\beta_4^{3,2}$	$\beta_4^{4,2}$	$\beta_5^{5,2}$
	1	0.2	0.8	0.1	0.9	0.2	0.8	1
Result	g^1	g^2	g^3	g^4	g^5			
	0.004	0.05	0.434	0.512	0			
Unconditional Prior Probability	0.3865							

4.5.4. Analytic Hierarchy Process (AHP) Methodology *(Step 6)*

The relative importance (influence) of each parent node for its associated child node is revealed by an *AHP* methodology. The *AHP* methodology and its mathematical backgrounds were presented in Section 3.9.4. The obtained results (Section 3.10.4) are shown in Table 4.7.

4.5.5. Conditional Probability Table *(Step 7)*

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 the "symmetric model" and based on Equation 4.24 a *CPT* for each child node can be quantified. For instance, based on Table 4.7 (normalized weight) and Equation 4.24 the *CPT* for Technical proficiency is constructed as follows:

Table 4.6: CPT for Technical Proficiency

	QU (R)				*QU (¬R)*			
	EXP (R)		*EXP (¬R)*		*EXP (R)*		*EXP (¬R)*	
	ST(R)	*ST (¬R)*	*ST(R)*	*ST (¬R)*	*ST(R)*	*ST (¬R)*	*ST(R)*	*ST (¬R)*
Ω (TP)	1	0.7116	0.6592	0.3708	0.6292	0.3408	0.2884	0
Ω (¬ TP)	0	0.2884	0.3408	0.6292	0.3708	0.6592	0.7116	1

where "*R*" and "¬ *R*" stand for reliable and unreliable respectively,

$\Omega\ (TP) = P\ (TP = Reliable \mid QU, EXP, ST)$

$\Omega\ (\neg\ TP) = P\ (TP = Unreliable \mid QU, EXP, ST)$

4.5.6. Comparison of Results (FBN versus FER)

Based on available information (Section 3.10.1) and by means of the subsequent six steps, the unconditional probabilities of all root nodes and their corresponding weights, as shown in Table 4.7, are evaluated. A *CPT* for each child node can be quantified via step 7. Accordingly by exploiting the Hugin software the marginal probability of the Third Officer's reliability, as shown in Figure 4.7, is evaluated as 0.7231 (i.e. 72.31% reliable). The result was evaluated by the *FER* (Section 3.10.11, Table 3.15) as 0.7493 (i.e. 74.93% reliable).

Table 4.7: Unconditional Prior Probabilities of Root Nodes

Child Node Description (Normalized Weight)	Root Node Description	Unconditional Prior Probability of Root Node		Relative importance of each parent nodes for their associated child node (Normalized Weight)
		Reliable	Unreliable	
Technical Proficiency $(\frac{1}{6})$	Qualification	0.3865	0.6135	0.3708
	Experience	0.363	0.637	0.3408
	Specific Training	0.796	0.204	0.2884
Human Fatigue $(\frac{1}{6})$	Environmental States	0.64	0.36	0.288
	Design & Habitability	0.84	0.16	0.2629
	Rest Hours	1	0	0.4491
Fitness & Strength $(\frac{1}{6})$	Nutrition	0.276	0.724	0.1518
	Age	0.88	0.12	0.1479
	Stress	0.88	0.12	0.3798
	Health	0.94	0.06	0.3205
Non-Technical skill $(\frac{1}{6})$	Communication and language skills	0.44	0.56	0.25
	Decision making	0.44	0.56	0.25
	Teamwork	0.84	0.16	0.25
	Situation awareness	0.84	0.16	0.25
Goal (Third Officer's Reliability)	Motivation	0.5975	0.4025	$(\frac{1}{6})$
	Design & Layout	1	0	$(\frac{1}{6})$

The percentage error between the results obtained by *FER* and *FBN* can be calculated as follows:

$$\Delta = \frac{(R_{FER} - R_{FBN})}{R_{FER}} \times 100 \qquad (4.26)$$

where, Δ stands for percentage error, R_{FER} and R_{FBN} stand for the results that is obtained by *FER* and *FBN* respectively.

$$\Delta = \frac{(0.7493 - 0.7231)}{0.7493} \times 100 \approx 3.5\%$$

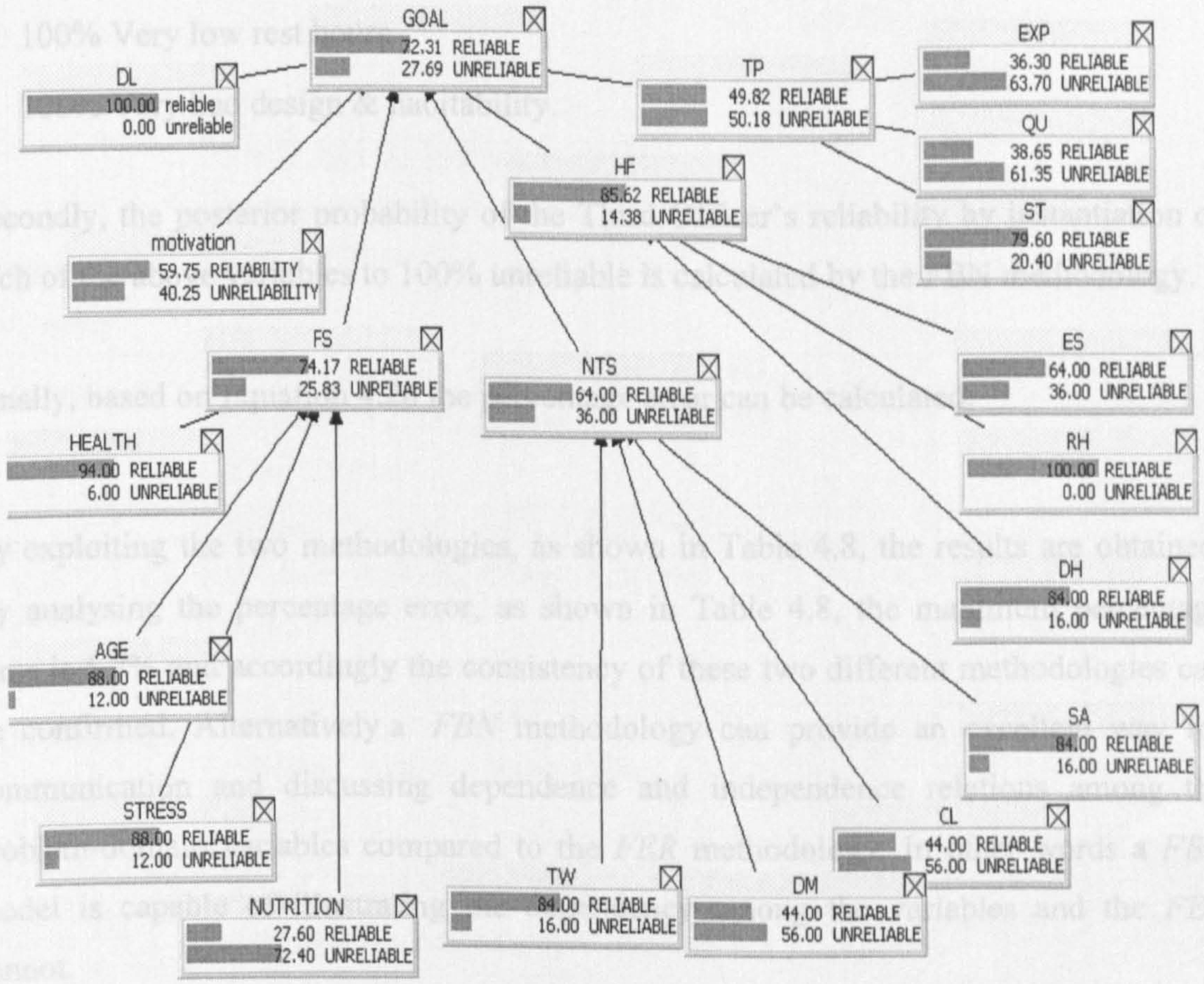

Figure 4.7: Evaluation of the Third Officer's Reliability

The following further studies are conducted for the calculation of the percentage error between the results obtained using the two developed methodologies (i.e. *FER* versus *FBN*):

Firstly, the Third Officer's reliability value due to alteration of each of the following criteria's value as an independent variable is evaluated by the FER methodology.

- 100% Low technical proficiency.

- 100% Very high human fatigue.
- 100% Low non-technical skill.
- 100% Very low fitness and strength.
- 100% Very low motivation.
- 100% Vey bad design & layout.
- 100% Very low rest hours.
- 100% Very bad design & habitability.

Secondly, the posterior probability of the Third Officer's reliability by instantiation of each of the above variables to 100% unreliable is calculated by the FBN methodology.

Finally, based on Equation 4.26 the percentage error can be calculated.

By exploiting the two methodologies, as shown in Table 4.8, the results are obtained. By analysing the percentage error, as shown in Table 4.8, the maximum percentage error is 5.7% and accordingly the consistency of these two different methodologies can be confirmed. Alternatively a *FBN* methodology can provide an excellent way for communication and discussing dependence and independence relations among the problem-domain variables compared to the *FER* methodology. In other words a *FBN* model is capable of illustrating the dependency among the variables and the *FER* cannot.

Table 4.8: FER methodology versus FBN methodology (percentage error)

Change of Event	FER		FBN	Percentage error
	Third Officer's reliability value ($\widetilde{G}$)	Third Officer's reliability value (R_{Γ})	Third Officer's reliability value	Δ
100% Low technical proficiency	{(High, 0.4378), (Fairly High, 0.1816), (Medium, 0.2003), (Fairly Low, 0.0209), (Low, 0.1594)}	0.679	0.6402	5.7%
100% Very high human fatigue	{(High, 0.3253), (Fairly High, 0.1748), (Medium, 0.2516), (Fairly Low, 0.0852), (Low, 0.1631)}	0.6035	0.5801	3.9%
100% Low non-technical skill	{(High, 0.4205), (Fairly High, 0.1557), (Medium, 0.1923), (Fairly Low, 0.0735), (Low, 0.158)}	0.6518	0.6165	5.4%
100% Very low fitness and strength	{(High, 0.3486), (Fairly High, 0.1502), (Medium, 0.2627), (Fairly Low, 0.0805), (Low, 0.158)}	0.6129	0.5994	2.2%
100% Very low motivation	{(High, 0.4382), (Fairly High, 0.1736), (Medium, 0.1404), (Fairly Low, 0.0862), (Low, 0.1616)}	0.66	0.6236	5.5%
100% Vey bad design and layout	{(High, 0.2616), (Fairly High, 0.2164), (Medium, 0.2711), (Fairly Low, 0.0876), (Low, 0.1633)}	0.5813	0.5561	4.3%
100% Very low rest hours	{(High, 0.3466), (Fairly High, 0.2160), (Medium, 0.2662), (Fairly Low, 0.0867), (Low, 0.0845)}	0.6633	0.6474	2.5%
100% Very bad design and habitability	{(High, 0.4316), (Fairly High, 0.1820), (Medium, 0.2606), (Fairly Low, 0.0849), (Low, 0.0409)}	0.719	0.6856	4.6%

4.5.7. Sensitivity Analysis (*Final Step)*

The sensitive analysis is used to test the logicality of the delivery of the analytical result. Three Axioms introduced in Section 4.4.2 are used. To carry out the research the reliability of all input variables (16 nodes) as shown in Tables 4.9 and 4.10 is decreased and increased by 5%, 10%, 15% and 20%. Accordingly the results (model output or goal) as shown in Tables 4.9 and 4.10 are obtained. Based on the obtained results (Tables 4.9 and 4.10) Figure 4.8 is drawn. All the results obtained keep harmony with Axioms 1 and 2. If the reliability of all input variables, as shown in Table 4.9, is decreased by 15% the rate or probability of occurrence of the model output (i.e. reliability of the Third Officer) is evaluated as "61.67% reliable" and "38.33% unreliable". By selection of ten input variables (i.e. Qualification, Experience, Specific Training, Environmental States, Design & Habitability, Rest Hours, Nutrition, Age, Stress and Health) from 16 input variables and by decreasing the reliability of those selected input variables (i.e. ten input variables) by 15% the rate or probability of occurrence of the model output (i.e. reliability of the Third Officer) is evaluated as "67.28% reliable" and "32.72% unreliable". In view of the fact that "61.67" is smaller than "62.78", the result is aligned with Axiom 3.

Apart from the above, like all other models, *FBNs* can be over fit. To avoid such a problem, it is common practice to use a sensitivity test to measure the effect of one variable over another. Variables for which the model output is particularly insensitive should be removed in order to produce the most parsimonious model description. On the other hand given the same variation of input probabilities, comparing their influence magnitudes on the output node enables differentiating the importance of the input nodes in terms of the individual contribution to the output variable. Thus, the probability of occurrence (i.e. reliability) of an individual root node, which is at the same stage corresponding to other nodes, has been decreased by 20% while the probabilities of occurrence of all the other input nodes are left unchanged. The results (i.e. reliability of the Third Officer) as shown in Table 4.11 are obtained. Based on the obtained results (Table 4.11) the sensitivity of the model output to the same variation of the each individual model input as illustrated in Figure 4.9 is assessed. Based on the analysis, as shown in Table 4.11, the model is not over fit. From Figure 4.9 it is obvious that the model output is more sensitive to the rest hours than the other variables. As a result a FBN model (dependency network) which is capable of illustrating the dependency among the variables and by concentrating on rest hours has to be constructed.

Table 4.9: Decrement of Root Nodes' Reliability

Root Node Description	Decrement of Reliability									
	0%		5%		10%		15%		20%	
	Reliability	Unreliability	Reliability	Unreliability	Reliability	Unreliability	Reliability	Unreliability	Reliability	Unreliability
Qualification	0.3865	0.6135	0.367	0.633	0.348	0.652	0.328	0.672	0.309	0.691
Experience	0.363	0.637	0.345	0.655	0.327	0.673	0.308	0.692	0.290	0.71
Specific Training	0.796	0.204	0.756	0.244	0.716	0.284	0.676	0.324	0.637	0.363
Environmental States	0.64	0.36	0.608	0.392	0.576	0.424	0.544	0.456	0.512	0.488
Design and Habitability	0.84	0.16	0.798	0.202	0.756	0.244	0.714	0.286	0.672	0.328
Rest Hours	1	0	0.95	0.05	0.9	0.1	0.85	0.15	0.8	0.2
Nutrition	0.276	0.724	0.262	0.738	0.240	0.76	0.234	0.766	0.220	0.78
Age	0.88	0.12	0.836	0.164	0.792	0.208	0.748	0.252	0.704	0.296
Stress	0.88	0.12	0.836	0.164	0.792	0.208	0.748	0.252	0.704	0.296
Health	0.94	0.06	0.893	0.107	0.846	0.154	0.799	0.201	0.752	0.248
Communication and Language Skills	0.44	0.56	0.418	0.582	0.396	0.604	0.374	0.626	0.352	0.648
Decision Making	0.44	0.56	0.418	0.582	0.396	0.604	0.374	0.626	0.352	0.648
Teamwork	0.84	0.16	0.798	0.202	0.756	0.244	0.714	0.286	0.672	0.328
Situation Awareness	0.84	0.16	0.798	0.202	0.756	0.244	0.714	0.286	0.672	0.328
Motivation	0.5975	0.4025	0.567	0.433	0.537	0.463	0.508	0.492	0.478	0.522
Design and Layout	1	0	0.95	0.05	0.9	0.1	0.85	0.15	0.8	0.2
Goal (Third Officer's Reliability)	0.7231	0.2769	0.6876	0.3124	0.6519	0.3418	0.6167	0.3833	0.5810	0.4190

Table 4.10: Increment of Root Nodes' Reliability

Root Node Description	Increment of Reliability									
	0%		5%		10%		15%		20%	
	Reliability	Unreliability	Reliability	Unreliability	Reliability	Unreliability	Reliability	Unreliability	Reliability	Unreliability
Qualification	0.3865	0.6135	0.405	0.595	0.425	0.575	0.444	0.556	0.464	0.536
Experience	0.363	0.637	0.381	0.619	0.399	0.601	0.417	0.583	0.436	0.564
Specific Training	0.796	0.204	0.836	0.164	0.876	0.124	0.915	0.085	0.955	0.045
Environmental States	0.64	0.36	0.672	0.328	0.704	0.296	0.736	0.264	0.768	0.232
Design and Habitability	0.84	0.16	0.882	0.118	0.924	0.076	0.966	0.034	1	0
Rest Hours	1	0	1	0	1	0	1	0	1	0
Nutrition	0.276	0.724	0.289	0.711	0.303	0.697	0.317	0.683	0.331	0.669
Age	0.88	0.12	0.924	0.076	0.968	0.032	1	0	1	0
Stress	0.88	0.12	0.924	0.076	0.968	0.032	1	0	1	0
Health	0.94	0.06	0.987	0.016	1	0	1	0	1	0
Communication and Language Skills	0.44	0.56	0.462	0.538	0.484	0.516	0.506	0.494	0.528	0.472
Decision Making	0.44	0.56	0.462	0.538	0.484	0.516	0.506	0.494	0.528	0.472
Teamwork	0.84	0.16	0.882	0.118	0.924	0.076	0.966	0.034	1	0
Situation Awareness	0.84	0.16	0.882	0.118	0.924	0.076	0.966	0.034	1	0
Motivation	0.5975	0.4025	0.627	0.373	0.657	0.343	0.687	0.313	0.717	0.283
Design and Layout	1	0	1	0	1	0	1	0	1	0
Goal (Third Officer's Reliability)	0.7231	0.2769	0.7527	0.2473	0.7676	0.2324	0.7878	0.2122	0.852	0.148

Table 4.11: Decrement of each Individual Root Node by 20%

Root Node Description	Decrement of reliability by 20%		Goal (Third Officer's Reliability)	
	Reliable	Unreliable	Reliable	Unreliable
Qualification	0.309	0.691	0.718	0.282
Experience	0.290	0.71	0.7189	0.2811
Specific Training	0.637	0.363	0.7152	0.2848
Environmental States	0.512	0.488	0.7169	0.2831
Design and Habitability	0.672	0.328	0.7154	0.2846
Rest Hours	0.8	0.2	0.7078	0.2922
Nutrition	0.220	0.78	0.7206	0.2794
Age	0.704	0.296	0.7208	0.2792
Stress	0.704	0.296	0.7137	0.2863
Health	0.752	0.248	0.7152	0.2848
Communication and Language Skills	0.352	0.648	0.7192	0.2808
Decision Making	0.352	0.648	0.7192	0.2808
Teamwork	0.672	0.328	0.7159	0.2841
Situation Awareness	0.672	0.328	0.7159	0.2841

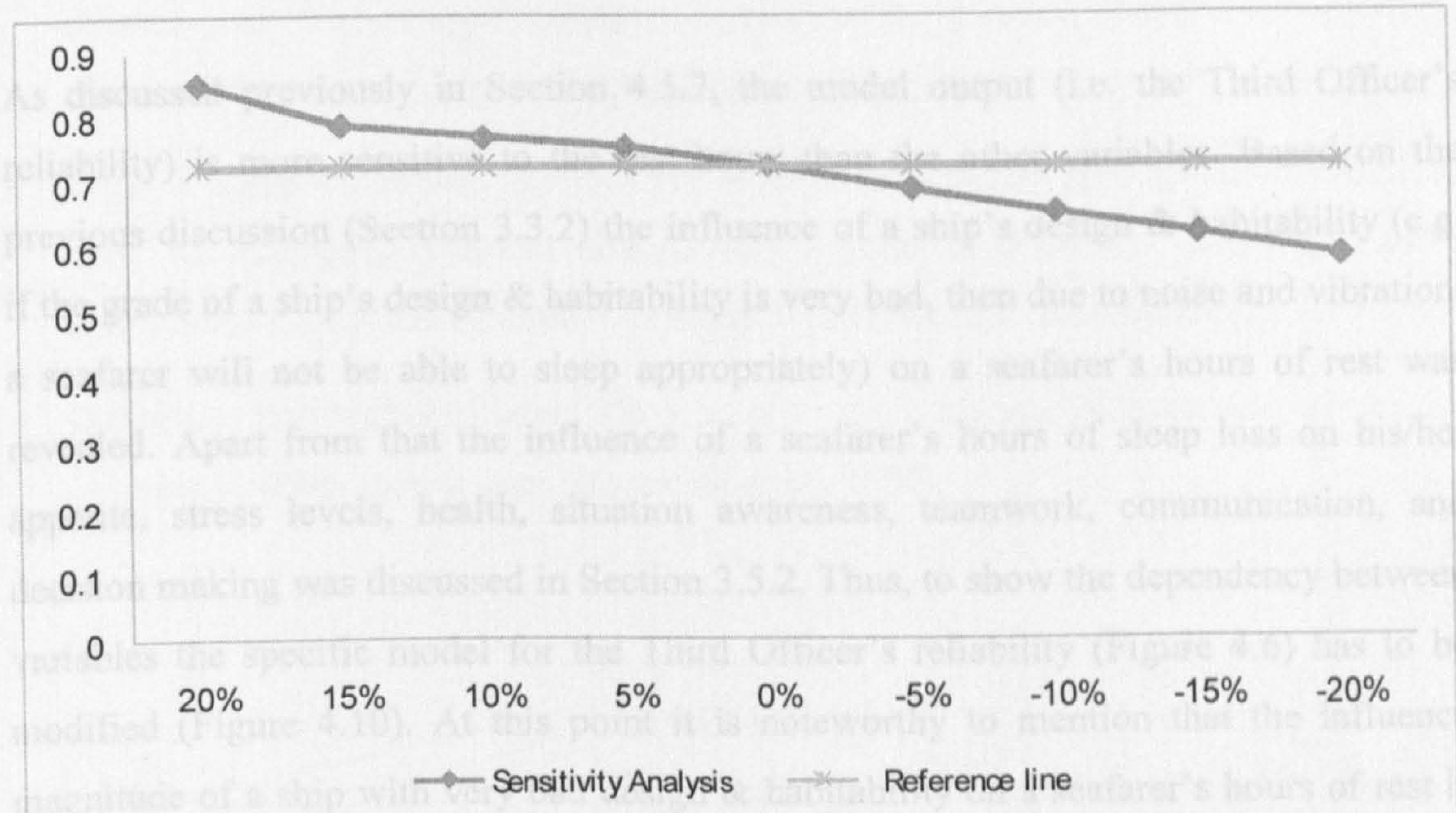

Figure 4.8: Third Officer's Reliability versus Increment/ Decrement of Root Nodes' Reliability

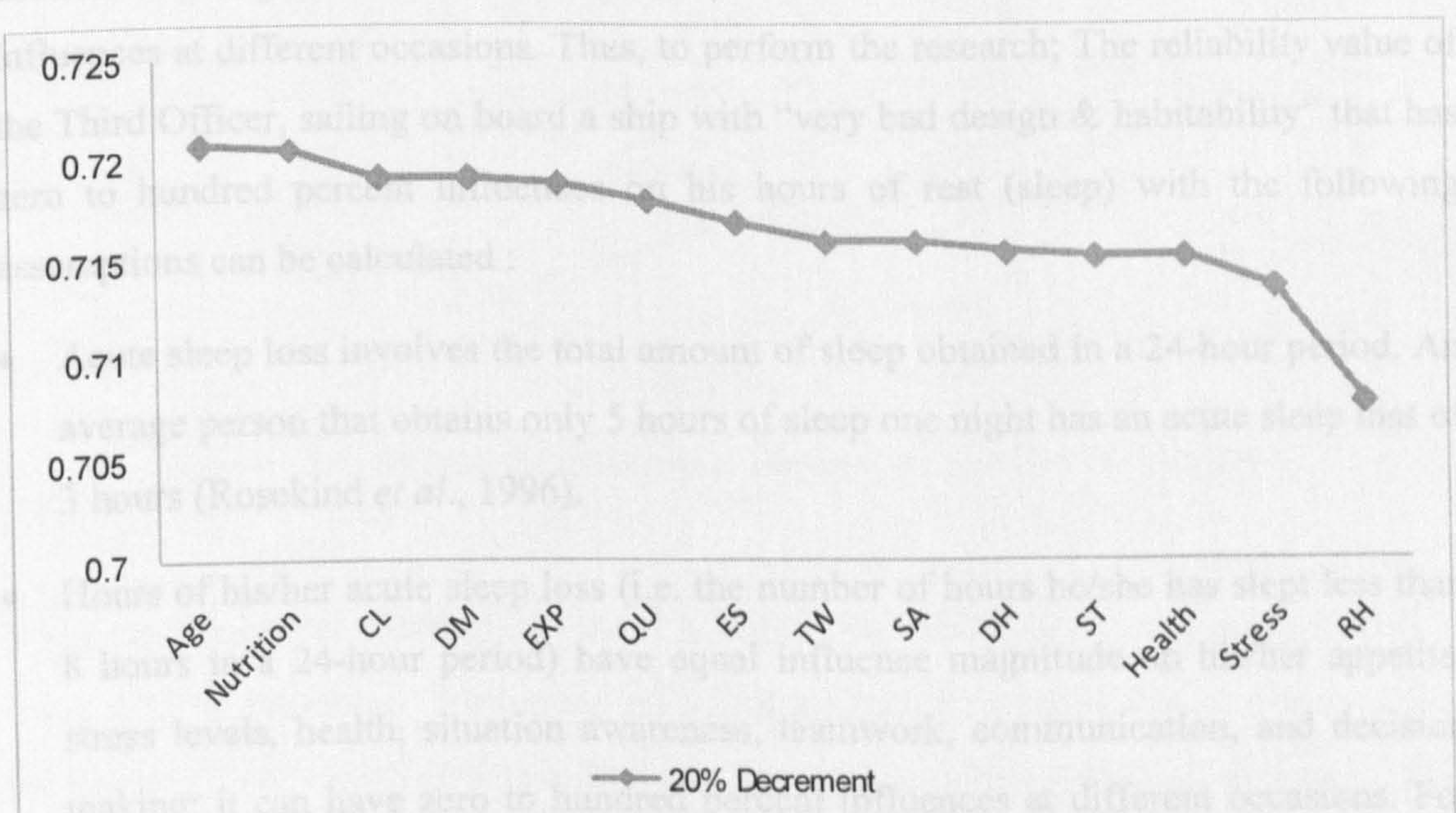

Figure 4.9: Sensitivity of the Model Output to the Same Variation of each Model Input

4.6. Dependency Network

As discussed previously in Section 4.5.7, the model output (i.e. the Third Officer's reliability) is more sensitive to the rest hours than the other variables. Based on the previous discussion (Section 3.3.2) the influence of a ship's design & habitability (e.g. if the grade of a ship's design & habitability is very bad, then due to noise and vibration, a seafarer will not be able to sleep appropriately) on a seafarer's hours of rest was revealed. Apart from that the influence of a seafarer's hours of sleep loss on his/her appetite, stress levels, health, situation awareness, teamwork, communication, and decision making was discussed in Section 3.5.2. Thus, to show the dependency between variables the specific model for the Third Officer's reliability (Figure 4.6) has to be modified (Figure 4.10). At this point it is noteworthy to mention that the influence magnitude of a ship with very bad design & habitability on a seafarer's hours of rest is difficult to predict; it can have zero to hundred percent influences at different occasions. On the other hand the influence magnitude of a seafarer's hours of sleep loss on his/her appetite, stress levels, health, situation awareness, teamwork, communication, and decision making is also difficult to predict; it can have zero to hundred percent influences at different occasions. Thus, to perform the research; The reliability value of the Third Officer, sailing on board a ship with "very bad design & habitability" that has zero to hundred percent influences on his hours of rest (sleep) with the following assumptions can be calculated :

- Acute sleep loss involves the total amount of sleep obtained in a 24-hour period. An average person that obtains only 5 hours of sleep one night has an acute sleep loss of 3 hours (Rosekind *et al.*, 1996).
- Hours of his/her acute sleep loss (i.e. the number of hours he/she has slept less than 8 hours in a 24-hour period) have equal influence magnitude on his/her appetite, stress levels, health, situation awareness, teamwork, communication, and decision making; it can have zero to hundred percent influences at different occasions. For instance if a person's hours of rest sailing on board a ship with "very bad design & habitability" falls from 8 hours in a 24-hour period (100% reliable) to 7.2 hours in a 24-hour period (90% reliable, 10% unreliable) and hours of his/her acute sleep loss have equal influence magnitude (e.g. 20%) on his/her appetite, stress levels, health,

situation awareness, teamwork, communication and decision making, then the reliability of his/her appetite, stress levels, health, situation awareness, teamwork, communication and decision making falls to 0.98 of their former reliability.

- Lack of sleep hours that occurs over several days builds into a cumulative sleep debt. An average person that obtains only 5 hours of sleep (i.e. each night) for 3 consecutive nights has a cumulative sleep debt of 9 hours (Rosekind et al., 1996).
- Generally, two nights of usual sleep, at a person's regular bedtime, can reduce the cumulative sleep debt to zero (Rosekind et al., 1996).

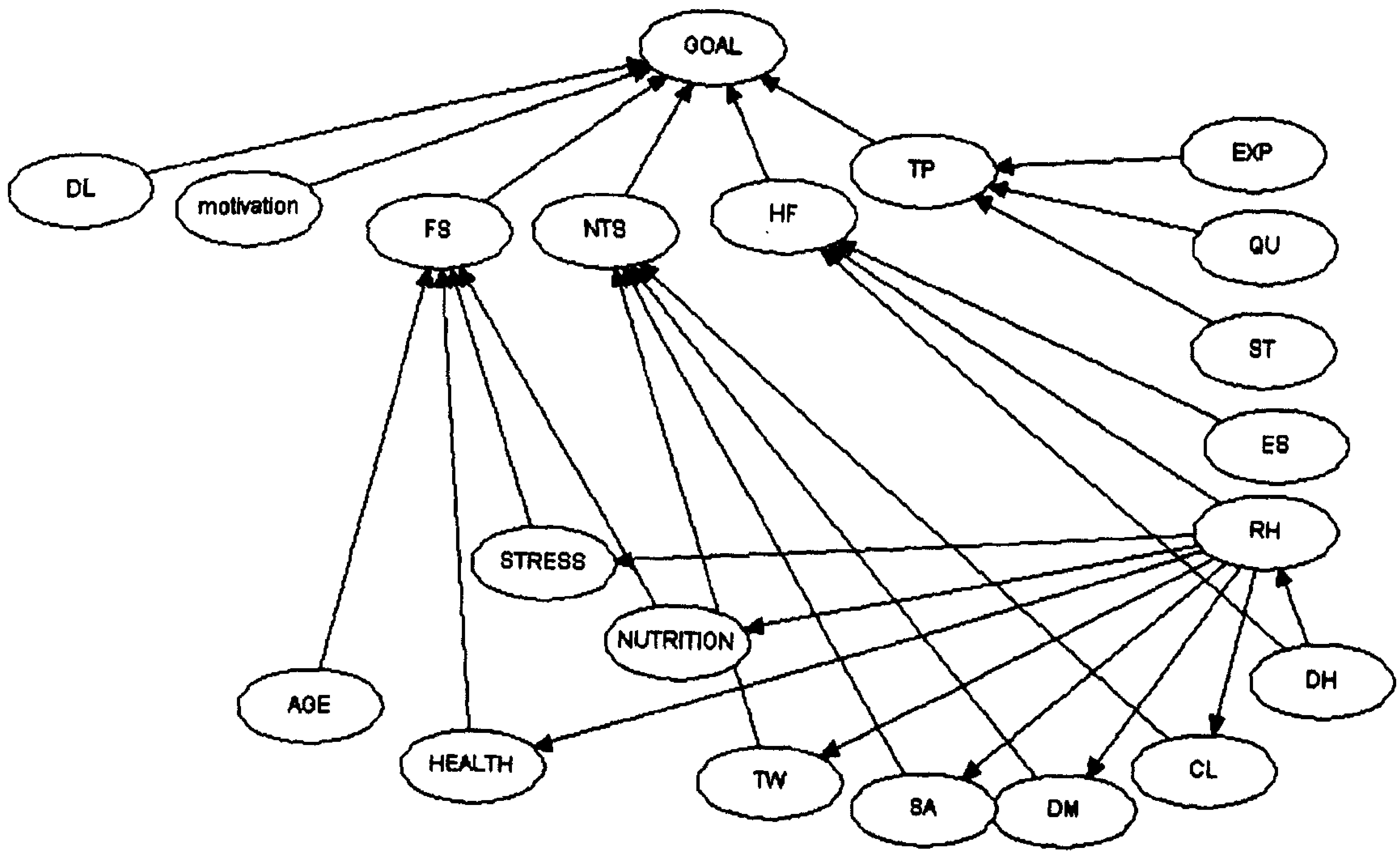

Figure 4.10: Specific Model (Dependency Network) for Third Officer's Reliability

Based on the above assumptions the Third Officer's reliability (i.e. R_{Γ}), as shown in Table 4.12, is evaluated. By further analysing the collected data it can be observed that the Third Officer's reliability (i.e. based on Figure 4.7, which was calculated as 0.7231) has fallen to 0.6856 due to sailing on board a ship with "100% very bad design and habitability" (Table 4.8) and further decreased due to reduction of his rest hours.

Table 4.12: Calculation of Third Officer's Reliability

The influence magnitude of a ship with very bad design & habitability on the Third Officer's hours of sleep.	The influence magnitude of the Third Officer's hours of acute sleep loss on his appetite, stress levels, health, situation awareness, teamwork, communication, and decision making.										
	00%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0%	0.6856	0.6856	0.6856	0.6856	0.6856	0.6856	0.6856	0.6856	0.6856	0.6856	0.6856
5%	0.6818	0.6808	0.6798	0.6787	0.6777	0.6767	0.6756	0.6745	0.6735	0.6724	0.6713
10%	0.6780	0.6760	0.6740	0.6719	0.6698	0.6678	0.6656	0.6635	0.6614	0.6592	0.6570
15%	0.6743	0.6712	0.6681	0.6651	0.6619	0.6589	0.6557	0.6525	0.6492	0.6460	0.6427
20%	0.6705	0.6664	0.6623	0.6582	0.6541	0.6501	0.6457	0.6415	0.6371	0.6328	0.6283
25%	0.6667	0.6616	0.6565	0.6514	0.6462	0.6412	0.6357	0.6304	0.6250	0.6196	0.6140
30%	0.6629	0.6568	0.6507	0.6445	0.6383	0.6323	0.6257	0.6194	0.6129	0.6064	0.5997
35%	0.6592	0.6520	0.6449	0.6377	0.6304	0.6234	0.6158	0.6084	0.6008	0.5932	0.5854
40%	0.6554	0.6472	0.6391	0.6308	0.6226	0.6146	0.6058	0.5973	0.5887	0.5800	0.5711
45%	0.6516	0.6425	0.6333	0.6240	0.6147	0.6057	0.5958	0.5863	0.5766	0.5668	0.5568
50%	0.6478	0.6377	0.6274	0.6172	0.6068	0.5968	0.5859	0.5753	0.5645	0.5535	0.5425
55%	0.6441	0.6329	0.6216	0.6103	0.5989	0.5879	0.5759	0.5642	0.5523	0.5403	0.5282
60%	0.6403	0.6281	0.6158	0.6039	0.5911	0.5790	0.5659	0.5532	0.5402	0.5271	0.5139
65%	0.6365	0.6233	0.6100	0.5966	0.5832	0.5702	0.5559	0.5422	0.5281	0.5139	0.4996
70%	0.6328	0.6185	0.6042	0.5898	0.5753	0.5613	0.5460	0.5311	0.5160	0.5007	0.4853
75%	0.6290	0.6137	0.5984	0.5829	0.5674	0.5524	0.5360	0.5201	0.5039	0.4875	0.4710
80%	0.6252	0.6089	0.5925	0.5761	0.5595	0.5435	0.5260	0.5091	0.4918	0.4743	0.4566
85%	0.6214	0.6041	0.5867	0.5693	0.5517	0.5346	0.5160	0.4980	0.4794	0.4611	0.4423
90%	0.6177	0.5993	0.5809	0.5624	0.5438	0.5258	0.5061	0.4870	0.4675	0.4479	0.4280
95%	0.6139	0.5945	0.5751	0.5556	0.5359	0.5169	0.4961	0.4760	0.4554	0.4347	0.4137
100%	0.6101	0.5897	0.5693	0.5488	0.5280	0.5080	0.4861	0.4650	0.4433	0.4215	0.3994

More concretely, based on the collected data in Table 4.12, the Third Officer's reliability value (i.e. R_{Γ}) can be linked to his reliability value on board a ship with "very bad design and habitability" (i.e. 0.6856) and reduction of his reliability value due to reduction of his rest hours (i.e. R_S). Accordingly the following formula can be written:

$$R_S = 0.6856 - R_\Gamma \quad (4.27)$$

Based on Equation 4.27, Table 4.13 which presents the reduction of the Third Officer's reliability value due to reduction of his rest hours is illustrated.

Table 4.13: Reduction of Third Officer's Reliability Attributable to Acute Sleep Loss

Percentage of sleep loss in a 24- hour period.	The influence magnitude of the Third Officer's hours of acute sleep loss on his appetite, stress levels, health, situation awareness, teamwork, communication, and decision making.									
	00%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0%	0	0	0	0	0	0	0	0	0	0	0
5%	**0.004**	0.005	0.006	0.007	0.008	0.009	0.01	0.011	0.012	0.013	0.014
10%	**0.008**	**0.01**	0.012	0.014	0.016	0.018	0.02	0.022	0.024	0.026	0.029
15%	**0.011**	0.014	**0.017**	0.020	0.024	0.027	0.030	0.033	0.036	0.039	0.043
20%	**0.015**	0.019	**0.023**	0.027	0.031	0.035	0.039	0.044	0.048	0.052	0.057
25%	**0.019**	0.024	**0.029**	0.034	0.039	0.044	0.049	0.055	0.061	0.066	0.072
30%	**0.023**	0.029	0.035	**0.041**	0.047	0.053	0.060	0.066	0.072	0.079	0.085
35%	**0.026**	0.034	0.041	**0.048**	0.055	0.062	0.070	0.077	0.085	0.092	0.10
40%	**0.030**	0.038	0.047	0.055	**0.063**	0.071	0.080	0.088	0.097	0.106	0.115
45%	**0.034**	0.043	0.052	0.062	**0.071**	0.080	0.090	0.100	0.109	0.119	0.129
50%	**0.038**	0.048	0.058	0.068	**0.079**	0.089	0.100	0.110	0.121	0.132	0.143
55%	**0.041**	0.053	0.064	0.075	0.087	**0.098**	0.110	0.121	0.133	0.145	0.157
60%	**0.045**	0.058	0.070	0.082	0.095	**0.107**	0.120	0.132	0.145	0.158	0.172
65%	**0.049**	0.062	0.076	0.089	0.102	0.115	**0.130**	0.143	0.158	0.172	0.186
70%	**0.053**	0.067	0.081	0.096	0.110	0.124	**0.140**	0.155	0.170	0.185	0.200
75%	**0.057**	0.072	0.087	0.103	0.118	0.133	0.150	**0.166**	0.182	0.198	0.215
80%	**0.060**	0.077	0.093	0.110	0.126	0.142	0.160	**0.177**	0.194	0.211	0.229
85%	**0.064**	0.082	0.099	0.116	0.134	0.151	0.170	0.188	**0.206**	0.225	0.243
90%	**0.068**	0.086	0.105	0.123	0.142	0.160	0.180	0.200	**0.218**	0.240	0.258
95%	**0.072**	0.091	0.111	0.130	0.150	0.169	0.190	0.210	**0.230**	0.251	0.272
100%	**0.075**	0.096	0.116	0.137	0.158	0.178	0.199	0.220	0.242	**0.264**	0.286

Based on Table 4.13 and by further scrutinizing the available data, an equation for reduction of the Third Officer's reliability due to his continuous hours of wakefulness, acute sleep loss and cumulative sleep debt, based on a regression principle, can be suggested as follows:

$$R_S = \frac{\Delta t}{100} \times (1 + \frac{k}{4}) \tag{4.28}$$

$$\Delta t = 8 \times d - T \tag{4.29}$$

where $k = 0, 1, \ldots, 10$ and "Δt" stands for cumulative sleep debt, "d" stands for the number of consecutive calendar days (i.e. 24-hour period) within the research period, "T" stands for hours of sleep obtained by a person within "d" consecutive calendar days. For instance, an average person that obtains only five hours of sleep in each night of three consecutive calendar days has a cumulative sleep debt of 9 hours (i.e. $\Delta t = 8 \times 3 - 15 = 9$). It is noteworthy to mention that "$k = 0$" stand for the lower band and "$k = 10$" for the upper band of "R_S".

Furthermore, by limiting the influence magnitude of the Third Officer's hours of acute sleep loss on his appetite, stress levels, health, situation awareness, teamwork, communication, and decision making a mathematical relationship between "k" and Δt, based on a regression principle, can be suggested as follows:

$$k = \Delta t + \frac{\Delta t^2}{54} \tag{4.30}$$

Equations 4.28 and 4.30 can be combined and an approximate equation for R_S is suggested as follows:

$$R_S = \frac{1}{100} \times \sum_{m=1}^{n} (\frac{\Delta t}{m!})^m \tag{4.31}$$

where $n = 1, 2, 3$ and "$n = 1$" stand for the lower band and "$n = 3$" for the upper band of "R_S".

For instance, for 40% of sleep loss in a 24-hour period the calculation can be evaluated as follows:

Hours of acute sleep loss = 0.4×8 = 3.2 hours in a 24-hour period.

T = Hours of sleep = 8-3.2 = 4.8 hours.

d = Number of consecutive calendar days within research period = 1

$$\Delta t = 8\times1-4.8=3.2$$

Based on Equation 4.28 the lower and upper bands for R_S can be evaluated as follows:

$$\text{“}k = 0\text{”},\ R_S = \frac{1}{100}\times\frac{3.2}{1} = 0.032 \text{ and}$$

$$\text{“}k = 10\text{”},\ R_S = \frac{1}{100}\times 3.2\times(1+\frac{10}{4}) = 0.112\,.$$

Based on Equation 4.31 (i.e. an approximate solution) the lower and upper bands for R_S can be evaluated as follows:

$$\text{“}n = 1\text{”},\ R_S = \frac{1}{100}\times\frac{3.2}{1} = 0.032 \text{ and}$$

$$\text{“}n = 3\text{”},\ R_S = \frac{1}{100}\times\left[\left(\frac{3.2}{1!}\right)^1+\left(\frac{3.2}{2!}\right)^2+\left(\frac{3.2}{3!}\right)^3\right]\approx 0.059\,.$$

Based on the above calculation and as shown in Table 4.13 (i.e. bold type) the adjacent values to the above calculation for 40% of sleep loss in a 24-hour period can be estimated as 0.030 and 0.063 for the lower and upper bands of R_S. Based on Equations 4.29 and 4.31 the lower and upper bands of R_S for different percentages of sleep loss in a 24-hour period can be calculated. The adjacent values, as illustrated in Table 4.13, are shown in bold type. Therefore by exploiting Equation 4.31 the influence magnitude of the Third Officer's hours of acute sleep loss on his appetite, stress levels, health, situation awareness, teamwork, communication, and decision making is limited. For instance, as shown in Table 4.13, for 90% of sleep loss in a 24-hour period the upper band value is limited to 80%. If the reduction of the human reliability due to a person's acute sleep loss follows the former assumption (i.e. hours of a person acute sleep loss have equal influence magnitude on his/her appetite, stress levels, health, situation awareness, teamwork, communication, and decision making), then Equation 4.31 can be suggested as a general equation. For validation of Equation 4.31 as a general equation for the reduction of the human reliability due to a person's continuous hours of wakefulness, acute sleep loss and cumulative sleep debt the following research is conducted.

4.6.1. Lindbergh's Flight to Paris

Charles Lindbergh undertook the first transatlantic flight in the Spirit of St. Louis in May 1927. The flight from New York (i.e. 7:52 am, May 20) to Paris (i.e. 10:22 pm, May 21) took over 33.5 hours (i.e. 5 hours time difference between Paris and New York) to complete (Lindbergh, 1927). It prevented Lindbergh from sleeping at least for 35.5 hours (i.e. his sleep/wake histories before takeoff are unknown). It may be the first example of the effect of fatigue in aviation. On 21st of May at 11:00 AM when he was continuously awake for 27 hours (i.e. at least) the following is quoted (Lindbergh, 1953):

"The lack of sleep I feel now, at eleven o'clock in the morning, is a grain of sand compared to the mountain that will tower over me when dawn breaks tomorrow. Past dawns I have flown through come forward in memory to warn me what torture the desire for sleep can be. How wonderful it would be if this really was a dream, and I could lie down on a cloud's soft, fluffy quilt and sleep. I have never wanted anything so much. I would pay any price except life itself. But life itself is the price".

Equation 4.31 is plotted, as shown in Figure 4.11, for a person with 100% initial reliability. Based on Figure 4.11 after 27 hours of continuous wakefulness, Lindbergh is with only 67.15% reliability. Based on the frame of reference (Figure 3.14), the grade of Lindbergh's performance after 27 hours of continuous wakefulness can be assessed as 100% "Fairly Low" and by the time of landing as 100% Low (i.e. 51.21% reliable). The obtained result is fully supported with Lindbergh's autobiography.

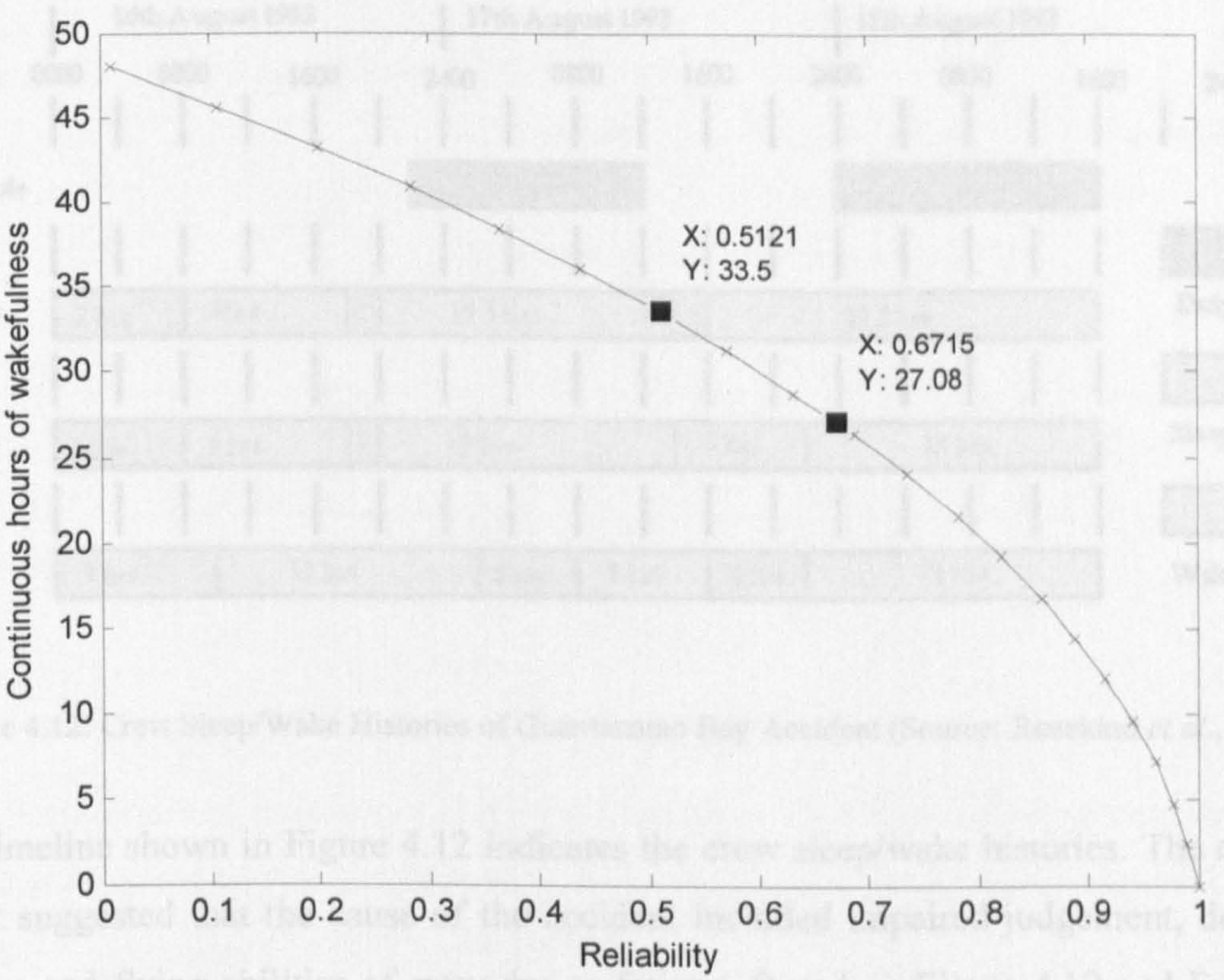

Figure 4.11: Lindbergh's Reliability versus Continuous Hours of Wakefulness

4.6.2. Guantanamo Bay Aviation Accident

On the 18th August 1993 a Douglas DC-8 freighter crashed while landing at the US Naval Air Station in Guantanamo Bay, Cuba. The National Transportation Safety Board (NTSB) conducted the official investigation. It requested the National Aeronautics and Space Administration (NASA) fatigue countermeasures programme to assess the potential of fatigue in the accident. Based on the available data four physiological factors were identified as being present in the crew (Rosekind *et al.*, 1996):

1. Acute sleep loss and cumulative sleep debt.
2. Continuous hours of wakefulness.
3. Time of day and circadian effects.
4. Presence of sleep disorder.

Table 4.14: Crew's Cumulative Sleep Debt

Crew Member	Research Period	"*d*" Number of consecutive calendar days within research period	"*T*" hours of sleep obtains by a person within "*d*" consecutive calendar days	"Δ*t*" Cumulative sleep debt
Captain	65 hrs	2.7	15hrs	6.6
First Officer	65 hrs	2.7	18hrs	3.6
Second Officer	65 hrs	2.7	21hrs	0.6

Based on Figures 4.12 and 4.13, the following is obtained:

1. After 8 hours of continuous sleep the Captain's reliability can be assumed as 100% reliable; since he was continuously awake for 9 hours, as shown in Figure 4.13 (i.e. data 1), his reliability falls to 94.58%.

2. The Captain's reliability remains constant during his 2 hours sleep (i.e. 94.58% reliable); since he was continuously awake for 17.5 hours, as shown in Figure 4.13 (i.e. data 2), his reliability falls to 79.31%.

3. The Captain's reliability remains constant during his 5 hours sleep (i.e. 79.31% reliable); since he was continuously awake for 23.5 hours, as shown in Figure 4.13 (i.e. data 3), his reliability falls to 53.76%.

Based on the frame of reference (Figure 3.14), the grade of the Captain's performance prior to the accident (i.e. 53.76% reliable) can be assessed as 100% "Low" and accordingly the occurrence likelihood of an accident is "100% High". The obtained result is fully supported by the crash of Douglas DC-8 freighter due to the Captain's continuous hours of wakefulness, acute sleep loss and cumulative sleep debt. The frame of reference (Figure 3.14) and Equations 4.29 and 4.31 can be used to estimate the level of human performance so as to take appropriate preventative measures.

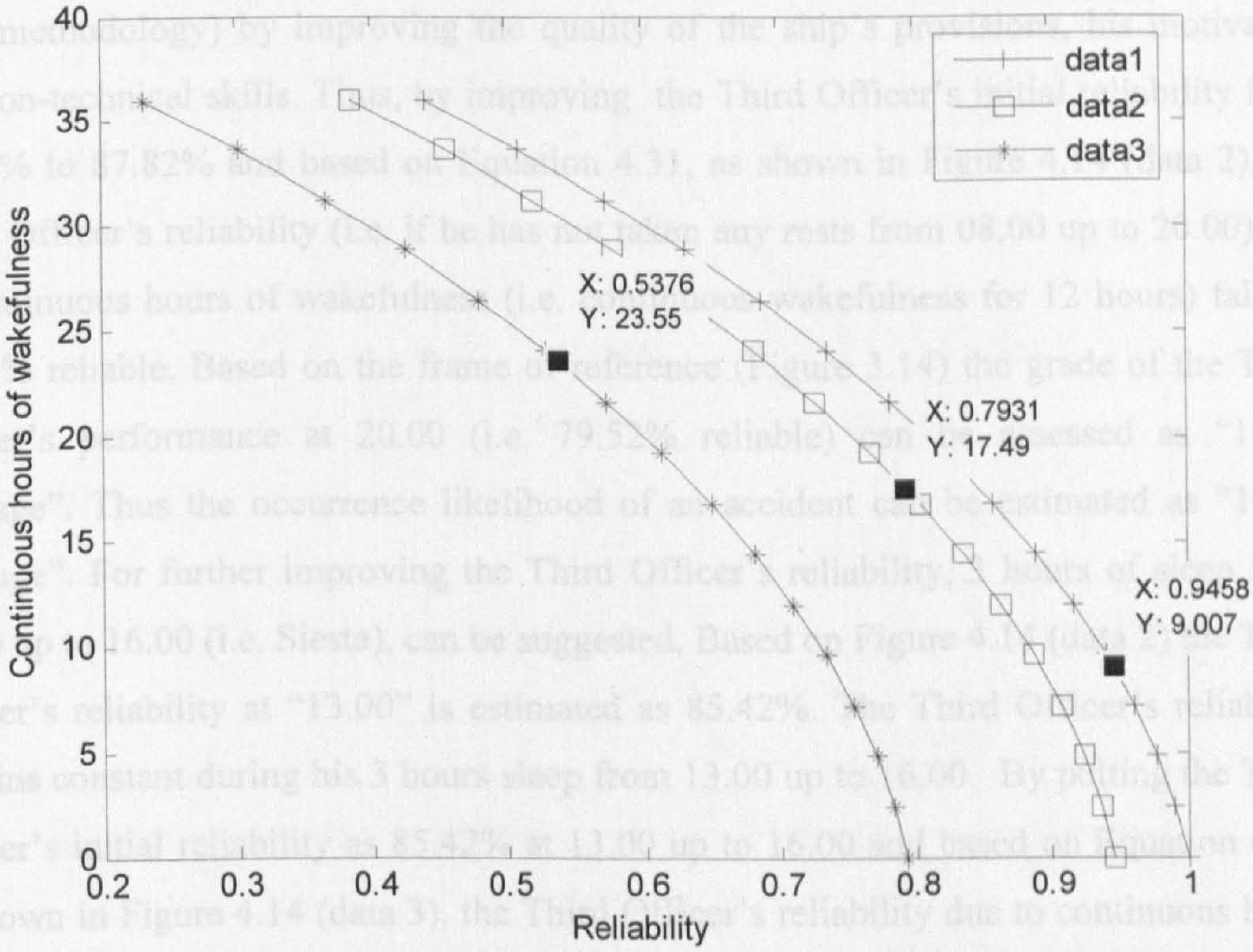

Figure 4.13: Captain's Reliability versus Continuous Hours of Wakefulness

4.7. Results and Discussions

Based on the guidelines which are followed by many shipping companies, the Third Officer conducts his duties (i.e. watch keeping in the bridge) from "08.00" up to "12.00" and from "20.00" up to "24.00". Based on the above information and Figure 4.7, The Third Officer's reliability was evaluated as 72.31% reliable at "08.00". Based on Equation 4.31, as shown in Figure 4.14 (data 1), the Third Officer's reliability (i.e. if he has not taken any rests from 08.00 up to 20.00) due to continuous hours of wakefulness (i.e. continuous wakefulness for 12 hours) falls to 64.02% reliable. Based on the frame of reference (Figure 3.14) and Equation 3.20 the grade of the Third Officer's performance at "20.00" (i.e. 64.02% reliable) can be assessed as "20% Low" and "80% Fairly Low". Thus the occurrence likelihood of an accident can be estimated as "20% High" and "80% Fairly High". As discussed previously in Section 3.11.2 (i.e. control options), the Third Officer's reliability can be increased from 75% to 90%

(based on the *FER* methodology, Table 3.22) or from 72.31% to 87.82% (based on the *FBN* methodology) by improving the quality of the ship's provisions, his motivation and non-technical skills. Thus, by improving the Third Officer's initial reliability from 72.31% to 87.82% and based on Equation 4.31, as shown in Figure 4.14 (data 2), the Third Officer's reliability (i.e. if he has not taken any rests from 08.00 up to 20.00) due to continuous hours of wakefulness (i.e. continuous wakefulness for 12 hours) falls to 79.52% reliable. Based on the frame of reference (Figure 3.14) the grade of the Third Officer's performance at 20.00 (i.e. 79.52% reliable) can be assessed as "100% Average". Thus the occurrence likelihood of an accident can be estimated as "100% Average". For further improving the Third Officer's reliability, 3 hours of sleep from 13.00 up to 16.00 (i.e. Siesta), can be suggested. Based on Figure 4.14 (data 2) the Third Officer's reliability at "13.00" is estimated as 85.42%. The Third Officer's reliability remains constant during his 3 hours sleep from 13.00 up to 16.00. By putting the Third Officer's initial reliability as 85.42% at 13.00 up to 16.00 and based on Equation 4.31, as shown in Figure 4.14 (data 3), the Third Officer's reliability due to continuous hours of wakefulness (i.e. continuous wakefulness for 4 hours) falls to 83.56% reliable at 20.00. Based on frame of reference (Figure 3.14) the grade of the Third Officer's performance at 20.00 (i.e. 83.56% reliable) can be assessed as "28.8% Average" and "71.2% Fairly High". Thus the occurrence likelihood of an accident can be estimated as "28.8% Average" and "71.2% Fairly Low". By improving the Third Officer's reliability owing to 3 hours of sleep (from 13.00 up to 16.00) the occurrence likelihood of an accident can be reduced from "100% Average" to 28.8% Average" and "71.2% Fairly Low".

Evaluation of seafarers' performance can not only be used for developing a preventative measure against hazards but also against security incidents. It is noteworthy to mention that in order to identify and take preventive measures against security incidents in a port as well as at sea and for ensuring the performance of all ship security duties (i.e. controlling, monitoring and supervising), the grade of seafarers' performance is highly significant. Thus, by improving seafarers' reliability not only the occurrence likelihood of an accident can be reduced but also the grade of security can be enhanced.

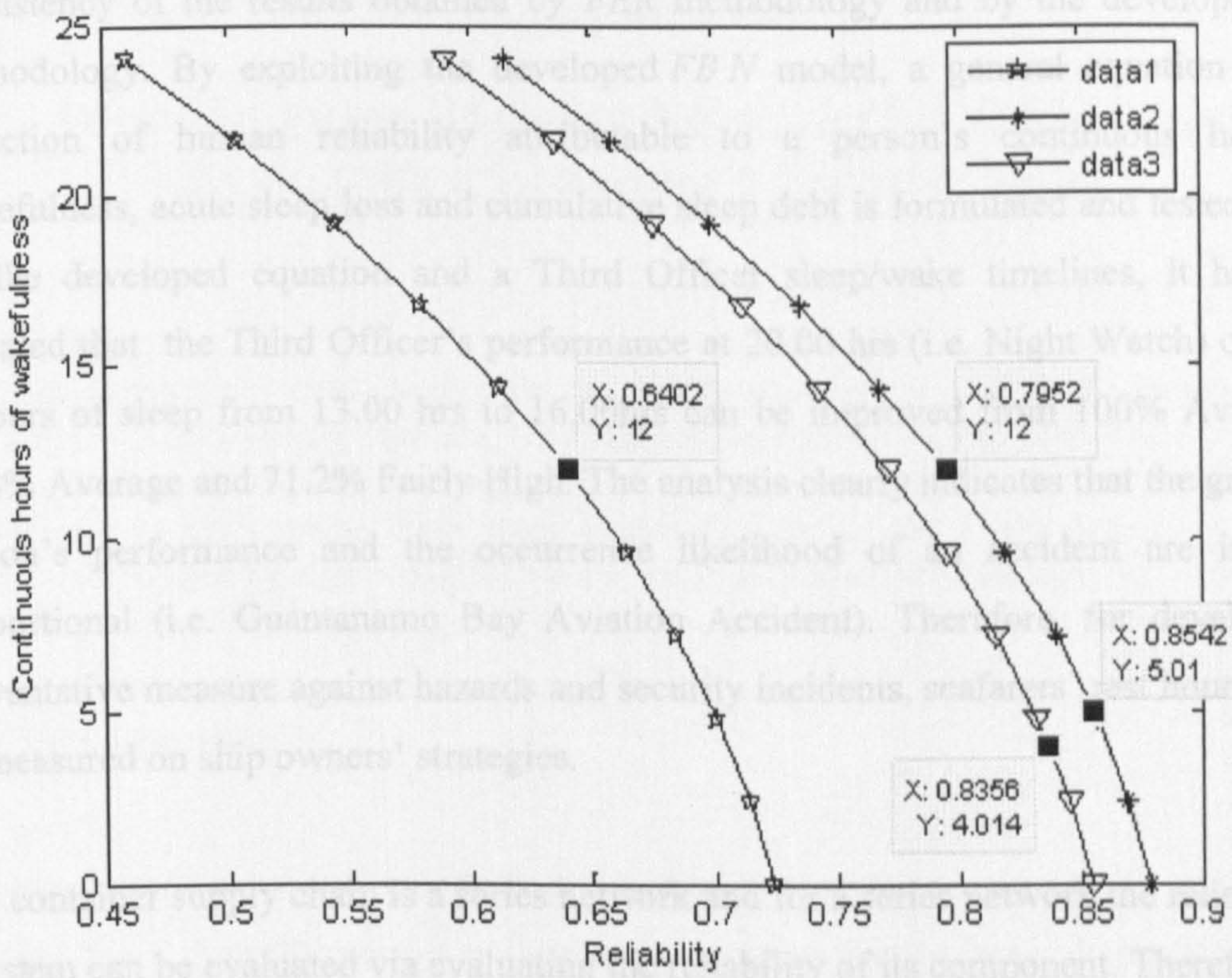

Figure 4.14: Third Officer's Reliability versus Continuous Hours of Wakefulness

4.8. Conclusion

Within the previous chapter and based on the detailed and comprehensive review of root causes for human error a generic model with a hierarchical structure for evaluating the seafarers' reliability, by using fuzzy logic and *ER* approach, was constructed and those significant criteria that are influencing the seafarers' reliability were found. Accordingly, control options to enhance seafarers' reliability were suggested.

Within this chapter, firstly, the developed *FER* model in the previous chapter is converted to a *FBN* model to deal with the dependencies between criteria. Secondly, a new and novel approach to pre-processing of input data that allows the use of standard *BN* techniques and software tool for evaluating the seafarers' reliability is constructed. Thirdly, a *symmetric model* to enable the wider application of *FBN* in a generic mode is created. The model applies *FBN* construction to allow researchers to appreciate a novel attempt of unifying possibility and probability theories by introduction of the proposed *FBN* approach. The developed *FBN* methodology validated by confirming the consistency of the results obtained by *FER* methodology and by the developed *FBN* methodology. By exploiting the developed *FB N* model, a general equation for the reduction of human reliability attributable to a person's continuous hours of wakefulness, acute sleep loss and cumulative sleep debt is formulated and tested. Based on the developed equation and a Third Officer sleep/wake timelines, it has been revealed that the Third Officer's performance at 20.00 hrs (i.e. Night Watch) owing to 3 hours of sleep from 13.00 hrs to 16.00hrs can be improved from 100% Average to 28.8% Average and 71.2% Fairly High. The analysis clearly indicates that the grade of a person's performance and the occurrence likelihood of an accident are inversely proportional (i.e. Guantanamo Bay Aviation Accident). Therefore, for developing a preventative measure against hazards and security incidents, seafarers' rest hours should be measured on ship owners' strategies.

The container supply chain is a series network and for a series network the reliability of a system can be evaluated via evaluating the reliability of its component. Therefore, it is essential to develop a model for evaluating the reliability of the container supply chain via aggregating its components' reliability. The developed methodology within this chapter can be used as a tool for aggregating the reliability of the supply chain's components. Furthermore, the developed model for evaluating a seafarer's reliability can be used as a tool for calculating a containership's reliability.

Chapter Five

Adopting Fuzzy Bayesian Network (FBN) Model for Evaluating a Container's Security Score

Summary

The aim of this study is to employ the set of data elements (i.e. importer security filling and shipping documents) that are provided electronically twenty four hours prior to a vessel loading to exploit a mathematical decision making model for evaluating a container's security score. This study makes full use of the Fuzzy Bayesian Network (FBN) advantages by exploiting a conceptual and sound methodology for evaluating a container's security score.

5.1. Introduction

Sea transportation plays a major role in most international trade and much of economic growth. More than 90 percent of international cargo moves through seaports, which have an approximately 99 percent contribution to the economy of the world (Branch, 1996). Seaports around the world can be described as the kernel of commercial activities from which cities, national capitals, and thriving hinterland have emerged (Ramani, 1996). In so many countries, container transport, especially container sea transport, has become a widely used transport method of great importance. At the beginning of 2006, the world container port traffic totalled 336.1 million Twenty Feet Equivalent Units (TEUs) and the ports of developing countries and territories handled 137.0 million TEUs, or 40.7% of the total (UNCTAD, 2006). Following the 9/11 attacks, it was well established that sea transportation is vulnerable to a wide variety of crimes against persons or property; and it can be used as a channel for the movement of weapons of mass destruction, hostile operations, and various types of contraband by terrorists. Thus the IMO moved very quickly to circulate new international requirements to strengthen marine security. The International Ship and Port Facility Security (ISPS) code was adopted in December 2002 and entered into force worldwide on the first of July 2004 (IMO, 2003). The purpose of the code is to provide a standardised, consistent framework for evaluating risk, enabling governments to counteract changes in threat with changes in vulnerability for ships and port facilities (IMO, 2002).

5.2. Container Supply Chains

A container supply chain (CSC) can be subdivided to two types of flow; the first one is called information flow and the other physical flow. A physical cargo flow means the physical movements of cargo from place to place and from mode to mode.

CSC includes dozens of stakeholders who can physically come into contact with containers and their contents or are potentially related with the container trade and transportation. As shown in Figure 5.1, at the commencement of every container journey there is an originating shipper most often a manufacturer. There are hundreds of thousands of manufacturers around the world and many of them are active in international trade. These manufacturers may produce high enough volumes that they can ship full container loads (*FCL*) directly. In this case, the shipment is palletised and/or packed into a container within the manufacturing site and will be transported by road or rail either directly to a port, or to an intermediary's premises. Most of the manufacturers, however, produce less than full container load (*LCL*) shipments that must be consolidated before being shipped by sea. In this case, the shipment will be consolidated with others and transported to a multi-modal stacking area or to a port (OECD, 2003). Buying agents and/or freight forwarders serve as the most common intermediaries between originating shippers and ocean carriers. While many freight forwarders handle *FCL* shipments for their clients, their principal task turns the assembly and consolidation of *LCL* shipments into full containers. They also facilitate the entire international trade transaction by serving as agents with other transport intermediaries, the customs and other government agencies, banks and consignees. In some cases, the forwarders will negotiate each transaction on behalf of shippers while in other case the forwarders will be the principal agents contracting with the shippers. When forwarders offer multiple services in a logistics chain, other parties also offer these individually (i.e. customer brokers, truckers/rail carriers, warehouse agents, etc.) (ibid). While in transit, the container may be stationary for various periods of time as trucks are stopped on the roadside and/or container-carrying trains are assembled in freight yards (ibid). Once in ports, the container is sent to a stacking area before it is placed immediately next to a vessel on the jetty. Even within the port area, a container may be moved several times as required by port operators and/or the customs (ibid). After being placed on board, the container can be removed and transhipped through another port onto another vessel before arriving at its destination port. Here again, the container may be moved several times for customs clearance and temporary storage while waiting to be picked up and carried by road or rail to its final destination. The shipment may again transit several intermediaries' facilities where the container is unpacked and the palletised shipments it contains are distributed to the final consignees (ibid).

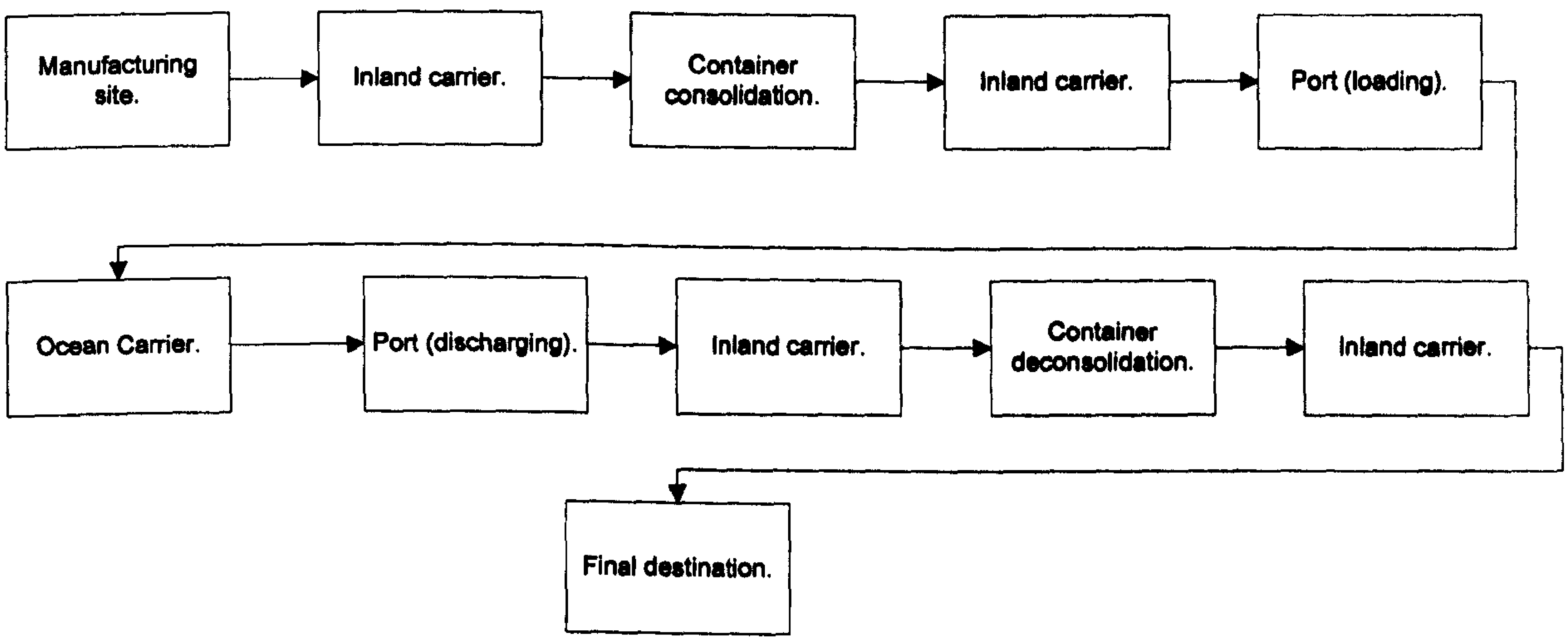

Figure 5.1: Container Supply Chain

5.3. Security of Container Supply Chains

Supply chain security has materialised as an area of vital importance for both the exporters and importers of the freight transportation system. This importance is in large part due to the economic importance of global international trade. Possible future terrorist attacks on the U.S, or any other global countries, may make use of the international and/or domestic freight transportation system, and such attacks may have devastating consequences in terms of fatalities and economic destruction (O'Hanlon *et al.*, 2002). For instance, "the economic impact on U.S supply chains due to higher shipping costs, increased travel times, increased inventories, border delays, and other changes as a direct result of the 9/11 terrorist attacks is estimated to be $150 billion per year" (Bernasek, 2002).

Security-based disruptions can occur at various points along the supply chain. Containers are one of the major sources of security concerns and they have been used to smuggle illegal immigrants, weapons, and drugs. Recent events have created a fundamental shift in thinking regarding the types of threats that may affect supply chain systems. Supply chain and freight transportation security now typically refers to a state of protection against various terrorism threats, most notably the weapon of mass destruction (WMD) as the freight transport vehicle (e.g. container, ship, air-craft, train, truck). The consequences of the use of a WMD or discovery of such a device in a container can be serious. "Estimates suggest that a WMD explosion and the resulting port closure could cost $1 trillion, while a twelve-day closure following discovery of an un-detonated WMD could cost $58 billion" (O'Hanlon *et al.*, 2002). Smuggling of terrorists and terrorist weapons using freight containers is another major threat. It is noteworthy to mention that security against terrorist threats, similar to security against narcotics smuggling or security against hazardous materials spills, is a public good in the parlance of economics. Market forces alone may not provide motivation for firms to protect themselves against supply chain terrorism threats. Since the likelihood is supposed to be very small and potential consequences are difficult to measure, firms are unlikely to bear protection costs. However, the potential societal impact of terrorist attacks to supply chains and/or the transportation infrastructure supporting supply chains is high, and therefore societies have begun to employ regulation, as revealed in Appendix 1, to ensure some degree of supply chain security (Savelsberg *et al.*, 2004).

5.4. Data Requirements for Container Supply Chains Security

In addition to the 24-hour advance cargo rule (19 CFR 4.7(a)), as revealed in Appendix 1, the Custom and Border Protection (CBP) proposed to require an additional set of data elements to be produced twenty four hours prior to vessel loading for maritime cargo destined to the U.S (CBP, 2009). The rules came into effect on 26th January 2009 and full enforcement took effect on 26th January 2010. Bases on the current rule, the importer is responsible for filling the first 10 data elements (i.e. importer security filling (ISF)) and the ocean carrier is responsible for filling the "plus 2" data elements.

The aim of this research is to employ (10+2) data elements and cargo manifest to exploit a model for measuring a container's security score (CSS). The accuracy of the security score depends on the degree of partnership with different parties which are involved in international exports and imports. A partnership with importers, exporters, shipper and carriers facilitates a reduction in risk because it will provide the information about who is moving goods and containers. The success of such a programme depends on the degree of confidence of a government in its partners. To overcome the mentioned deficiency, the best solution is to involve the classification societies on behalf of contracting governments to regularly evaluate and audit the companies and the commercial premises (e.g. manufacturing site, container stuffing locations, warehouses) from a security point of view. Thus by assistance of classification societies, security scores of manufacturing sites, container consolidation facilities and warehouses, as shown in Appendix 4, can be evaluated internationally. Accordingly for a decision making process the security scores as well as the names and addresses (i.e. ports, manufacturers, manufacturing sites, container consolidation centre, and warehouses) should be accessible internationally to administrators.

Within this chapter it is assumed the commercial operators and premises (i.e. manufacturers, ports, consolidators, de-consolidators, and warehouses) are certified. Based on the basic physical security requirements and procedural security standards, as shown in Appendix 4, the security score can be evaluated and accordingly a certificate can be issued by the classification societies on behalf of governments. Furthermore, this certificate is only valuable if regular monitoring and auditing is carried out by an independent competent body such as a reputable classification society.

The 10 data elements that are readily available in current logistics processes and have to be filled by an importer and methodologies for evaluating the reliability of different parties (e.g. manufacturer, exporter, importer, etc.) are listed in the following sub-sections.

5.4.1. Manufacturer Name and Address

The first data element that has to be filled by an importer is the name and address of the entity that last manufactures, produces, or grows the imported commodity (CBP, 2009). If the container is stuffed within the manufacturing site, then the manufacturing site is the primary point of vulnerability in CSCs where goods can be tampered with, or hazardous materials can be packaged and concealed as the product is being prepared for the shipment (Kumar and Verruso, 2008). The security measures (i.e. the basic physical security requirements and procedural security standards) that should be taken to reduce threats, as well as other illicit activity (e.g. smuggling, counterfeit goods) are listed in Appendix 4. Furthermore, if the manufacturer is the exporter of a shipment, then the manufacturer should be assessed for the export readiness. The methodologies for calculating the reliability of a manufacturer and its perimeter from security point of view are shown in Appendix 4.

5.4.2. Exporter/ Consignor/ Seller Name and Address

The second data element that has to be filled by an importer is the last named overseas sellers, consignors, or exporters addresses on the transaction invoice or purchase order (CBP, 2009). Based on Zakner and Belisa (2004)'s research a questionnaire to assess the exporter's reliability from business and security point of view, as shown in Appendix 4, is designed and adapted.

5.4.3. Container Stuffing Location

The third data element that has to be filled in by an importer is the physical overseas location (i.e. street, city, country) where the goods were stuffed into the container prior to the closing of the container (CBP, 2009). For a *LCL* shipment or if final packaging and consolidation is not performed in a factory or a manufacturer's perimeter, it will usually take place at a warehouse or a staging area. At this stage, illicit activity can occur while products are being consolidated into a large shipping load. Based on McNicholas (2008)'s research a questionnaire to assess the reliability of the container stuffing location from a security point of view, as shown in Appendix 4, is designed and adapted. It is noteworthy to mention that, when a container is stuffed at more than one location and/or more than one container is on a single bill of lading, all of the stuffing location for the goods listed on a bill of lading must be provided (ISF, 2009).

5.4.4. Ship to Name and Address

The fourth data element that has to be filled in by an importer is the named party and the address on the transaction that will physically receive the merchandise, may be different from the consignee (e.g. de-consolidator, warehouse) (CBP, 2009). Based on McNicholas (2008)'s research a questionnaire to assess the reliability of a warehouse or de-consolidator's perimeter from a security point of view, as shown in Appendix 4, is designed and adapted.

5.4.5. Commodity Harmonized Tariff Schedule (HTS) Number

The fifth data element that has to be filled in by an importer is the HTS number. HTS codes are the language of international trade and can be used to calculate and assess duties, taxes, determine import and export admissibility and conduct risk assessment and targeting. The first 6 digits are used universally and each country may then add to original six digits to suit its own tariff and statistical needs (Taxation and Customs union, 2009). For instance the HTS number for bearing housings, incorporating ball or roller bearings is 8483200000.

5.4.6. Consignee Number

The sixth data element that has to be filled in by an importer is the consignee number. The consignee number is the unique identifying number of the entity to which the goods are to be consigned (CBP, 2009). For the parties without the destination's country social security numbers in this instance, the passport number, country of issuance and date of birth is accepted. In practice most of bills of lading are consigned "to order" which means the importer can authorise someone to collect the goods.

5.4.7. Consolidator Name and Address

If it is applicable, the seventh data element that has to be filled in by an importer is the name and address of the consolidator. The consolidator's address identifies the physical location of cargo, which may differ from the usual manufacturer or shipper premises (CBP, 2009). In other words the consolidator is the party who stuffs the container or arranges for the stuffing of the container. If the manufacturer is the party that stuffs the container or arranges for the container to be stuffed, then the manufacturer is the consolidator.

5.4.8. Importer

For custom purpose the party who makes (or on whose behalf an agent or a broker makes) the importer declaration, and who is liable for the payment of duties (if any) on the importer goods, is called the importer (ISF, 2009). Normally this party is named either as the consignee in the shipping document and/or as the buyer in the exporter's invoice. The eighth data element that has to be filled in by an importer is the last named buyer and addresses 24 hours prior to foreign loading (CBP, 2009).

For custom purposes the entity responsible for the following is called the importer of record "IOR" (ISF, 2009):

1. Ensuring the imported goods comply with local laws and regulations.
2. Filling a completed duty and associated document.
3. Paying the assessed import duties and other taxes on those goods.

In most cases, the ultimate consignee and importer of record are one and the same. However, in some cases the exporter's custom broker may be the importer of record and another party may be the ultimate consignee. The ninth data element that has to be filled in by an importer is the IOR number (CBP, 2009). For the parties without the destination's country social security numbers in this instance, the passport number, country of issuance and date of birth is accepted (ISF, 2009).

It is noteworthy to mention that, within this chapter the party causing the goods to enter the limit of a port and being ultimately responsible for the complete and timely filling of the ISF is called the importer. Based on the number of containers inspected, reviewed information about an importer's compliance with customs laws and regulations and violation history, the reliability of an importer can be measured as follows:

- If an importer is importing to a concerned country for the first time, then due to uncertainty the prior reliability of the importer can be assigned as 50% reliable and 50% unreliable (i.e. $R_{Pim} = 0.5$).

- If an importer is importing to a concerned country and no violation with customs laws and regulations, by means of scanning or screening of "N" consecutive containers, is observed, then the posterior reliability of an importer can be evaluated as follows:

$$R_{im} = R_{Pim} + \delta \qquad (5.1)$$

R_{im} stands for posterior reliability of an importer, δ stands for increment of reliability of an importer due to observation of no violation with customs laws and regulations through inspection or scanning of "N" consecutive containers, and R_{Pim} stands for prior reliability of an importer. It is obvious that the maximum possible value for an importer's reliability is one (i.e. 100% reliable). Therefore if δ approaches to its maximum possible value, then R_{im} approaches to one. Based on Equation 5.1, the value of δ_{max} can be evaluated as follows:

$$\delta_{max} = 1 - R_{Pim} \qquad (5.2)$$

If "N" stands for the number of consecutive containers selected by an authorised group for inspection, then by selecting the value of "N" as high as possible and by observation of no violation with customs laws and regulations the degree of trust to a concerned importer may be maximised. Thus, a mathematical relationship (i.e. an exponential distribution) between δ and N can be suggested as follows:

$$\frac{d\delta}{dN} = \frac{1}{C} \times \frac{1}{N} \qquad (5.3)$$

C is a constant and based on the security requirement its value can be assigned by an authorised group (e.g. CBP). If the value of N within Equation 5.3 approaches to infinity, then the right hand side of the equation approaches to zero and accordingly δ approaches to its maximum value. Equation 5.3 can be integrated as follows:

$$\int d\delta = \int \frac{1}{C} \times \frac{1}{N} \times dN$$
$$\delta = \frac{Ln(N)}{C} + C_1 \qquad (5.4)$$

C_1 is a constant and to avoid bias its value can be assigned as zero. To evaluate *"N"*, let us assume *"C=6"* and prior reliability of an importer is 0.5. Based on Equations 5.2 and 5.4 the values of δ_{max} and *"N"* are evaluated as 0.5 and 20 respectively. Thus, the number of the consecutive containers for inspection should be selected by an authorised group is equal to 20. It is noteworthy to mention that for *"C=10"* the value of *"N"* is evaluated as 150.

The possibility that a supposedly legitimate export and import company after a number of years problem free shipping, might attempt to smuggle the illicit material exists. To overcome this deficiency some containers may be randomly selected for inspection as follows:

$$N + (n-1) \times K < \Phi \leq N + n \times K$$
$$1 \leq n \leq \frac{M-N}{K} \qquad (5.5)$$

"M" stands for the total number of containers estimated to be imported weekly/monthly or annually by an importer to a concerned country, n is a natural number, Φ stands for a random container that may be selected for inspection, K is a constant and based on security level its value can be assigned by an authorised group, "*(100/K) %*" stands for the percentage of containers selected for random inspection. Assume "*n=1, M=200, K=5 and N=20*". Based on Equation 5.5, from 21st to 25th container (if their security scores are within the acceptable limit), one container at random (e.g. 24th) may be selected for inspection. This procedure can continue for other values of n (i.e. $n = 2, 3, 4, 5, \ldots, 36$). Thus, apart from N (i.e. the

number of consecutive containers selected by an authorised group for inspection), "*(100/K) %*" (i.e. 20% for $K=5$) of unexamined containers $(M - N)$ should be inspected.

$$Total\ number\ of\ containers\ should\ be\ selected\ for\ inspections = N + \frac{M-N}{K} \quad (5.6)$$

- If through inspection or scanning of many containers or examination of their ISF a violation with customs laws and regulations is observed, then the posterior reliability of an importer can be evaluated as follows:

$$\begin{aligned} R_{im} &= R_{Pim} - \Omega \\ R_{im} &\leq 0 \Rightarrow R_{im} = 0 \end{aligned} \quad (5.7)$$

Ω stands for decrement of reliability as a result of a non-compliance and its value can be evaluated by a fuzzy set of non-compliance ($\tilde{\Omega}$) and by means of Equations 3.14-3.19. The fuzzy set of non-compliance ($\tilde{\Omega}$) can be evaluated as follows:

$$\begin{aligned} &\tilde{\Omega} = \{(\beta_1, High),(\beta_2, Fairlyhigh),(\beta_3, Medium),(\beta_4, Firlylow),(\beta_5, Low)\} \\ &\sum_{i=1}^{5} \beta_i = 1 \\ &C_{new} = \beta_1(C+5) + \beta_2(C+4) + \beta_3(C+3) + \beta_4(C+2) + \beta_5(C+1) \end{aligned} \quad (5.8)$$

C_{new} stands for new value of C due to a non-compliance, $\beta_1, \beta_2, \beta_3, \beta_4$ and β_5 stand for belief degrees. Let us assume "$C=6$" and prior reliability of an importer is 0.5, based on Equations 5.1 and 5.4, by scanning of 10 consecutive containers and by observation of no violation with the customs laws and regulations the importer's reliability can be evaluated as 0.883. Based on Equations 5.7-5.8 and 3.14-3.19, if through the random inspection of the 11^{th} container a noncompliance with customs laws and regulations is observed, by assuming the grade of the noncompliance as 100% fairly low, the values of Ω and C_{new} can be evaluated as 0.25 and 8 respectively. Accordingly the importer's reliability can be evaluated as 0.633 and based on Equations 5.2 and 5.4 the values of δ_{max} and "N" are evaluated as 0.367 and 19 respectively. Thus, due to a minor mistake the total number of consecutive containers selected for inspection is increased from 20 to 30 (i.e. 11+19). It is noteworthy to mention that, by assuming the grade of the noncompliance as 100%

high, the importer's reliability is evaluated as zero and the number of consecutive containers should be selected by an authorised group for inspection can be increased from 20 to 59874.

5.4.9. Country of Origin

The tenth data element that has to be filled in by an importer is the country of origin. Based on "CFR 19 102.11, Subpart B-rule of origin", the country of origin of a good is the country in which the good is wholly obtained or produced (CBP, 2009). Within this chapter the country of origin is the country in which the container supply chain is initiated (i.e. the good is produced, stuffed inside a container and sealed, stored in a warehouse, carried by an inland carrier and transported to a port). For measuring the reliability of a country the effect of environment on reliability of a country from a security point of view can be categorised as the political, economical, social and natural ones. Major and familiar environmental effects are listed as follows (CLSCM, 2003):

- Socio-political reasons, such as wars, regulatory changes and protests.
- Geo-political reasons, such as the disorganisation of country's union.
- Economical reasons, such as economic crisis, currency fluctuation and other cyclical downturns.
- Natural reasons, such as earthquake, flood and diseases.

For measuring the reliability of a country from an economical point of view the gross domestic product (GDP) can be assigned as a basic measure of a country's overall economic performance. GDP per capita may therefore be viewed as an approximate indicator of a nation's prosperity, while GDP per employed person can provide a general picture of a country's productivity (U.S Department of Labour, 2009). For measuring and comparing the reliability of different countries, GDPs must be converted to a common unit value. Purchasing power parities (PPPs) are currency conversion rates that allow GDPs to be expressed in a common unit value (U.S Department of Labour, 2009):

"A PPP for a given country is a ratio, in which the numerator is the number of national currency units needed to purchase a basket of goods and services in that country and the dominator is the number of currency units needed to purchase a similar basket of goods and service in the base country (i.e. United State)".

Based on the U.S Department of Labour (2009) report, as shown in Figure 5.2, the GDP per employed person for 17 countries converted to U.S dollars using PPPs is illustrated.

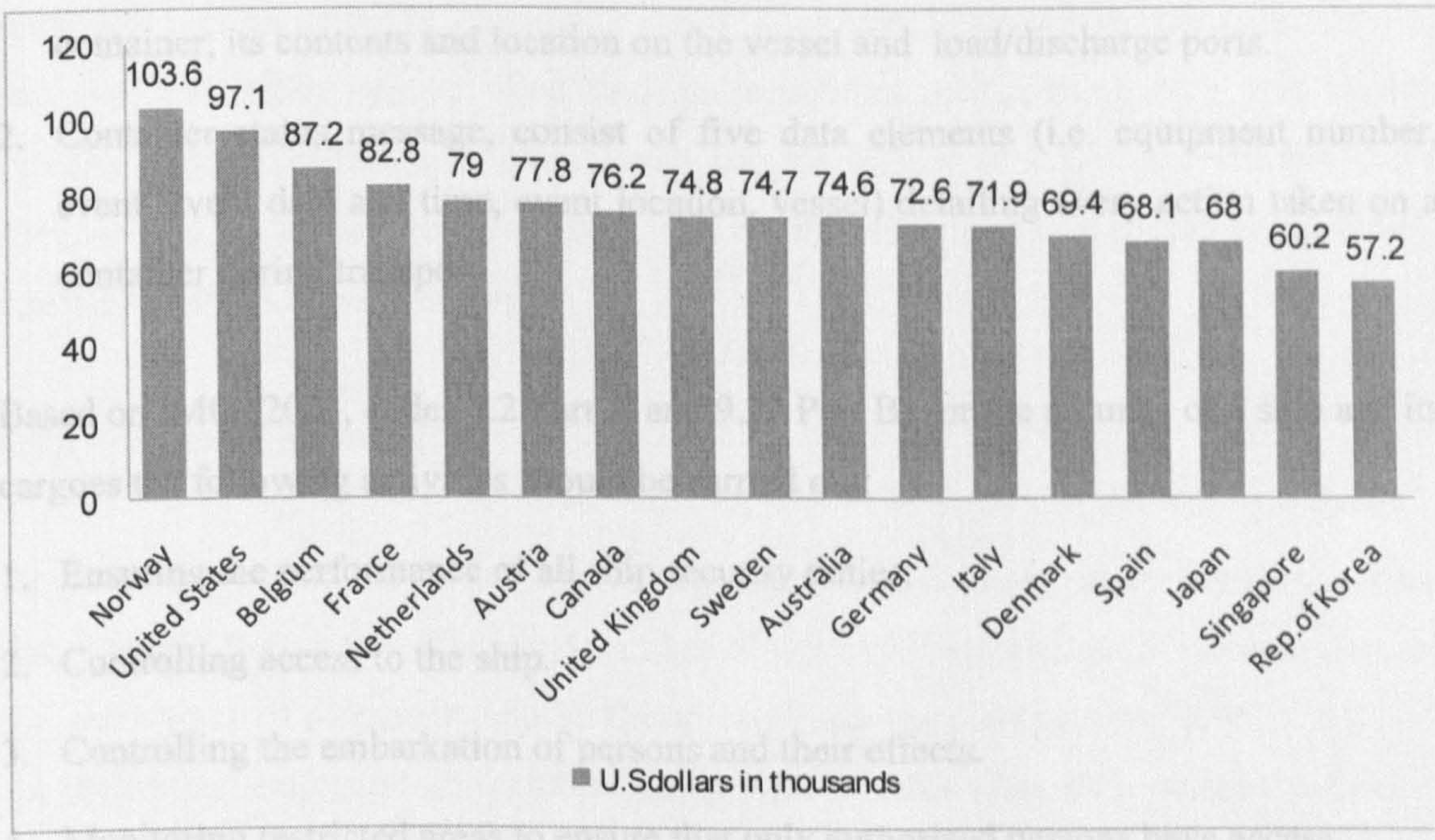

Figure 5.2: GDP per Employed Person, 2008 Converted to U.S dollars using 2008 PPPs

[Source: U.S Department of Labour, 2009]

Based on Figure 5.2 and from an economical point of view, by assigning the reliability of Norway as 100% reliable, the reliability of any other country from economical point of view (i.e. R_{ec}^{CO}) can be evaluated as follows:

$$R_{ec}^{CO} = \frac{GDP\ per\ Employed\ Person}{103.6} \qquad (5.9)$$

For instance, the reliability of Spain from an economical point of view can be evaluated as 65.7% reliable.

5.4.10. Ocean or Sea Carriers

In addition to the ten data elements outlined in Sub-Sections 5.4.1-5.4.9, ocean carriers should provide the following two additional data sets to complete the security filling (CBP, 2009):

1. Vessel stow plans, consist of nine data elements (i.e. the vessel name, vessel operator, voyage number, container operator, equipment number, equipment size/ type, stow position, Hazmat-UN code, vessel location) concerning the vessel, the container, its contents and location on the vessel and load/discharge ports.
2. Container status message, consist of five data elements (i.e. equipment number, event, event date and time, event location, vessel) detailing every action taken on a container during transport.

Based on IMO (2003, codes 7.2 Part A and 9.27 Part B) for the security of a ship and its cargoes the following activities should be carried out:

1. Ensuring the performance of all ship security duties.
2. Controlling access to the ship.
3. Controlling the embarkation of persons and their effects.
4. Monitoring restricted areas to ensure that only authorised persons have access.
5. Monitoring of deck area and area surrounding the ship.
6. Supervising the handling of cargo and ship's stores.
7. Ensuring the security communication is readily available.
8. Routine checking of cargo, cargo transport units and cargo spaces prior to, and during cargo handling operations.
9. Check to ensure that cargo being loaded matches the cargo documentation.
10. Checking of seals or other methods used to prevent tampering.

Containerships often stop at various seaports to discharge and load containers. Furthermore, the containership's transits through various routes and ports pose different levels of security risk. Thus, if the above mentioned tasks are not performed successfully, for instance the containers are not routinely checked for seals or signs of tampering, the degree of risk will be increased. Therefore, the security of a container is directly proportional to the reliability of ocean or sea carriers. The four most important persons, who are dealing with the cargo as well as the security of a ship, are Master, Chief Officer, Second Officer and Third Officer. Accordingly, the reliability of an ocean carrier can be evaluated by aggregation of Master's, Chief Officer's, Second Officer's and Third Officer's reliability. The methodology for evaluating a seafarer's reliability was presented in Chapters 3 and 4. The fuzzy input sets for the assessment of seafarers' reliability can be filled through inspection and auditing of a port facility security officer (PFSO) and a port state control officer (PSCO). Accordingly for a decision making process the fuzzy input sets for the concerned ship should be accessible internationally to administrators.

5.4.11. Inland Carriers

Based on Figure 5.1, an inland carrier (e.g. truck) is a primary means for transporting cargo to and from ports. The large number of trucks at major container ports increases the probability of a terrorist attack. Based on Flynn and Kirkpatrick (2006)'s research the biggest security gap in the transportation system is due to the following essentials:

1. Local truck drivers are poorly paid.
2. There are no mandated standards for seal or locks on containers and criminals have long ago determined how to gain access to a container without even tampering with the seal.

Furthermore, if a terrorist attempts to infiltrate a container the two most likely approaches are (Flynn *et al.*, 2006):

1. Individual terrorist to become truck drivers.
2. A terrorist cell to set up its own shipping company.

To overcome the above deficiencies, as will be shown in Figure 5.7, the following can be suggested:

1. A maritime worker's identification card for a truck driver, based on his back ground and history can be issued.
2. A truck driver's photo, licence and identification card upon entry at port's entrance door should be scanned.
3. Based on "α" value (i.e. a natural number greater than 2 and less than 187, assuming a driver does not visit a port more than once every day, which is designated by PFSO through consultancies with contracting government agencies) and the number of times a driver in the past entered the port within a six months period, his truck and the cargo (i.e. the container) may be selected for inspection. It is noteworthy to mention that due to security reasons, the procedure is to be initiated every six months. For instance, if a driver has entered the port for 120 times within the past six months, by termination of the six months period the number of times of his entrance should be automatically reset to zero.
4. Based on licences numbers of those drivers previously entering the port within a six months period, some numbers at random will be selected for inspection on a daily basis.

To appreciate the above security barriers, let us assume an importer imports M containers on a daily basis from "country A" to "country B" via sea. At "country A" the containers are palletised within the manufacturer's perimeter and are transported by road via M trucks to the port A. One of the drivers is working with a terrorist group and attempts to send an illicit material to country B by means of gaining access to the container without even tampering with the seal. Based on the value of "α" at day one and day two all the trucks and their containers will be inspected. On the third day and all other consecutive days based on Equations 5.1-5.6, after completion of scanning "N" consecutive containers, if every container's CSS is within the acceptable limit, "$(100/K)$ %" of the reaming containers (i.e. M - N) at random will be scanned. Therefore the probability of his success ($P(S)$) on consecutive days can be evaluated as follows:

$$P(S) \approx [1 - \frac{K}{(K-1)\times(M-N)}] \times P(\alpha) \times P(\xi) \times P(CSS) \qquad (5.10)$$

$P(\alpha)$ stands for probability that the value of "α" is smaller than the number of times a driver entered the port within six months period, $P(\xi)$ stands for the probability that a driver's licence number is not to be selected at random, $P(CSS)$ stands for the probability that the CSS of the concerned container is within the acceptable limit.

5.4.12. Port

There are two types of threats related to ports (MIT, 2007):

1. Direct attacks on the ports themselves.
2. Transport of dangerous materials through ports for use in a terrorist plot elsewhere in a country.

To avoid direct attacks on a port of destination via sea, the best proactive strategy is to measure a container's CSS prior to vessel loading at the loading port. If the CSS is lower than the requirements, the container should be screened at the loading or transitional port. Furthermore, the reliability of an ocean or sea carrier from a security point of view should be considered. To avoid the transport of illicit materials through a port, the terminal operators should routinely check containers for seals or signs of container tampering. Furthermore the inland carrier's security (i.e. Sub-Section 5.4.11) to be considered and the suspicious container should be targeted, scanned and inspected. Within a port the shipping containers may be at risk of tampering, especially if they must sit for extended periods of time before being staged and loaded onto a containership. As a result, the security of the shipping containers depends upon the reliability of a port. Based on McNicholas (2008)'s research a questionnaire to assess the reliability of a port from the security point of view, as shown in Appendix 4, is designed and adapted.

5.5. Methodology

In order not to hamper the logistic process in an intolerable manner, the number of physical checks should be cautiously chosen. The percentage of inspections, as will be shown, may differ from port to port. However, experience has shown that even a limited percentage, coupled with a targeted approach based on risk analysis, can provide an acceptable security level (IAPH, 2002). Based on the CSS result, companies that do more to secure their supply chains, those that go above and beyond the minimal requirements, should be recognised. Accordingly those companies benefit from the increased supply chain security by realising more efficient supply chains, improved use of assets, reduced costs, revenue growth, and reduced pilferage.

Based on ISF filling (i.e. information provided by an importer) and cargo manifest a mathematical decision making model for measuring of a container's CSS can be constructed. As a result, the information provided by an importer as well as an exporter has a significant influence on the model's accuracy. Therefore if an importer's reliability and an exporter's reliability are not 100% reliable, then the evaluated CSS may not be precise. As a result the first "*if-then*" rule is constructed as follows:

- *Rule one: If an importer's reliability and an exporter's reliability are calculated as 100% reliable and CSS is evaluated as 75% reliable and above, then the concerned container may not be scanned or screened.*

Furthermore, most security experts think that, "if terrorists were to use a container, they would be involved in the container stuffing origin of the shipment, and almost certainly affix appropriate container seals or devices to the container" (Maritime Security Expo, 2006). Thus the reliability of a country of origin and the reliability of those premises (i.e. loading ports, warehouses, container consolidation centre, etc.) located within the country of origin are playing an important role in the security of supply chains. The reliability of a loading port, warehouse and container consolidation facility not only depends upon their physical and procedural security standards but also their locations (i.e. country of origin). The influence magnitude of a country of origin's reliability on the reliability of a loading port, warehouse and container consolidation facility is difficult to predict; it can have zero to hundred percent influences at different occasions. As a result the second "*if-then*" rule is constructed as follows:

- *Rule two: If an assessor is uncertain about the reliability of a country of origin (i.e. 50% reliable and 50% unreliable), then he/she should remain uncertain about reliability of loading ports, warehouses and container consolidations' perimeter located within that country.*

Based on the set of data elements (i.e. Importer Security Filling (ISF) and shipping documents) that are provided twenty four hours prior to a vessel loading, security scores of various commercial operators and premises (i.e. manufacturers, manufacturing sites, ports, warehouses, container consolidation and de-consolidation facilities) provided by classification societies through auditing, and ocean or sea carriers' reliability that can be computed by the assessments of PSCO and PFSO, the security score of a container can be evaluated by a *FBN* decision making technique. Based on the available data, as shown in Figure 5.3, all the root causes that are not directly influenced by any other variables are found. All the root causes are then assigned a node each. Furthermore all variables that are directly influenced by the root nodes are discovered. This hierarchical process continues until all variables have a place in the graph and all the parents-child links are accounted by the edge of the graph. The dependency among the variables (i.e. loading port, warehouse, container consolidation facility and country of origin) can be computed by means of Rule two. The *FBN* logic and its mathematical backgrounds were presented in Chapter 4. Furthermore, the network built in Figure 5.3 has been checked for concept of directional separation and it is aligned with the concept of d-separation as discussed in Section 4.2.6. The abbreviations in Figure 5.3 are shown in Table 5.1.

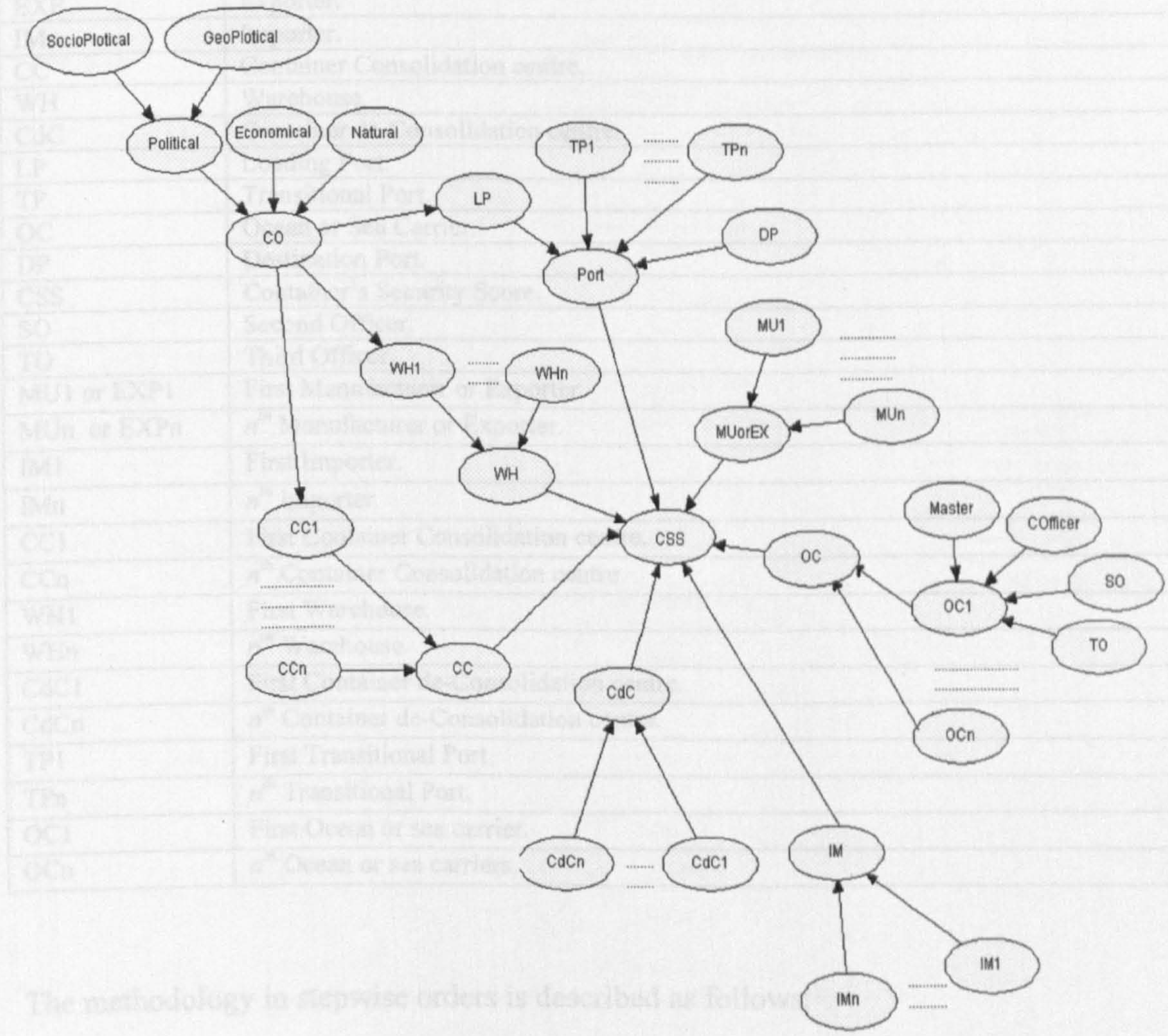

Figure 5.3: Generic Model for Evaluating the CSS

Table 5.1: Table of Abbreviations

Abbreviation	Description
CO	Country of Origin.
MU	Manufacturer.
EXP	Exporter.
IM	Importer.
CC	Container Consolidation centre.
WH	Warehouse.
CdC	Container de-Consolidation centre.
LP	Loading Port.
TP	Transitional Port.
OC	Ocean or Sea Carrier.
DP	Destination Port.
CSS	Container's Security Score.
SO	Second Officer.
TO	Third Officer.
MU1 or EXP1	First Manufacturer or Exporter.
MUn or EXPn	n^{th} Manufacturer or Exporter.
IM1	First Importer.
IMn	n^{th} Importer.
CC1	First Container Consolidation centre.
CCn	n^{th} Container Consolidation centre.
WH1	First Warehouse.
WHn	n^{th} Warehouse.
CdC1	First Container de-Consolidation centre.
CdCn	n^{th} Container de-Consolidation centre.
TP1	First Transitional Port.
TPn	n^{th} Transitional Port.
OC1	First Ocean or sea carrier.
OCn	n^{th} Ocean or sea carriers.

The methodology in stepwise orders is described as follows:

Firstly, the container cargo's information and the manufacture's or the exporter's data, as shown in Figure 5.4, are investigated. If the ISF is accepted, then the manufacturer's or the exporter's reliability, as shown in Appendix 4, can be calculated. For a *LCL* shipment, the same calculation has to be carried out for each individual manufacturer or exporter.

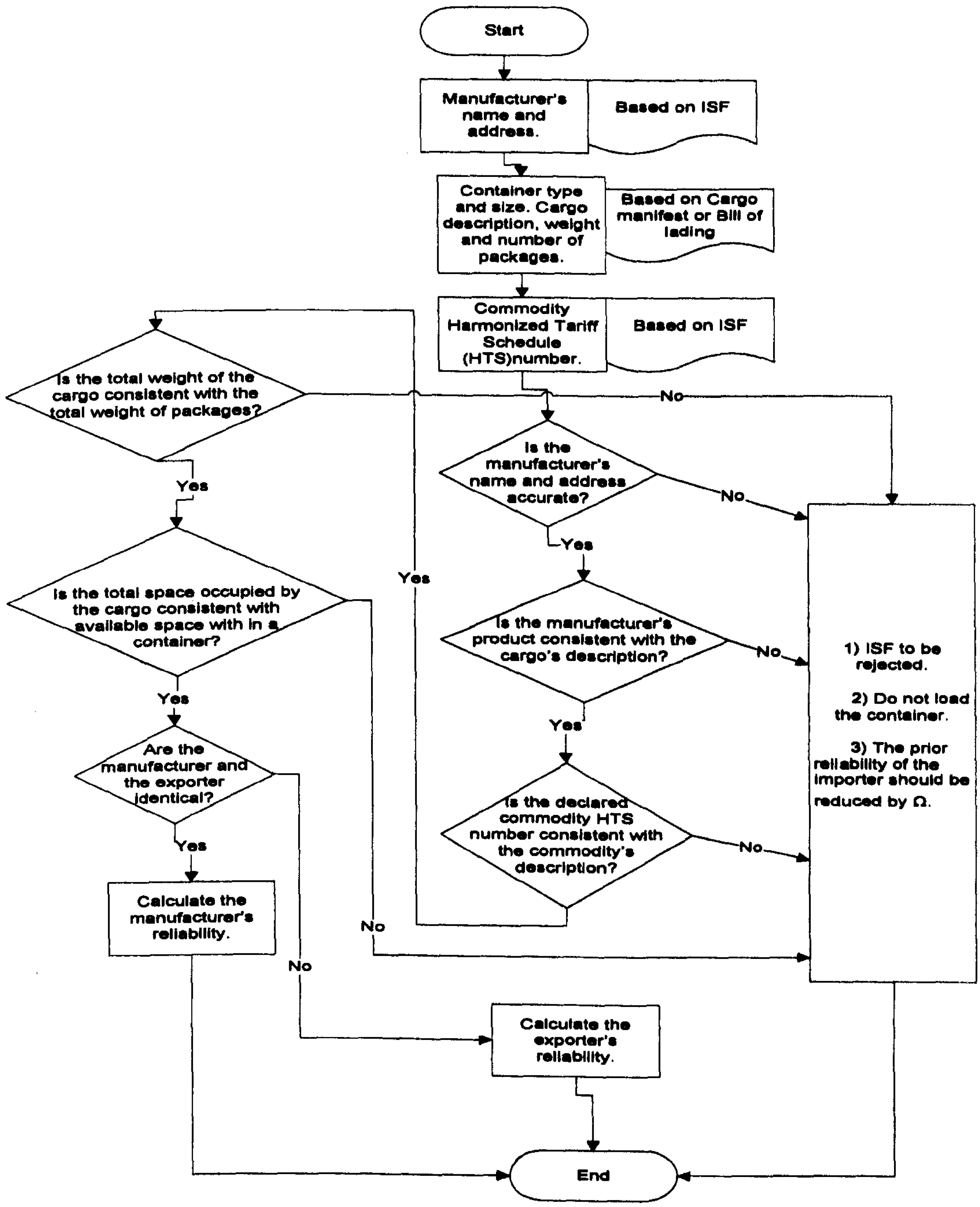

Figure 5.4: An Outline of Security Procedure for Manufacturers or Exporters

Secondly, the name and address of importer (buyer), importer of record and consignee, as shown in Figure 5.5, is investigated. If the ISF is accepted, as shown in Sub-Section 5.4.8, the importer's reliability can be calculated. For a *LCL/LCL* shipment, the same calculation has to be carried out for each individual importer.

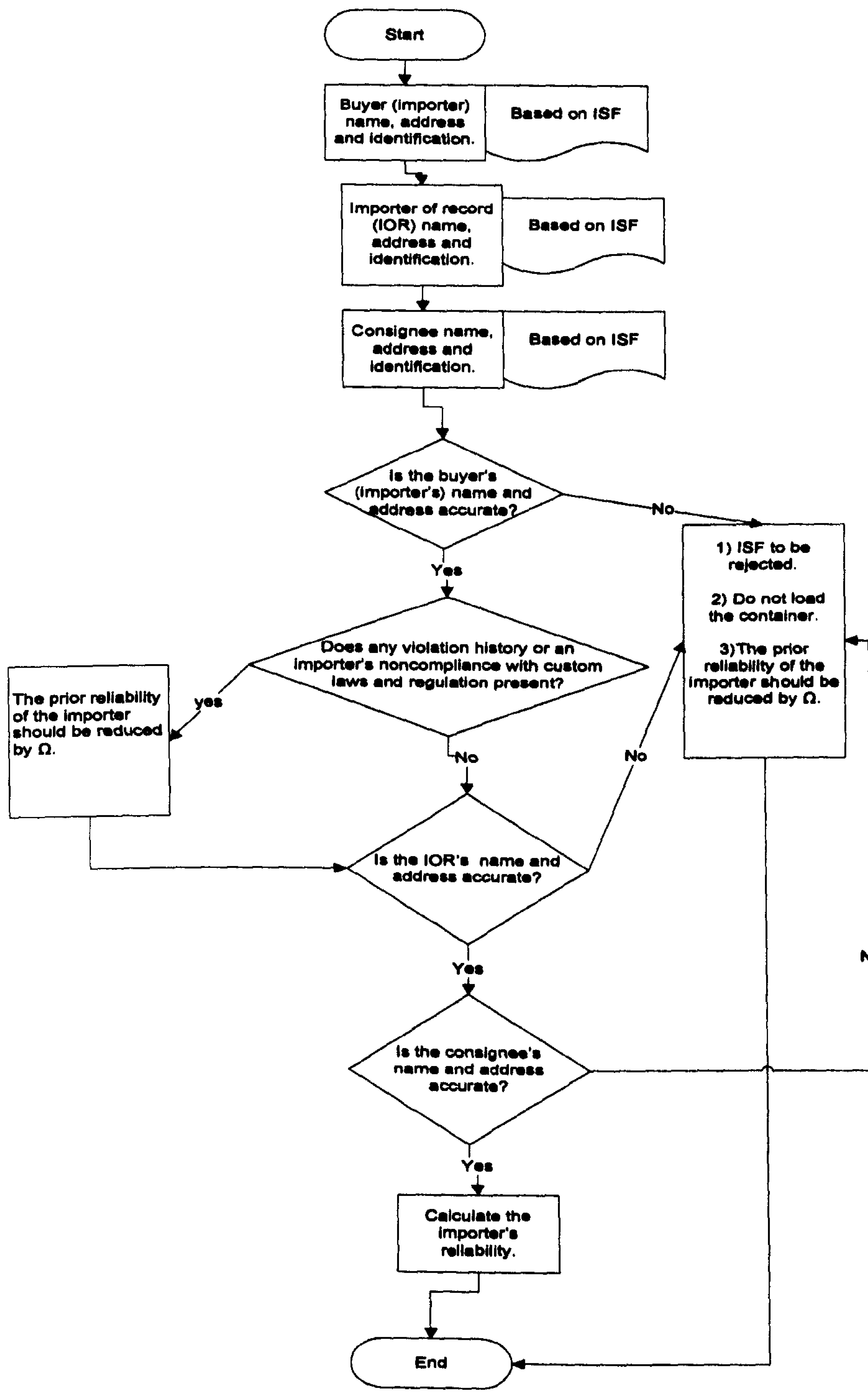

Figure 5.5: An Outline of Security Procedure for Importers

Thirdly, the consolidator and the container stuffing location data, as shown in Figure 5.6, are investigated. If the ISF is accepted, then the reliability of the container stuffing location or the manufacturer's perimeter, as shown in Appendix 4, can be calculated. For a shipment that has been stuffed in multiple locations, the same calculation has to be carried out for each individual stuffing location.

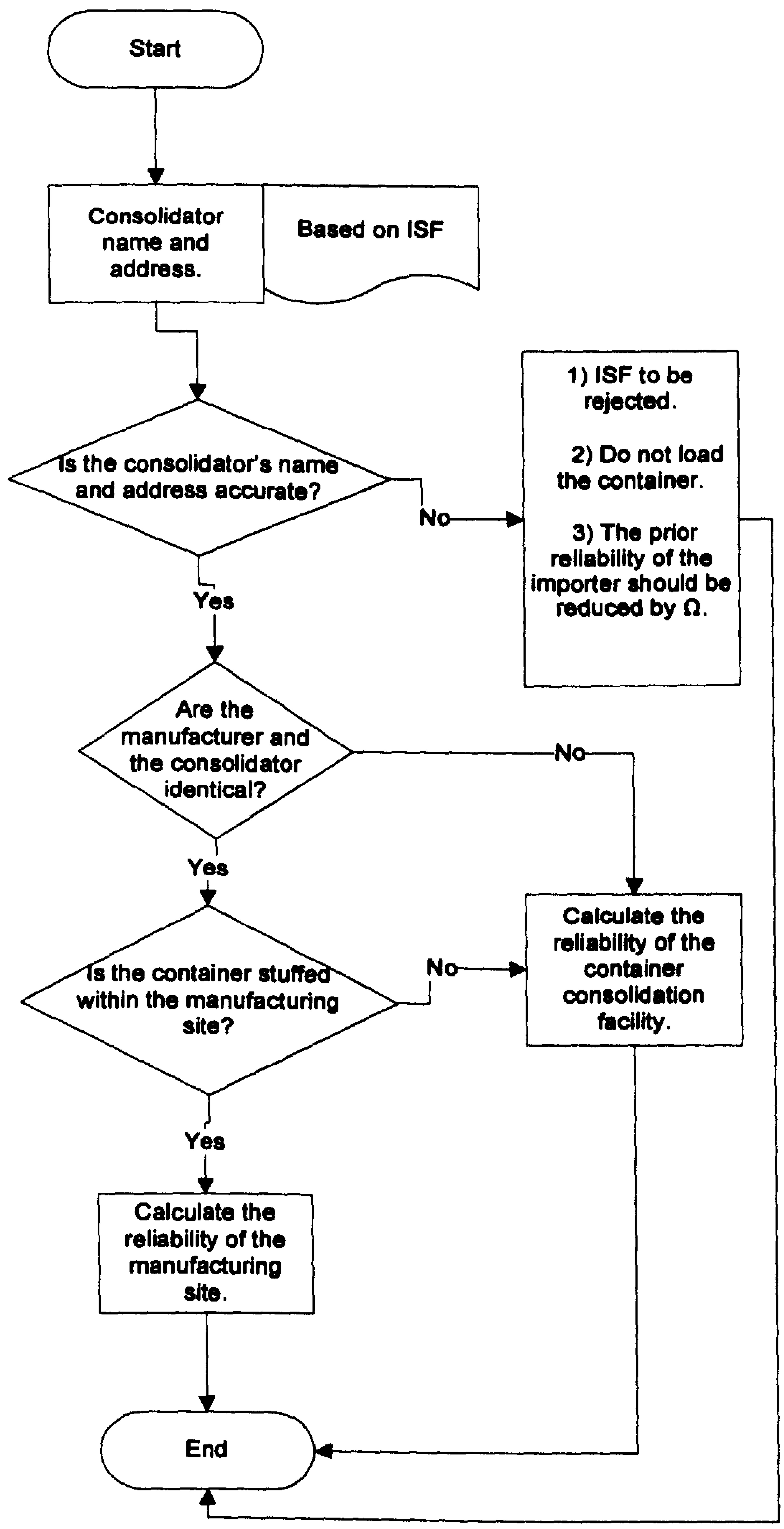

Figure 5.6: An Outline of Security Procedure for Container Consolidation Facility

Fourthly, the container and its seal, as shown in Figure 5.7, are investigated by an authorised person at the loading port. If the container and its seal are secured, then the reliability of the loading port, as shown in Appendix 4, can be calculated. If the same container is discharged and transhipped through another port onto another vessel before arriving at its destination port, the same calculation has to be carried out for each individual transitional port.

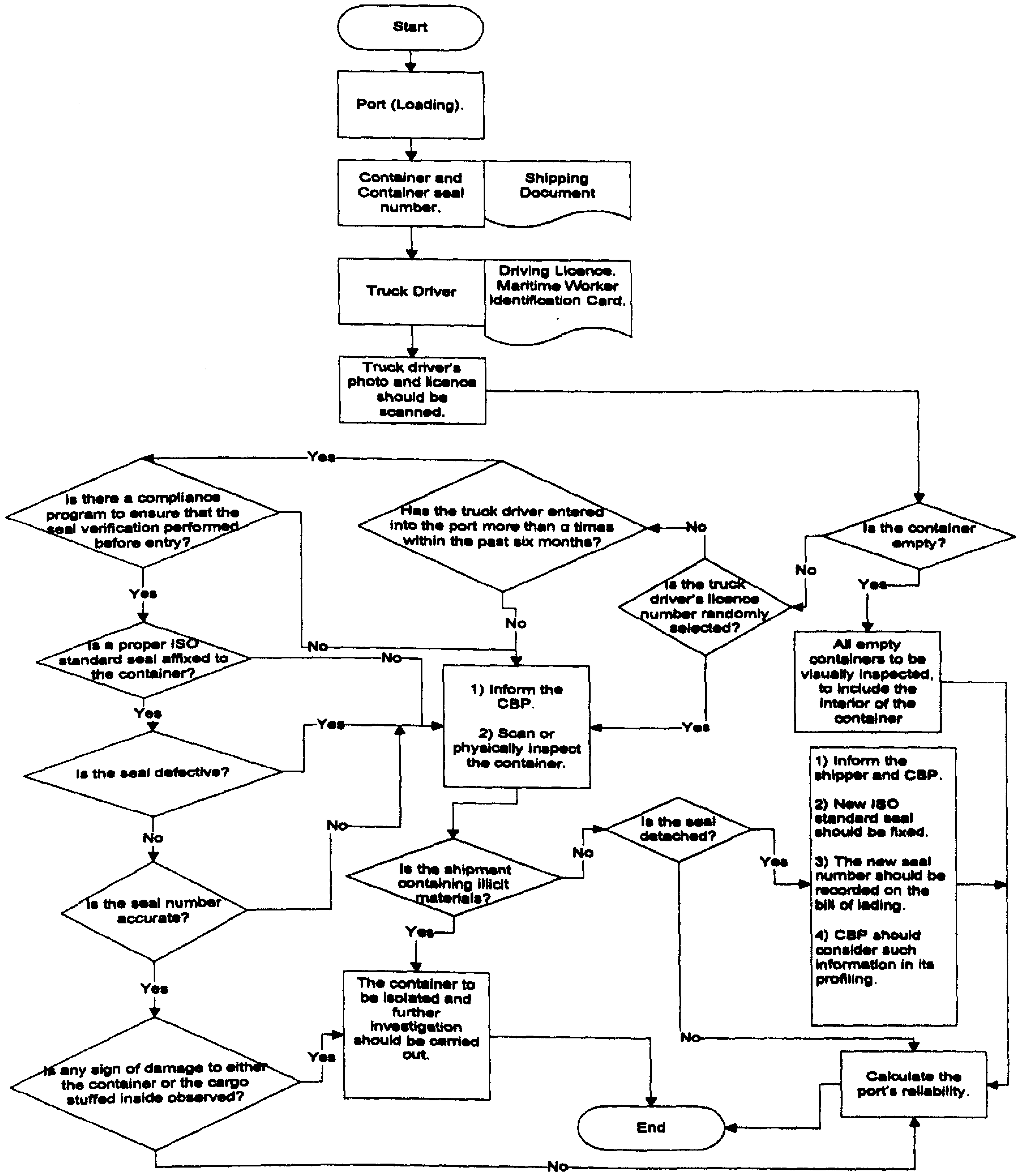

Figure 5.7: An Outline of Security Procedure for Ports

Fifthly, the container and its seal, as shown in Figure 5.8, are investigated by the Chief

Officer or an authorised person. If the container and its seal are secured, then the reliability of the ocean (or sea) carrier, as shown in Sub-Section 5.4.10, can be calculated. If the same container is discharged and transhipped through another port onto another vessel before arriving at its destination port, the same calculation has to be carried out for each individual carrier.

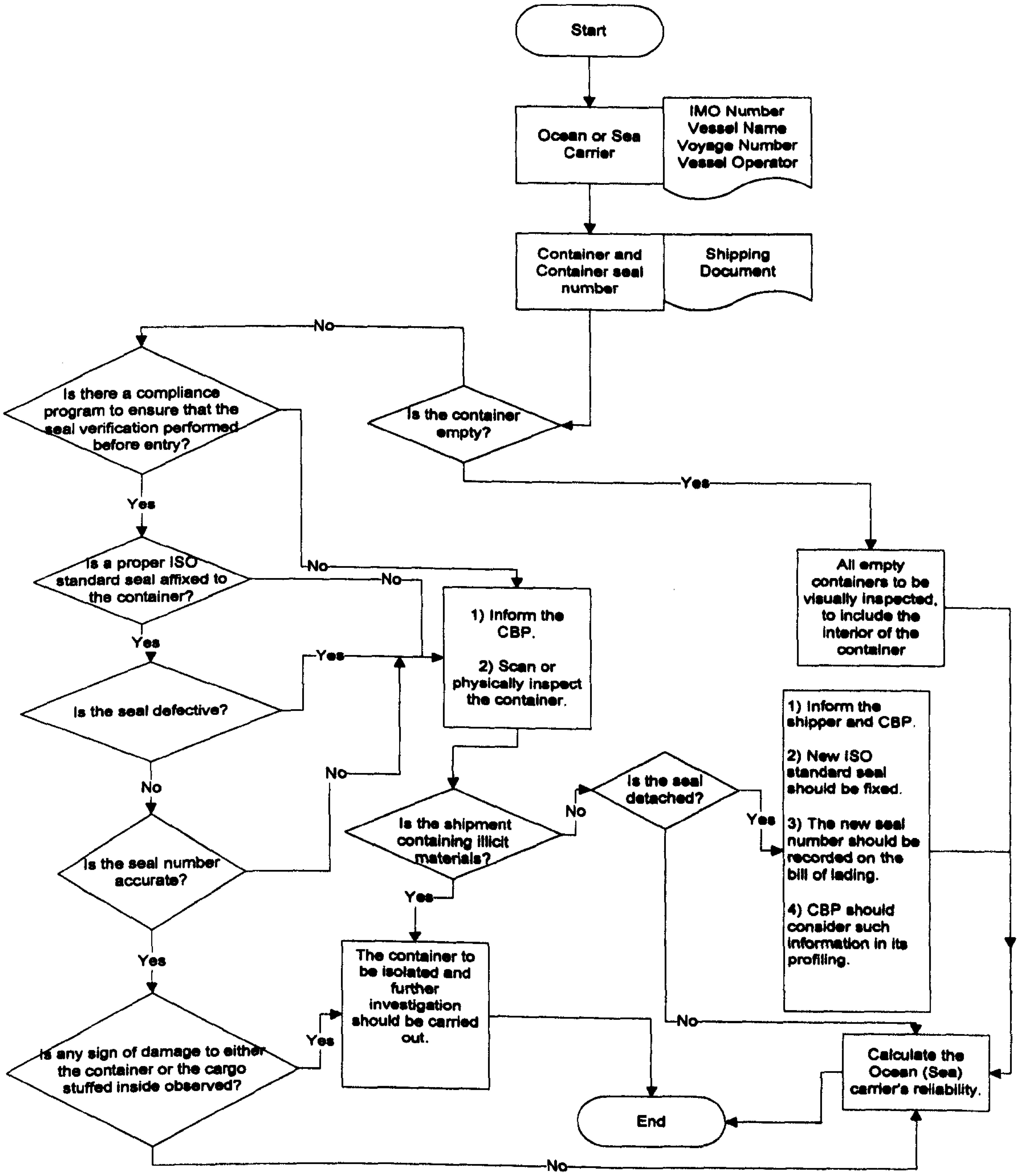

Figure 5.8: An Outline of Security Procedure for Ocean or Sea Carriers

Sixthly, the named party and address, as shown in Figure 5.9, are investigated. If the ISF is accepted, then the reliability of the de-consolidation's perimeter or warehouse, as shown in Appendix 4, can be calculated. For a shipment that has been stored in so many warehouses, the same calculation has to be carried out for each individual warehouse.

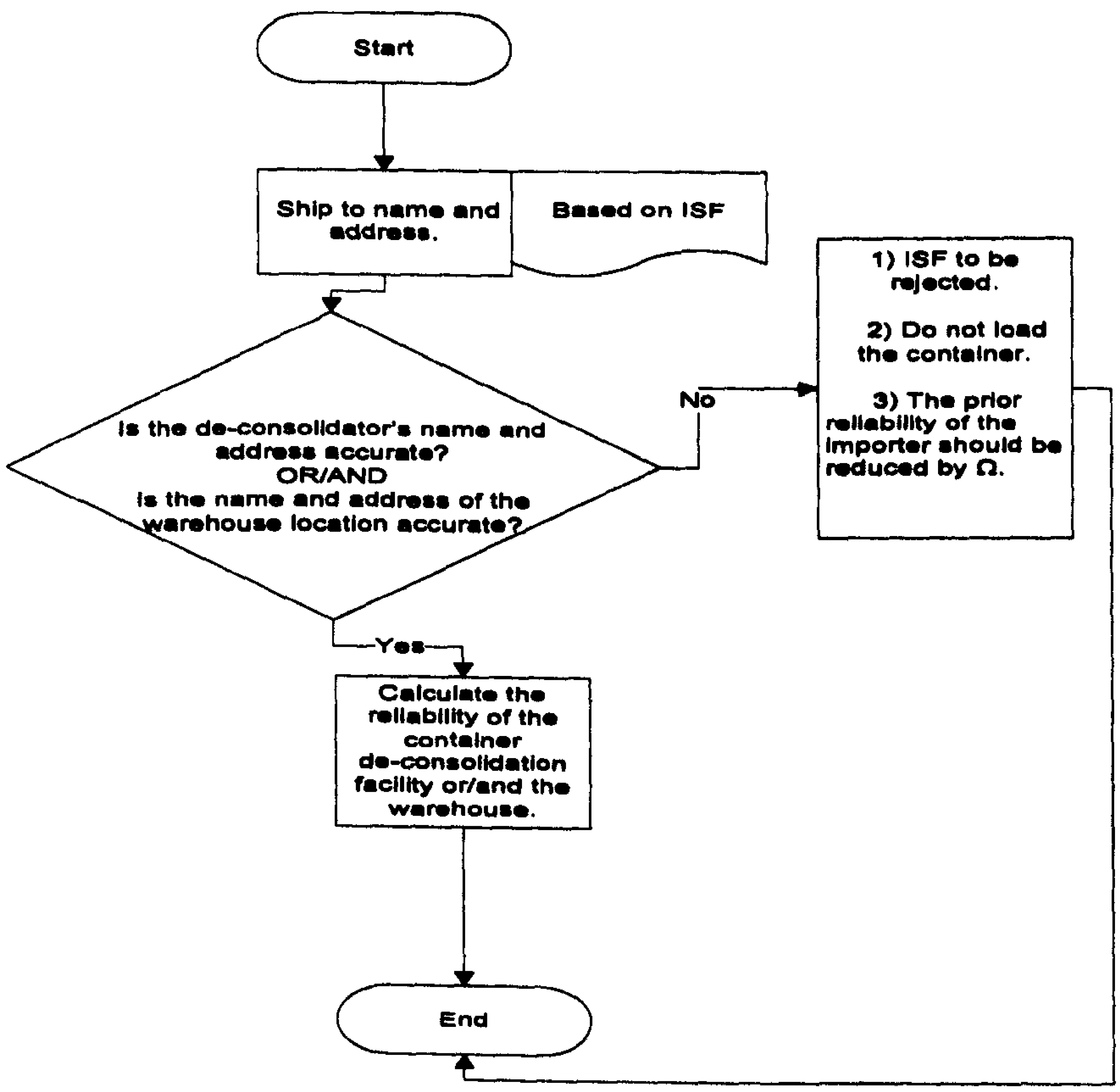

Figure 5.9: An Outline of Security Procedure for de-Consolidation Facility

Seventhly, to obtain the relative importance (influence) of each parent node for its associated child node an *AHP* methodology is used (Section 3.9.4). 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 the "*Symmetric Model*" (Chapter 4).

Eighthly, based on the *FBN* model output (i.e. CSS) and Rule one a decision regarding scanning or not scanning of a container can be made.

Finally, the sensitivity of the *FBN* model will be analysed.

5.6. Test Case

An importer (i.e. *IM*) imports sport shoes by means of 200 containers from country *A* (i.e. *CO*, country of origin) to country *B* (i.e. country of destination). The country of origin is assumed to be 100% reliable. The sport shoes are manufactured by two manufacturers (i.e. *MU1* and *MU2*). The shipment is palletised and packed into a container within a container consolidation centre (i.e. *CC*) and fitted with an ISO standard seal; all 200 containers are stuffed in the same location. The containers kept in a warehouse (i.e. *WH*) for some days are later on transported by inland carriers to port *A* (i.e. LP, loading port). At port *A*, all the containers may be loaded onto a containership (i.e. *OC*) for discharging at port *B* (i.e. *DP*, port of destination). At port *B*, once the containers are cleared by customs, they are de-consolidated at a centre (i.e. *CdC*) and transported by inland carriers to the final destination. Based on information provided electronically by the importer (i.e. ISF and cargo manifest), twenty four hours prior to vessel loading, the security scores of various commercial operators and premises provided by classification societies through auditing and ocean or sea carriers' reliability that can be evaluated by the assessments of PSCO and PFSO, the custom officials at the destination port can measure CSS of each individual container. By help of the proposed methodology (Section 5.5) and based on the generic model for measuring a CSS (Figure 5.3) a specific model for measuring the CSS, as shown in Figure 5.10, can be exploited.

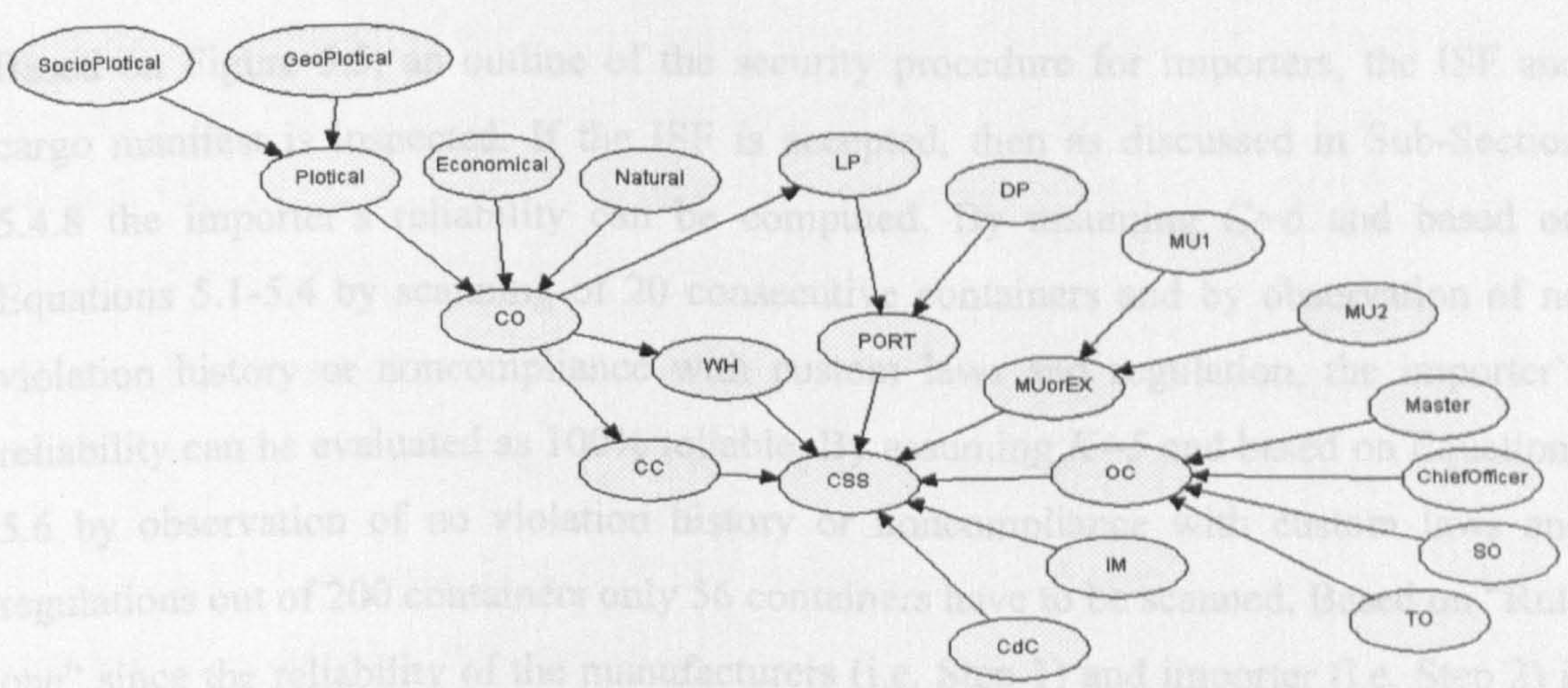

Figure 5.10: Specific Model for Evaluating the CSS

5.6.1. Step 1

Based on Figure 5.4, an outline of the security procedure for manufacturers or exporters, the ISF and cargo manifest is inspected. If the ISF is accepted, then the reliability of each individual manufacturer for the export readiness, as shown in Appendix 4 (Section A4.2) and based on the audit result can be calculated. If both the manufacturers are being exported for the first time and the score of each individual manufacturer is above 84 points (Table A4.2 and Figure A4.3), both the manufacturers are ready to export from the business point of view. However, based on "Rule one" a container cannot be exempted from inspection, until the reliability of exporters or manufacturers is evaluated as 100% reliable. As shown in Appendix 4 (Section A4.2, items 6 and 7) by inspection of the first four containers and observation of no violation history or noncompliance with the custom laws and regulation, the score of *MU1* and *MU2* can be evaluated as 104 points. Based on Figure A4.3 the fuzzy sets for *MU1* and *MU2* can be assessed as follows:

$$\tilde{MU}1 = \{(1, High), (0, Fairlyhigh), (0, Medium), (0, Firlylow), (0, Low)\}$$

$$\tilde{MU}2 = \{(1, High), (0, Fairlyhigh), (0, Medium), (0, Firlylow), (0, Low)\}$$

By means of Equations 3.14-3.19, the reliability of *MU1* and *MU2* can be evaluated as 100% reliable.

5.6.2. Step 2

Based on Figure 5.5, an outline of the security procedure for importers, the ISF and cargo manifest is inspected. If the ISF is accepted, then as discussed in Sub-Section 5.4.8 the importer's reliability can be computed. By assuming $C=6$ and based on Equations 5.1-5.4 by scanning of 20 consecutive containers and by observation of no violation history or noncompliance with custom laws and regulation, the importer's reliability can be evaluated as 100% reliable. By assuming $K=5$ and based on Equations 5.6 by observation of no violation history or noncompliance with custom laws and regulations out of 200 containers only 56 containers have to be scanned. Based on "Rule one" since the reliability of the manufacturers (i.e. Step 1) and importer (i.e. Step 2) is evaluated as 100% reliable. If the other 144 containers' CSS are within the acceptable limit, they may be exempted from inspection.

5.6.3. Step 3

Based on Figure 5.6, an outline of the security procedure for a container consolidation facility, the ISF and cargo manifest is inspected. If the ISF is accepted, then by means of the name and address of the container stuffing location as well as the warehouse the audit result for the concerned premise can be viewed. Assuming the audit scores for the concerned *CC* and *WH* are evaluated respectively as 108 and 106 points and based on Figure A4.1 (Appendix 4) and Equation 3.20 the fuzzy sets for *CC* and *WH* can be assessed as follows:

$$C\widetilde{C} = \{(0, High), (0.6, Fairlyhigh), (0.4, Medium), (0, Firlylow), (0, Low)\}$$

$$W\widetilde{H} = \{(0, High), (0.53, Fairlyhigh), (0.47, Medium), (0, Firlylow), (0, Low)\}$$

By means of Equations 3.14-3.19, the reliability of *CC* and *WH* can be evaluated respectively as 65% and 63% reliable.

5.6.4. Step 4

Based on Figure 5.7, an outline of the security procedure for ports, the container and its seal are investigated by an authorised person at the loading port. If the container and its seal are secured, then by means of the name and address of the loading and discharging ports the audit result of the concerned loading and discharging ports can be viewed. Assuming the audit scores for the concerned *LP* and *DP* are evaluated respectively as 116 and 118 points and based on Figure A4.2 (Appendix 4) and Equation 3.20 the fuzzy sets for *LP* and *DP* can be assessed as follows:

$$L\widetilde{P} = \{(0, High), (0.625, Fairlyhigh), (0.375, Medium), (0, Firlylow), (0, Low)\}$$

$$D\widetilde{P} = \{(0, High), (0.687, Fairlyhigh), (0.313, Medium), (0, Firlylow), (0, Low)\}$$

By means of Equations 3.14-3.19, the reliability of *LP* and *DP* can be evaluated respectively as 66% and 67% reliable.

5.6.5. Step 5

Based on Figure 5.8, an outline of the security procedure for an ocean or sea carrier, the container and its seal are investigated by the Chief Officer or an authorised person. If the container and its seal are secured, by means of the vessel name and IMO number, the latest audit result provided by the assessments of PSCO and PFSO can be viewed. Assuming the latest audit for Third Officer, Second Officer, Chief Officer and Master, as shown in Tables 5.2-5.5, are assessed. The reliability of the Third Officer, Second Officer, Chief Officer and Master, as shown in Table 5.6 and explained in Chapters 3 and 4, can be computed.

Table 5.2: Fuzzy Input Sets for Third Officer

Sub-Criteria Description	*Fuzzy Input Set*
Qualification	{(Excellent, 0), (Very good, 0), (Good, 0.2), (Average, 0.8), (Low, 0)}
Experience	{(Very Good, 0), (Good, 0), (Average, 0.2), (Low, 0.8), (Very Low, 0)}
Specific Training	{(Excellent, 0.2), (Very good, 0.8), (Good, 0), (Average, 0), (Low, 0)}
Environmental States	{(Very Calm, 0), (Calm, 0.5), (Moderate, 0.5), (Rough, 0), (Very Rough, 0)}
Design and Habitability	{(Very Good, 0), (Good, 1.0), (Average, 0), (Bad, 0), (Very Bad, 0)}
Rest Hours	{(Very Good, 1), (Good, 0), (Average, 0), (Low, 0), (Very Low, 0)}
Nutrition	{(Very Good, 0), (Good, 0), (Average, 0.4), (Bad, 0.6), (Very Bad, 0)}
Age	{(Very Young, 0), (Young, 1.0), (Average, 0), (Old, 0), (Very old, 0)}
Stress	{(Low, 0), (Moderate, 1), (High, 0), (Very High, 0)}
Health	{(Very Healthy, 0.5), (Healthy, 0.5), (Mol. Fit, 0), (Unhealthy, 0)}
Communication and Language Skills	{(Very Good, 0), (Good, 0), (Medium, 1.0), (Low, 0), (Very Low, 0)}
Decision Making	{(Very Good, 0), (Good, 0), (Medium, 1.0), (Low, 0), (Very Low, 0)}
Teamwork	{(Very Good, 0), (Good, 1.0), (Medium, 0), (Low, 0), (Very Low, 0)}
Situation Awareness	{(Very Good, 0), (Good, 1.0), (Medium, 0), (Low, 0), (Very Low, 0)}
Motivation	{(Very High, 0), (High, 0.3), (Medium, 0.7), (Low, 0), (Very Low, 0)}
Design and Layout	{(Very Good, 1), (Good, 0), (Average, 0), (Bad, 0), (Very Bad, 0)}

Table 5.3: Fuzzy Input Sets for Second Officer

Sub-Criteria Description	*Fuzzy Input Set*
Qualification	{(Excellent, 0), (Very good, 0), (Good, 1), (Average, 0), (Low, 0)}
Experience	{(Very Good, 0), (Good, 0), (Average, 1), (Low, 0), (Very Low, 0)}
Specific Training	{(Excellent, 0.2), (Very good, 0.8), (Good, 0), (Average, 0), (Low, 0)}
Environmental States	{(Very Calm, 0), (Calm, 0.5), (Moderate, 0.5), (Rough, 0), (Very Rough, 0)}
Design and Habitability	{(Very Good, 0), (Good, 1.0), (Average, 0), (Bad, 0), (Very Bad, 0)}
Rest Hours	{(Very Good, 1), (Good, 0), (Average, 0), (Low, 0), (Very Low, 0)}
Nutrition	{(Very Good, 0), (Good, 0), (Average, 0.4), (Bad, 0.6), (Very Bad, 0)}
Age	{(Very Young, 0), (Young, 1.0), (Average, 0), (Old, 0), (Very old, 0)}
Stress	{(Low, 0), (Moderate, 1), (High, 0), (Very High, 0)}
Health	{(Very Healthy, 0.5), (Healthy, 0.5), (Mol. Fit, 0), (Unhealthy, 0)}
Communication and Language Skills	{(Very Good, 0), (Good, 0), (Medium, 1.0), (Low, 0), (Very Low, 0)}
Decision Making	{(Very Good, 0), (Good, 0), (Medium, 1.0), (Low, 0), (Very Low, 0)}
Teamwork	{(Very Good, 0), (Good, 1.0), (Medium, 0), (Low, 0), (Very Low, 0)}
Situation Awareness	{(Very Good, 0), (Good, 1.0), (Medium, 0), (Low, 0), (Very Low, 0)}
Motivation	{(Very High, 0), (High, 0.3), (Medium, 0.7), (Low, 0), (Very Low, 0)}
Design and Layout	{(Very Good, 1), (Good, 0), (Average, 0), (Bad, 0), (Very Bad, 0)}

Table 5.4: Fuzzy Input Sets for Chief Officer

Sub-Criteria Description	*Fuzzy Input Set*
Qualification	{(Excellent, 0), (Very good, 1), (Good, 0), (Average, 0), (Low, 0)}
Experience	{(Very Good, 0), (Good, 1), (Average, 0), (Low, 0), (Very Low, 0)}
Specific Training	{(Excellent, 1), (Very good, 0), (Good, 0), (Average, 0), (Low, 0)}
Environmental States	{(Very Calm, 0), (Calm, 0.5), (Moderate, 0.5), (Rough, 0), (Very Rough, 0)}
Design and Habitability	{(Very Good, 0), (Good, 1.0), (Average, 0), (Bad, 0), (Very Bad, 0)}
Rest Hours	{(Very Good, 1), (Good, 0), (Average, 0), (Low, 0), (Very Low, 0)}
Nutrition	{(Very Good, 0), (Good, 0), (Average, 0.4), (Bad, 0.6), (Very Bad, 0)}
Age	{(Very Young, 0), (Young, 0), (Average, 1), (Old, 0), (Very old, 0)}
Stress	{(Low, 0), (Moderate, 0), (High, 1), (Very High, 0)}
Health	{(Very Healthy, 0.2), (Healthy, 0.8), (Mol. Fit, 0), (Unhealthy, 0)}
Communication and Language Skills	{(Very Good, 0), (Good, 1), (Medium, 0), (Low, 0), (Very Low, 0)}
Decision Making	{(Very Good, 0), (Good, 1), (Medium, 0), (Low, 0), (Very Low, 0)}
Teamwork	{(Very Good, 0), (Good, 1.0), (Medium, 0), (Low, 0), (Very Low, 0)}
Situation Awareness	{(Very Good, 0), (Good, 1.0), (Medium, 0), (Low, 0), (Very Low, 0)}
Motivation	{(Very High, 0), (High, 1), (Medium, 0), (Low, 0), (Very Low, 0)}
Design and Layout	{(Very Good, 1), (Good, 0), (Average, 0), (Bad, 0), (Very Bad, 0)}

Table 5.5: Fuzzy Input Sets for Master

Sub-Criteria Description	*Fuzzy Input Set*
Qualification	{(Excellent, 1), (Very good, 0), (Good, 0), (Average, 0), (Low, 0)}
Experience	{(Very Good, 1), (Good, 0), (Average, 0), (Low, 0), (Very Low, 0)}
Specific Training	{(Excellent, 1), (Very good, 0), (Good, 0), (Average, 0), (Low, 0)}
Environmental States	{(Very Calm, 0), (Calm, 0.5), (Moderate, 0.5), (Rough, 0), (Very Rough, 0)}
Design and Habitability	{(Very Good, 0), (Good, 1.0), (Average, 0), (Bad, 0), (Very Bad, 0)}
Rest Hours	{(Very Good, 1), (Good, 0), (Average, 0), (Low, 0), (Very Low, 0)}
Nutrition	{(Very Good, 0), (Good, 0), (Average, 0.4), (Bad, 0.6), (Very Bad, 0)}
Age	{(Very Young, 0), (Young, 0), (Average, 1), (Old, 0), (Very old, 0)}
Stress	{(Low, 0), (Moderate, 0), (High, 1), (Very High, 0)}
Health	{(Very Healthy, 0.2), (Healthy, 0.8), (Mol. Fit, 0), (Unhealthy, 0)}
Communication and Language Skills	{(Very Good, 1), (Good, 0), (Medium, 0), (Low, 0), (Very Low, 0)}
Decision Making	{(Very Good, 1), (Good, 0), (Medium, 0), (Low, 0), (Very Low, 0)}
Teamwork	{(Very Good, 0), (Good, 1.0), (Medium, 0), (Low, 0), (Very Low, 0)}
Situation Awareness	{(Very Good, 1), (Good, 0), (Medium, 0), (Low, 0), (Very Low, 0)}
Motivation	{(Very High, 0), (High, 1), (Medium, 0), (Low, 0), (Very Low, 0)}
Design and Layout	{(Very Good, 1), (Good, 0), (Average, 0), (Bad, 0), (Very Bad, 0)}

Table 5.6: Ship Staff s' Reliability

Node's description	*Third Officer*		*Second Officer*		*Chief Officer*		*Master*	
	Reliable	Unreliable	Reliable	Unreliable	Reliable	Unreliable	Reliable	Unreliable
Qualification	0.3865	0.6135	0.5525	0.4475	0.84	0.16	1	0
Experience	0.363	0.637	0.435	0.565	0.88	0.12	1	0
Specific Training	0.796	0.204	0.796	0.204	1	0	1	0
Environmental States	0.64	0.36	0.64	0.36	0.64	0.36	0.64	0.36
Design and Habitability	0.84	0.16	0.84	0.16	0.84	0.16	0.84	0.16
Rest Hours	1	0	1	0	1	0	1	0
Nutrition	0.276	0.724	0.276	0.724	0.276	0.724	0.276	0.724
Age	0.88	0.12	0.88	0.12	0.43	0.12	0.43	0.12
Stress	0.88	0.12	0.88	0.12	0.43	0.12	0.43	0.12
Health	0.94	0.06	0.94	0.06	0.904	0.06	0.904	0.06
Communication and Language Skills	0.44	0.56	0.44	0.56	0.84	0.16	1	0
Decision Making	0.44	0.56	0.44	0.56	0.84	0.16	1	0
Teamwork	0.84	0.16	0.84	0.16	0.84	0.16	0.84	0.16
Situation Awareness	0.84	0.16	0.84	0.16	0.84	0.16	1	0
Motivation	0.5975	0.4025	0.5975	0.4025	0.825	0.175	0.825	0.175
Design and Layout	1	0	1	0	1	0	1	0
Result	0.7229	0.2771	0.7372	0.2628	0.8273	0.1727	0.8636	0.1364

5.6.6. Step 6

Based on Figure 5.9, an outline of the security procedure for the de-consolidation's perimeter, the named party and address are investigated. If the ISF is accepted, then by means of the name and address of the de-consolidation's perimeter (*CdC*) the audit result for the concerned perimeters can be viewed. Assuming the audit score for the concerned *CdC* is evaluated as 110 points and based on Figure A4.1 (Appendix 4) and Equation 3.20 the fuzzy set for *CdC* can be assessed as follows:

$$Cd\widetilde{C} = \{(0, High), (0.67, Fairlyhigh), (0.33, Medium), (0, Firlylow), (0, Low)\}$$

By means of Equations 3.14-3.19, the reliability of *CdC* can be evaluated as 67% reliable.

5.6.7. Step 7

To obtain the relative importance (influence) of each parent node for its associated child node an *AHP* methodology as explained in Section 3.9.4 can be used. In order to conduct the assessment a group of experts, which is composed of three experts is used. To avoid prejudgment, all experts utilized in the assessments are containing both academia and industrial related experience and they are assigned with equal weight.

1. A professor of marine technology who has been involved in the marine and offshore safety research for 20 years.
2. A lecturer and head of maritime studies (Master Mariner) who has been involved in the maritime and marine industry for more than 20 years.
3. A researcher who has been involved in the marine industry (Chief Engineer and Superintendent for fleet and new construction) for more than 20 years.

- Based on the experts' judgment, the first and second manufacturers are equally important. Therefore, they are assigned with equal weight (i.e. 0.5).
- Based on the experts' judgment, the socio-political and geo-political reasons are equally important and they are assigned with equal weight (i.e. 0.5).

- Based on the experts' judgment, for a country of origin the natural, economical and political reasons are equally important and they are assigned with equal weight (i.e. $\frac{1}{3}$).

- Based on the experts if terrorists were to use a container, they would be involved in the container stuffing origin of the shipment (Maritime Security Expo, 2006). Thus, a loading port is moderately more important than a discharge port. Based on Equations 3.7-3.10, their weights can be evaluated as follows:

$$\begin{bmatrix} \omega_{LP} \\ \omega_{DP} \end{bmatrix} = \begin{bmatrix} 0.75 \\ 0.25 \end{bmatrix}$$

The value of consistency ratio (i.e. CR) is computed as 0.

- Based on the authorities and responsibilities to deal with cargoes as well as the security of a ship a pair-wise comparison matrix for the Master, Chief Officer, Second Officer and Third Officer is illustrated in Table 5.7.

Table 5.7: Comparison Matrix for Ship Staff

	Master	Chief Officer	Second Officer	Third Officer
Master	1	1	2	2
Chief Officer	1	1	2	2
Second Officer	0.5	0.5	1	1
Third officer	0.5	0.5	1	1

Based on Equations 3.7-3.10, their weights can be evaluated as follows:

$$\begin{bmatrix} \omega_{Master} \\ \omega_{Chief} \\ \omega_{Second} \\ \omega_{Third} \end{bmatrix} = \begin{bmatrix} 0.3333 \\ 0.3333 \\ 0.1666 \\ 0.1666 \end{bmatrix}$$

The value of consistency ratio (i.e. CR) is computed as 0.

- Based on Figures 5.4-5.9, Rules 1-2, and the experts' judgement a pair-wise comparison matrix for the importer, ocean carrier, ports, warehouse, container consolidation centre, manufacturers or exporters, and container de-consolidation centre is illustrated in Table 5.8.

Table 5.8: Comparison Matrix

	IM	OC	Port	WH	CC	MU or EX	CdC
IM	1	0.2	0.2	0.25	0.25	1	1
OC	5	1	1	2	2	5	5
Port	5	1	1	2	2	5	5
WH	4	0.5	0.5	1	1	4	4
CC	4	0.5	0.5	1	1	4	4
MU or EX	1	0.2	0.2	0.25	0.25	1	1
CdC	1	0.2	0.2	0.25	0.25	1	1

Based on Equations 3.7-3.10, their weights can be evaluated as follows:

$$\begin{bmatrix} \omega_{IM} \\ \omega_{OC} \\ \omega_{Port} \\ \omega_{WH} \\ \omega_{CC} \\ \omega_{MU} \\ \omega_{CdC} \end{bmatrix} = \begin{bmatrix} 0.046863 \\ 0.266062 \\ 0.266062 \\ 0.163643 \\ 0.163643 \\ 0.046863 \\ 0.046863 \end{bmatrix}$$

The value of consistency ratio (i.e. CR) is computed as 0.0069.

Based on the above results, the strength of direct dependence of each child node to its associated parents can be quantified by assigning each child node a *CPT* by using the "symmetric model" (Chapter 4, Section 4.3.3).

5.6.8. Step 8

From the above seven steps, the reliability value of the nodes in Figure 5.10 and their weights are illustrated in Table 5.9. A conditional probability table by means of a "symmetric model" (Chapter 4, Section 4.3.3) is assigned for each child node. The dependency among the variables (i.e. loading port, warehouse, container consolidation's perimeter and country of origin) is evaluated by means of Rule two. Furthermore, the network built in Figure 5.10 has been checked for the concept of directional separation and is aligned with the concept of d-separation as discussed in Section 4.2.6. Accordingly, as shown in Figure 5.11, the value of CSS is computed as 72.85% reliable. Based on Rule one, in this instance all the containers (144 numbers) should be scanned prior to the vessel loading.

Table 5.9: Reliability Value of Nodes

Node's description & weight	Parents Node	Score	Fuzzy Input Set	Reliability	Unreliability	Weight
CC (0.163)	-	108	{(High, 0), (Fairly High, 0.6), (Medium, 0.4), (Fairly Low, 0), (Low, 0)}	0.65	0.35	-
WH (0.163)	-	106	{(High, 0), (Fairly High, 0.53), (Medium, 0.47), (Fairly Low, 0), (Low, 0)}	0.63	0.37	-
Port (0.266)	LP	116	{(High, 0), (Fairly High, 0.625), (Medium, 0.375), (Fairly Low, 0), (Low, 0)}	0.66	0.34	0.75
	DP	118	{(High, 0), (Fairly High, 0.687), (Medium, 0.313), (Fairly Low, 0), (Low, 0)}	0.67	0.33	0.25
OC (0.267)	Master		....	0.8636	0.1364	0.34
	Chief	-	....	0.8273	0.1727	0.33
	SO	-	....	0.7372	0.2628	0.17
	TO	-	....	0.7229	0.2771	0.16
MU or EXP (0.047)	MU_1	84	{(High, 1), (Fairly High, 0), (Medium, 0), (Fairly Low, 0), (Low, 0)}	1	0	0.5
	MU_2	84	{(High, 1), (Fairly High, 0), (Medium, 0), (Fairly Low, 0), (Low, 0)}	1	0	0.5
CdC (0.047)	-	110	{(High, 0), (Fairly High, 0.67), (Medium, 0.33), (Fairly Low, 0), (Low, 0)}	0.67	0.33	-
Importer (0.047)	-	-	....	1	0	-

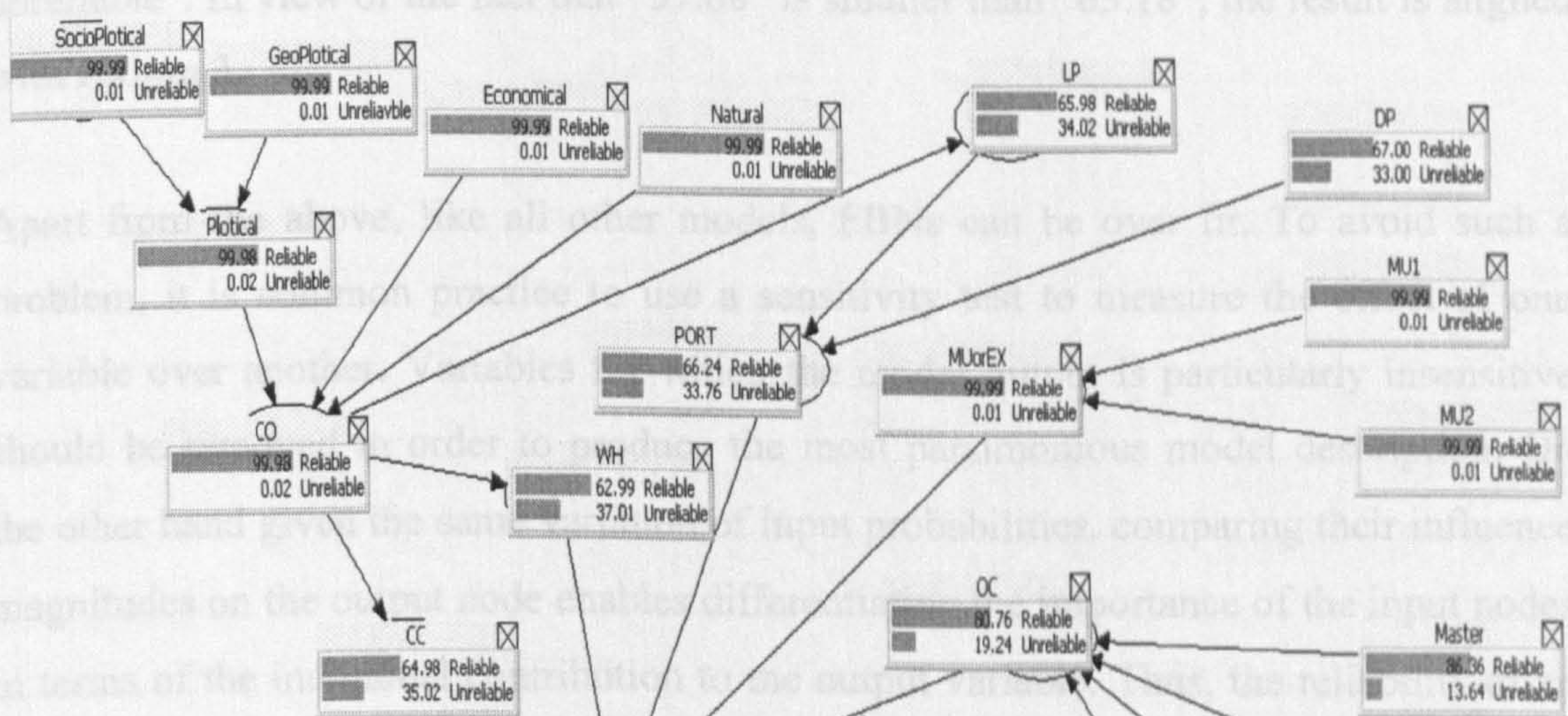

Figure 5.11: Evaluation of Containers' Security Score

5.6.9. Sensitivity Analysis (*Final Step)*

A sensitivity analysis is used to test the logicality of the delivery of the analytical result. Three Axioms introduced in Section 4.4.2 are used. To carry out the research the reliability of all the input variables (16 nodes) as shown in Tables 5.10 and 5.11 is decreased and increased by 5%, 10%, 15% and 20% respectively. Accordingly the results (CSS) as shown in Tables 5.10 and 5.11 are obtained. Based on the obtained results (Tables 5.10 and 5.11) Figure 5.12 is drawn. All the results obtained keep harmony with Axioms 1 and 2. If the reliability of all input variables, as shown in Table 5.10, is decreased by 15% the model output (i.e. CSS) is evaluated as "57.68% reliable" and "42.32% unreliable". By selection of ten input variables (i.e. warehouse, container consolidation's perimeter, Master, Chief Officer, Second Officer, Third Officer, loading port, destination port, fist and second manufacturer) from 16 input variables and by decreasing the reliability of those selected input variables (i.e. ten input variables) by 15% the model output (i.e. CSS) is evaluated as "63.18% reliable" and "36.82% unreliable". In view of the fact that "57.68" is smaller than "63.18", the result is aligned with Axiom 3.

Apart from the above, like all other models, FBNs can be over fit. To avoid such a problem, it is common practice to use a sensitivity test to measure the effect of one variable over another. Variables for which the model output is particularly insensitive should be removed in order to produce the most parsimonious model description. On the other hand given the same variation of input probabilities, comparing their influence magnitudes on the output node enables differentiating the importance of the input nodes in terms of the individual contribution to the output variable. Thus, the reliability of an individual node has been decreased by 10% and 20% respectively while the reliabilities of other input nodes are left unchanged. The results (i.e. CSS) as shown in Table 5.12 are obtained. Based on the obtained results (Table 5.12) the sensitivity of the model output to the same variation of the each individual model input as illustrated in Figure 5.13 is assessed. Based on the analysis, as shown in Table 5.12, the model is not over fit. From Figure 5.13 it is obvious that the model output is more sensitive respectively to the country of origin, ocean carrier and port rather than the other variables.

Table 5.10: Decrement of Nodes' Reliability

Node Description	Decrement of Reliability									
	0%		5%		10%		15%		20%	
	Reliability	Unreliability	Reliability	Unreliability	Reliability	Unreliability	Reliability	Unreliability	Reliability	Unreliability
Socio-political	1	0	0.95	0.05	0.9	0.1	0.85	0.15	0.8	0.2
Geo-political	1	0	0.95	0.05	0.9	0.1	0.85	0.15	0.8	0.2
Natural	1	0	0.95	0.05	0.9	0.1	0.85	0.15	0.8	0.2
Economical	1	0	0.95	0.05	0.9	0.1	0.85	0.15	0.8	0.2
Loading port	0.66	0.34	0.627	0.373	0.594	0.406	0.561	0.439	0.528	0.472
Destination port	0.67	0.33	0.636	0.364	0.603	0.397	0.5695	0.4305	0.536	0.464
Warehouse	0.63	0.37	0.5985	0.4015	0.567	0.433	0.5355	0.4645	0.504	0.496
Container Consolidation	0.65	0.35	0.6175	0.3825	0.585	0.415	0.5525	0.4475	0.52	0.48
First Manufacturer	1	0	0.95	0.05	0.9	0.1	0.85	0.15	0.8	0.2
Second Manufacturer	1	0	0.95	0.05	0.9	0.1	0.85	0.15	0.8	0.2
Importer	1	0	0.95	0.05	0.9	0.1	0.85	0.15	0.8	0.2
Master	0.8636	0.1364	0.82	0.18	0.777	0.223	0.734	0.266	0.6909	0.3091
Chief Officer	0.8273	0.1727	0.786	0.214	0.745	0.255	0.703	0.297	0.662	0.338
Second officer	0.7372	0.2668	0.7	0.3	0.663	0.337	0.627	0.373	0.5897	0.4103
Third officer	0.7229	0.2771	0.6867	0.3133	0.6506	0.3494	0.6145	0.3855	0.5783	0.4217
Container deconsolidation	0.67	0.33	0.6365	0.3635	0.603	0.397	0.5695	0.4305	0.536	0.464
CSS	0.7285	0.2715	0.6762	0.3238	0.6257	0.3743	0.5768	0.4232	0.531	0.469

Table 5.11: Increment of Nodes' Reliability

Root Node Description	Increment of Reliability									
	0%		5%		10%		15%		20%	
	Reliability	Unreliability	Reliability	Unreliability	Reliability	Unreliability	Reliability	Unreliability	Reliability	Unreliability
Socio-political	1	0	1	0	1	0	1	0	1	0
Geo-political	1	0	1	0	1	0	1	0	1	0
Natural	1	0	1	0	1	0	1	0	1	0
Economical	1	0	1	0	1	0	1	0	1	0
Loading port	0.66	0.34	0.693	0.307	0.726	0.274	0.759	0.241	0.792	0.208
Destination port	0.67	0.33	0.7035	0.2965	0.737	0.263	0.77	0.23	0.804	0.196
Warehouse	0.63	0.37	0.6615	0.3385	0.693	0.307	0.724	0.276	0.756	0.244
Container Consolidation	0.65	0.35	0.6825	0.3175	0.715	0.285	0.747	0.253	0.78	0.22
First Manufacturer	1	0	1	0	1	0	1	0	1	0
Second Manufacturer	1	0	1	0	1	0	1	0	1	0
Importer	1	0	1	0	1	0	1	0	1	0
Master	0.8636	0.1364	0.906	0.094	0.95	0.05	0.993	0.007	1	0
Chief Officer	0.8273	0.1727	0.889	0.111	0.91	0.09	0.951	0.049	0.993	0.007
Second officer	0.7372	0.2668	0.774	0.226	0.81	0.19	0.848	0.152	0.929	0.071
Third officer	0.7229	0.2771	0.759	0.241	0.795	0.205	0.831	0.169	0.867	0.133
Container deconsolidation	0.67	0.33	0.7035	0.2965	0.737	0.263	0.7705	0.2295	0.804	0.196
CSS	0.7285	0.2715	0.7613	0.2387	0.791	0.209	0.8225	0.1775	0.8529	0.1471

Table 5.12: Decrement of Each Individual Node's Reliability by 10% and 20%

Root Node Description	Decrement of Reliability								
	10%		CSS		20%		CSS		Rank
	Reliability	Unreliability	Reliability	Unreliability	Reliability	Unreliability	Reliability	Unreliability	
Socio-political	0.9	0.1	0.723	0.277	0.8	0.2	0.7171	0.2829	11
Geo-political	0.9	0.1	0.723	0.277	0.8	0.2	0.7171	0.2829	11
Natural	0.9	0.1	0.7175	0.2825	0.8	0.2	0.7062	0.2938	6
Economical	0.9	0.1	0.7172	0.2828	0.8	0.2	0.7055	0.2945	5
Loading port	0.594	0.406	0.7156	0.2844	0.528	0.472	0.7023	0.2977	4
Destination port	0.603	0.397	0.7241	0.2759	0.536	0.464	0.7194	0.2806	13
Warehouse	0.567	0.433	0.7184	0.2816	0.504	0.496	0.7080	0.2920	8
Container Consolidation	0.585	0.415	0.7181	0.2819	0.52	0.48	0.7074	0.2926	7
First Manufacturer	0.9	0.1	0.726	0.274	0.8	0.2	0.7232	0.2768	17
Second Manufacturer	0.9	0.1	0.726	0.274	0.8	0.2	0.7232	0.2768	17
Importer	0.9	0.1	0.7235	0.2765	0.8	0.2	0.7182	0.2818	12
Master	0.777	0.223	0.7205	0.2795	0.691	0.309	0.7123	0.2877	9
Chief Officer	0.745	0.255	0.7212	0.2788	0.662	0.338	0.7134	0.2866	10
Second officer	0.663	0.337	0.7251	0.2749	0.59	0.41	0.7214	0.2786	15
Third officer	0.6506	0.3494	0.7254	0.2746	0.578	0.422	0.7219	0.2718	16
Container deconsolidation	0.603	0.397	0.7251	0.2749	0.536	0.464	0.7213	0.2787	14
Country of Origin	0.9	0.1	0.6952	0.3048	0.8	0.2	0.6616	0.3384	1
Ocean Carrier	0.727	0.273	0.7067	0.2933	0.646	0.354	0.6846	0.3154	2
Port	0.596	0.404	0.7112	0.2888	0.53	0.47	0.6935	0.3065	3

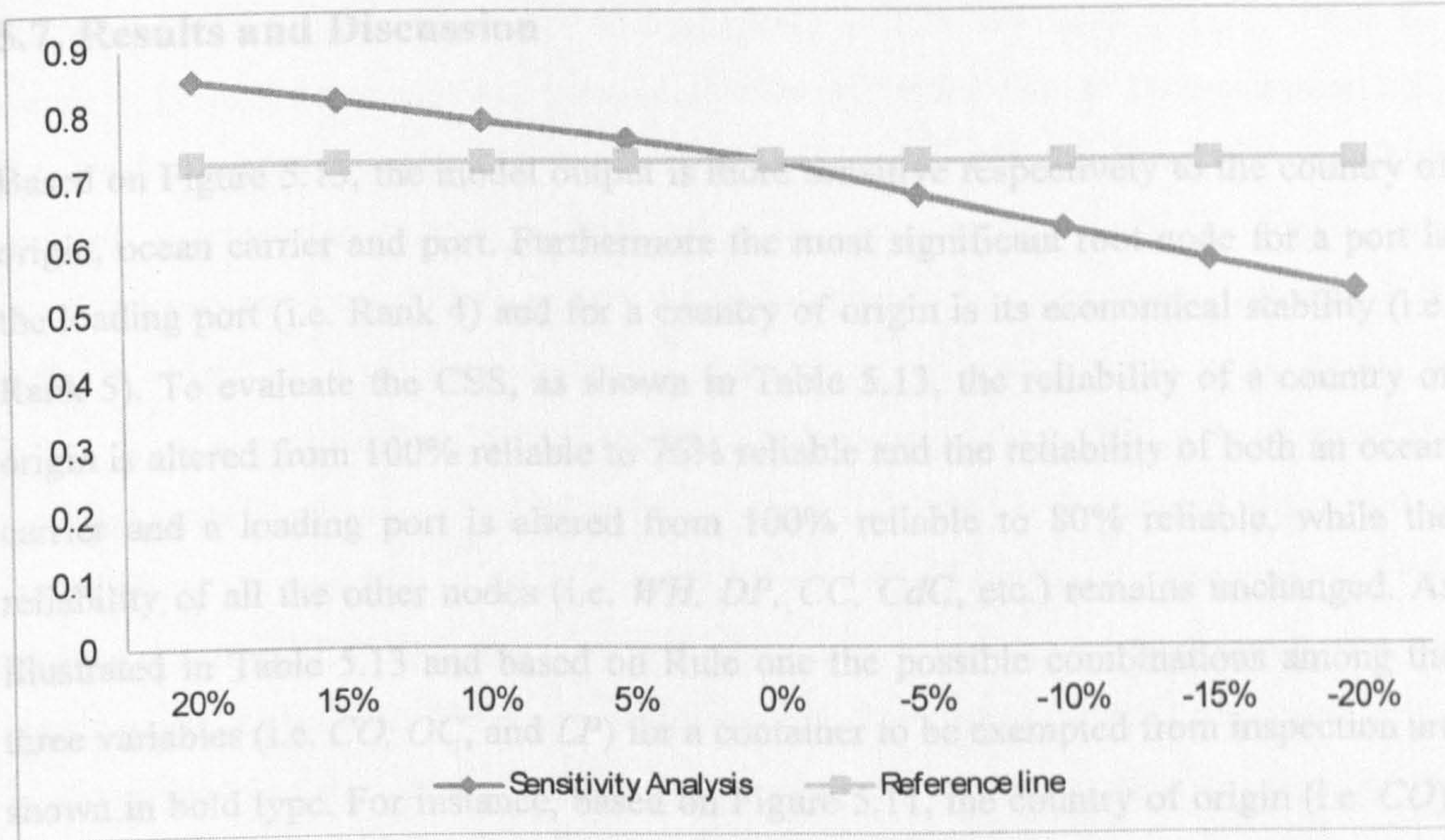

Figure 5.12: CSS versus Increment/Decrement of Nodes' Reliability

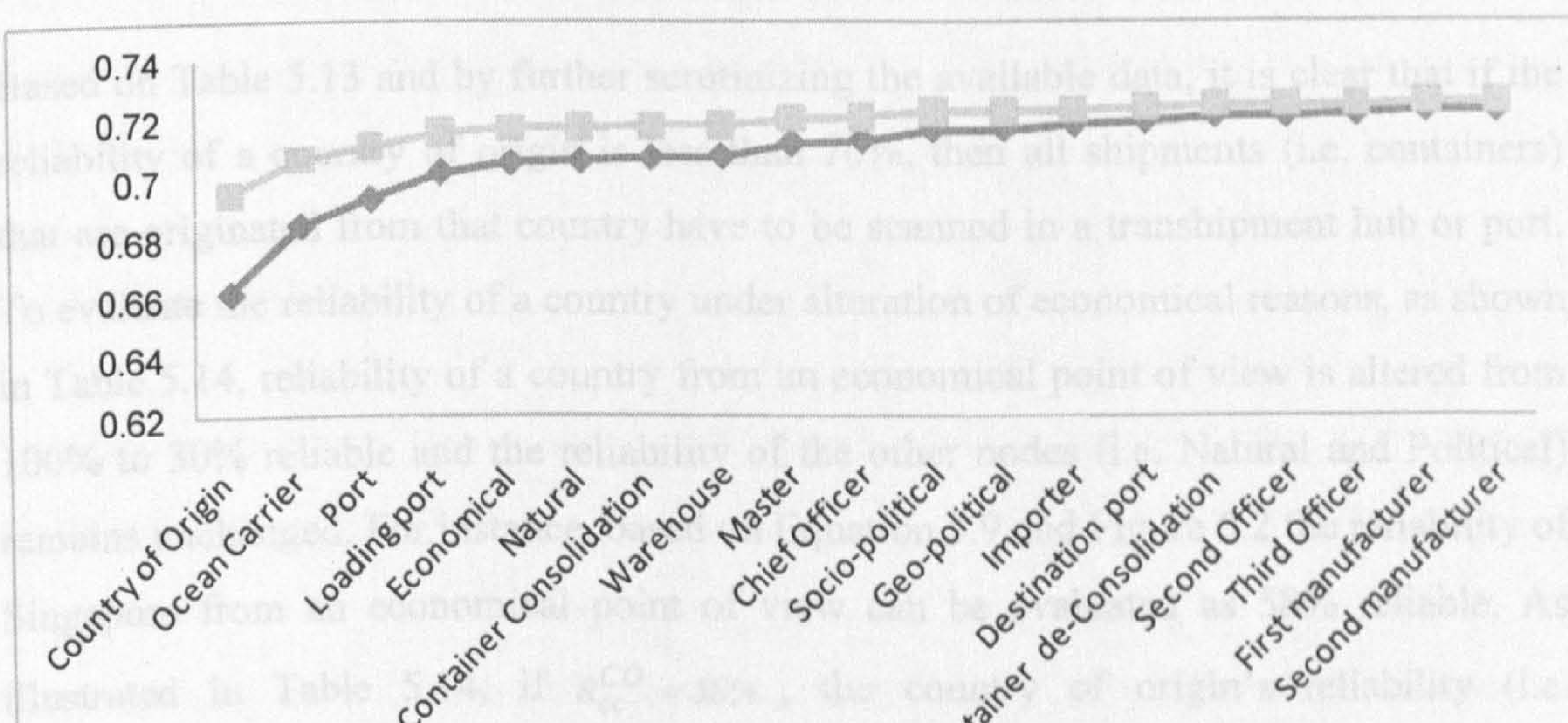

Figure 5.13: Sensitivity of the Model Output to the same Variation of Each Individual Model Input

5.7. Results and Discussion

Based on Figure 5.13, the model output is more sensitive respectively to the country of origin, ocean carrier and port. Furthermore the most significant root node for a port is the loading port (i.e. Rank 4) and for a country of origin is its economical stability (i.e. Rank 5). To evaluate the CSS, as shown in Table 5.13, the reliability of a country of origin is altered from 100% reliable to 76% reliable and the reliability of both an ocean carrier and a loading port is altered from 100% reliable to 80% reliable, while the reliability of all the other nodes (i.e. *WH, DP, CC, CdC*, etc.) remains unchanged. As illustrated in Table 5.13 and based on Rule one the possible combinations among the three variables (i.e. *CO, OC*, and *LP*) for a container to be exempted from inspection are shown in bold type. For instance, based on Figure 5.11, the country of origin (i.e. *CO*), ocean carrier (i.e. *OC*) and loading port (i.e. *LP*) respectively are 100%, 80.76%, and 66% reliable. Thus, based on Table 5.13, if the reliability of the loading port is increased from 66% to 80% or more, in this instance all the containers (i.e. 144 numbers) may not be scanned or screened prior to the vessel loading.

Based on Table 5.13 and by further scrutinizing the available data, it is clear that if the reliability of a country of origin is less than 76%, then all shipments (i.e. containers) that are originated from that country have to be scanned in a transhipment hub or port. To evaluate the reliability of a country under alteration of economical reasons, as shown in Table 5.14, reliability of a country from an economical point of view is altered from 100% to 30% reliable and the reliability of the other nodes (i.e. Natural and Political) remains unchanged. For instance, based on Equation 5.9 and Figure 5.2 the reliability of Singapore from an economical point of view can be evaluated as 58% reliable. As illustrated in Table 5.14, if $R_{ec}^{CO} = 58\%$, the country of origin's reliability (i.e. Singapore) can be computed as 85.7% (≈ 86%). Accordingly, as shown in Table 5.13 (bold type), a transhipment hub (e.g. Singapore) with 86% reliability can be a suitable place for scanning the containers if and only if the ports that are situated in that country are more than 91% reliable. For measuring CSS for a container after it is discharged and scanned at a transhipment hub and loaded onto a containership (i.e. *OC*) for discharging at the port of destination, the transhipment hub will be the country of origin (e.g.

Singapore) and its port (e.g. Port of Singapore) will be the loading port. Since the container is stuffed and stored in the country of origin rather than at a transhipment hub, the directed edges between *WH* and *CO* as well as *CC* and *CO* should be removed. Assume a transhipment hub is 86% reliability and its port is 91% reliable (i.e. unconditional prior reliability) and the reliability of all the other nodes (i.e. *OC, WH, DP, CC, CdC,* etc.) remains unchanged the container's security score, as shown in Figure 5.14, is evaluated as 75.03% reliable. In this instance (i.e. CSS is more than 75% reliable) from a security point of view the container may be exempted from further inspection at the port of destination. On the other hand, if a container's security score is evaluated less than 75% reliable, not only it has to be scanned at a transhipment port but also it should be scanned at the port of destination. The reason for such a security action is due to the fact that after scanning and loading the container onto an ocean or sea carrier, the ship often stops at various seaports and transits through various routes, thus, posing different levels of security risk on the containers as well as the vessel. The preventative measures are to recruit highly reliable ship staff and to measure their reliability appropriately and regularly. Based on Table 5.13 and Figure 5.14 and by further scrutinizing the available data, to circumvent scanning a container at the port of destination the minimum reliability of an ocean or sea carrier should not be less than 80% reliable.

5.7.1. Control Options

As discussed previously to avoid unnecessary delays and security screening the following can be suggested:

1. Improving the physical and procedural security standards of various commercial perimeters (i.e. warehouse, container consolidation's perimeter, etc.). For instance, based on Table 5.11 and Figure 5.12, by increasing the reliability of various perimeters to 5% or more the containers may be exempted for scanning.
2. Improving the physical and procedural security standards of loading ports, for example, as shown in Table 5.13 and discussed in Section 5.7, by increasing the reliability of the loading port from 66% to 80% or more, in this instance the

containers may be exempted for scanning.

3. Improving the security procedure for ports as outlined in Figure 5.7 and discussed in Sub-Sections 5.4.11-5.4.12.
4. Improving the reliability of ocean carriers (i.e. the minimum reliability of an ocean vessel should not be less than 80% reliable). The control options for improving the reliability of ship staff were suggested in Section 4.7 and Sub-Section 3.11.2.
5. Selecting the best possible transhipment hub for scanning of those containers that are originated from a country of origin with the reliability of less than 76%, to circumvent further inspection at the discharge port.

Table 5.13: Calculation of Containers' Security Score

Reliability of Country of Origin.	Reliability of Ocean or Sea Carrier and Loading Port										
	100%	97%	94%	91%	88%	85%	84%	83%	82%	81%	80%
100%	0.8466	0.8326	0.8186	0.8047	0.7907	0.7767	0.7721	0.7674	0.7628	0.7581	0.7535
98%	0.8387	0.8248	0.811	0.7971	0.7833	0.7694	0.7648	0.7602	0.7556	0.7510	0.7463
96%	0.8307	0.8170	0.8032	0.7895	0.7758	0.7620	0.7574	0.7529	0.7486	0.7437	0.7391
94%	0.8227	0.8091	0.7955	0.7818	0.7682	0.7546	0.7501	0.7455	0.741	0.7365	0.7319
92%	0.8147	0.8012	0.7877	0.7742	0.7607	0.7472	0.7427	0.7382	0.7337	0.7292	0.7247
90%	0.8067	0.7933	0.780	0.7666	0.7532	0.7398	0.7353	0.7309	0.7264	0.722	0.7175
88%	0.7987	0.7855	0.7722	0.7589	0.7457	0.7324	0.7280	0.7236	0.7191	0.7147	0.7103
86%	0.7907	0.7776	0.7644	0.7513	0.7381	0.725	0.7206	0.7162	0.7118	0.7075	0.7031
84%	0.7827	0.7697	0.7567	0.7436	0.7306	0.7178	0.7132	0.7089	0.7046	0.7002	0.6959
82%	0.7748	0.7618	0.7489	0.736	0.7231	0.7102	0.7059	0.7016	0.6973	0.6930	0.6887
80%	0.7667	0.7539	0.7411	0.7284	0.7156	0.7028	0.6985	0.6942	0.69	0.6857	0.6815
78%	0.7587	0.7461	0.7334	0.7207	0.708	0.6954	0.6911	0.6869	0.6827	0.6785	0.6742
76%	0.7507	0.7382	0.7256	0.7131	0.7005	0.6880	0.6838	0.6796	0.6754	0.6712	0.667

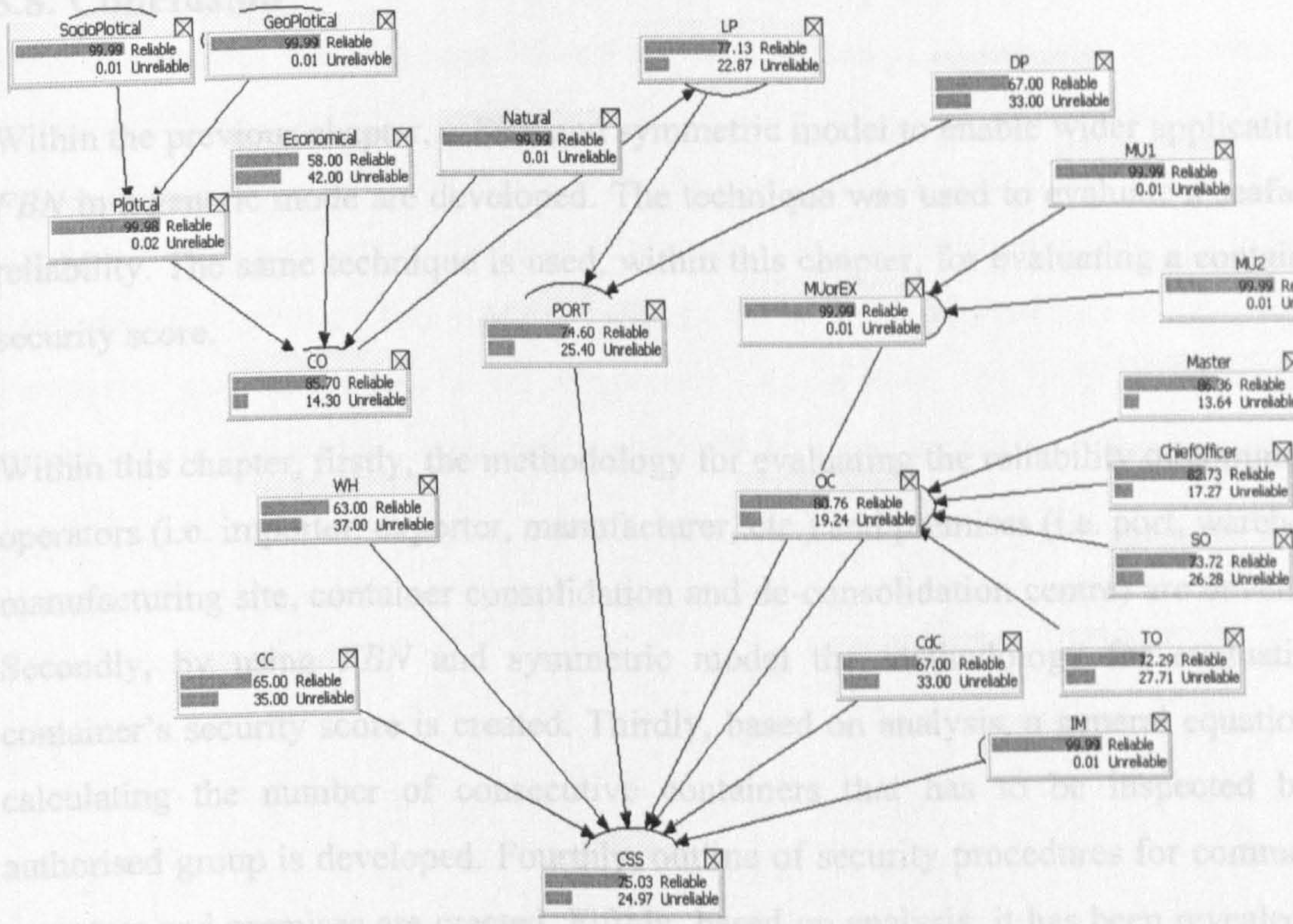

Figure 5.14: Evaluating the Container s' Security Score at a Transhipment Hub

Table 5.14: Evaluation of Country of Origin's Reliability

Reliability of country of origin from an economical point of view (R_{ec}^{CO})	Reliability of country of origin
100%	100%
90%	96.59%
80%	93.18%
70%	89.78%
60%	86.38%
58%	85.70%
55%	84.68%
50%	82.99%
40%	79.59%
30%	76.19%

5.8. Conclusion

Within the previous chapter, a *FBN* and symmetric model to enable wider application of *FBN* in a generic mode are developed. The technique was used to evaluate a seafarer's reliability. The same technique is used, within this chapter, for evaluating a container's security score.

Within this chapter, firstly, the methodology for evaluating the reliability of commercial operators (i.e. importer, exporter, manufacturer, etc.) and premises (i.e. port, warehouse, manufacturing site, container consolidation and de-consolidation centre) are developed. Secondly, by using *FBN* and symmetric model the methodology for evaluating a container's security score is created. Thirdly, based on analysis, a general equation for calculating the number of consecutive containers that has to be inspected by an authorised group is developed. Fourthly, outline of security procedures for commercial operators and premises are created. Fifthly, based on analysis, it has been revealed that if the security score of a container is less than 75%, then the container should be inspected at the loading port or a transhipment hub. Furthermore, based on analysis, it has been revealed that those containers that are originated from a country of origin with reliability of less than 76% reliable, transported via loading ports and containerships with reliability of less than 80% reliable have to be inspected / scanned in a transhipment hub.

Based on Allen (2006)'s research and according to the world bank report, daily spending in customs adds almost 1% to the cost of goods. The *FBN* methodology implemented in this chapter can be used for targeting those containers which pose high level of risk to the container supply chains. Furthermore, it can be used to identify the commercial operators that do not act appropriately to secure their supply chains. Based on the model output, in order to obtain a competitive advantage and to improve the commercial operators' motivations, the financial burden should be placed upon those operators that do not act appropriately. Consequently, the cost of any security system can be justified.

A containership, based on its cargo containers' security scores, poses a determinable level of security risk to a port. Therefore, it is essential to develop a mathematical decision making model for evaluating the security level of a port, based on security scores of a ship's cargo containers prior to ship / port interface. Such that the port authorities are able to assess the level of security risk prior to a containership's arrival at anchorage (i.e. prior to ship / port interface). If the level of security risk is low, then permission can be granted to the concerned ship to enter the berth. Otherwise, the security level of the port should be increased or the concerned ship not entitled to enter the port.

Chapter Six

Adopting Fuzzy Bayesian Network (FBN) Model for Evaluating the Security Level of a Port

Summary

The aim of this study is to exploit a FBN decision making model for evaluating the security level of a port, based on the security scores of a ship's cargo containers prior to ship/port interface. This study makes full use of the Fuzzy Bayesian Network (FBN) advantages by exploiting a conceptual and sound methodology for evaluating the security level of a port.

6.1. Introduction

Global commerce is totally dependent on the movement of shipping containers, which carry about 80% of world trade by volume (Allen, 2006). A container terminal connects sea and land and can be employed for transferring containers to and from ships. It can be used for handling containers rapidly, economically, precisely, and in greater volumes than conventional ports. Nowadays, container sea transport has become the major transport method of international main sea lines. In so many countries, container transport, especially container sea transport, has become a widely used transport method of great importance. In a container terminal the process begins when a ship arrives at the anchorage and joins a queue. The "first come first served" strategy is usually employed. If the berth is vacant, then permission is granted to enter the berth. Otherwise, a delay occurs for the ship until a berth is available. After the ship enters the berth, based on the infrastructure of the container terminal, it experiences an average delay of one or two hours before the loading and unloading operation takes place. A gantry crane (or cranes) is then assigned to start unloading and loading the containers. When these activities are completed the ship may have to wait (i.e. delay period) before it can leave the port. The movement of containers through a port is generally on a queuing system and this means that any delay snarls all operations (Goslin, 2008). As shown in Figure 6.1, the flow of containers is composed of import (i.e. containers unloaded from ships, to be directed to final destination by inland carriers), transhipment (i.e. containers unloaded from ships, to be transhipped to final destination by feeder ships or inland carriers), and export flow (i.e. containers loaded on ships leaving the terminal). The cargo containers that remain on board a vessel (ROB) are not flowing through the port. For the import flow, containers are unloaded by the cranes from the ship, then transported by prime mover to the interchange area before they are stacked in the yard. At the interchange area, the prime movers queue for the straddle carriers to stack the container in the yard, when the consignee claims the container/containers, truck/trucks will be used to transport them outside the port area. For the export containers, the reverse process applies. Millions of dollars worth of cargo pass through a port on a daily basis and if a port is closed to counteract a significant incident or in response to an attack, then a nationally recognised set of protocols must be followed to efficiently resume port operations (The Port Authority of NY & NJ, 2010). Aside from the direct effects of an attack on a port, the economic, social, and political consequences of a significant disruption in container supply chain would be staggering.

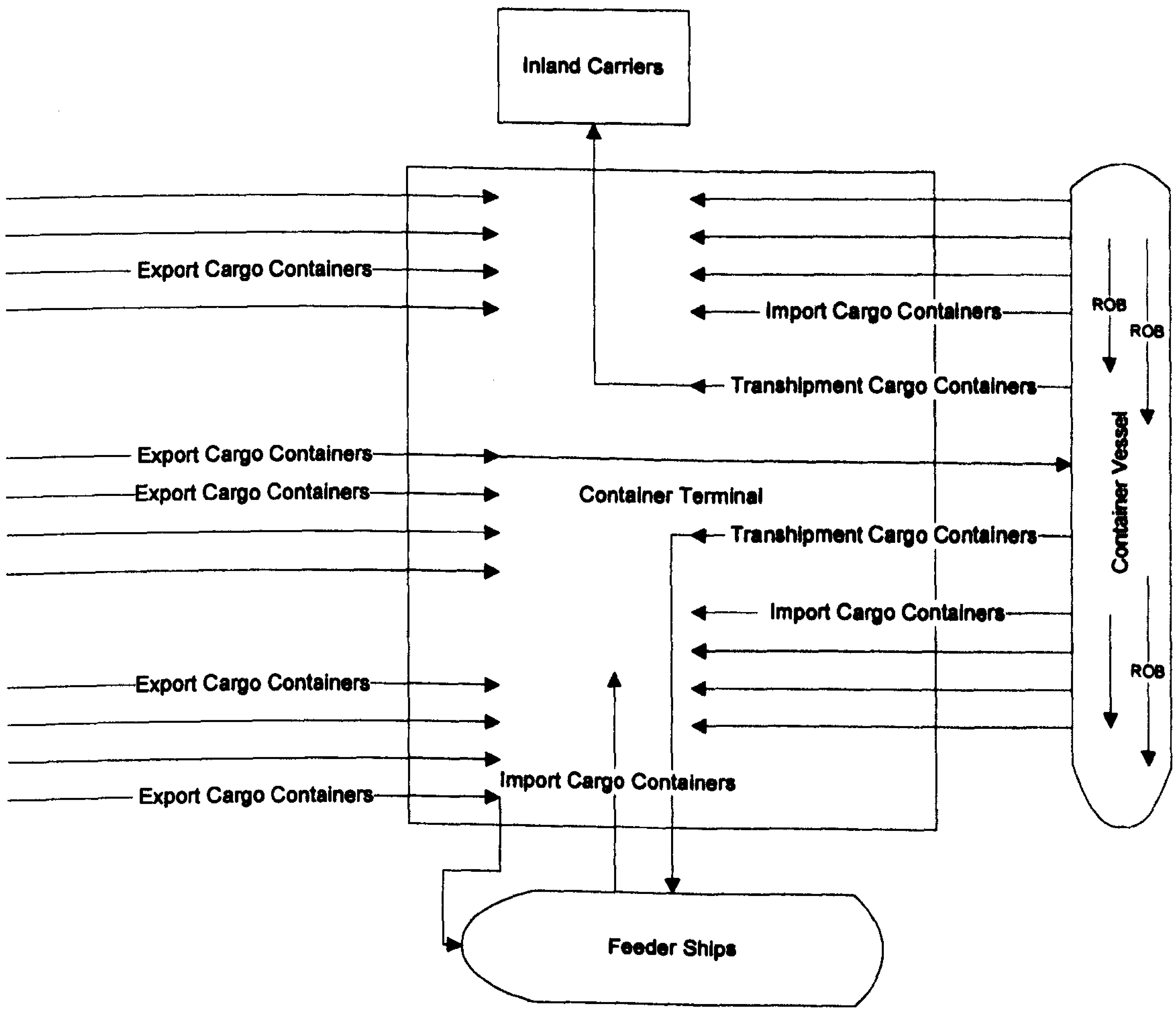

Figure 6.1: Flow of Containers

6.2. Port Security

Intelligence experts agree that global supply chains are significant targets for an eventual attack on ports (The Port Authority of NY & NJ, 2010). Ports are typically large so that they can concurrently accommodate ship, truck and rail traffic, petroleum product / liquid offload storage or piping and container storage (Godlin, 2008). Therefore, the topography of ports is the primary cause of their security dilemma. There are two types of threat related to ports, direct attacks or transport of dangerous materials through ports for use in a terrorist plot elsewhere in a country (MIT, 2007). Based on OECD (2005)'s research the technique used by drug and contraband smugglers (i.e. the criminal wishes to ensure that their illegal consignment gets to the final consignee unnoticed and untouched) is probably more in line with the potential of the terrorist than the technique used by cargo theft (i.e. the criminal is interested in removing the contents of a container in such a manner as to avoid, or at least delay, discovery). Based on expert opinion, a single security countermeasure such as the container security initiative (CSI) or terrorist watch list, cannot adequately address port or marine security and safety concerns (Goslin, 2008). Technology alone cannot secure ports or shipping, nor can adding additional security procedures, physical barriers, or additional manpower fully mitigate the risk (Goslin, 2008). Based on expert opinion the only truly effective measure remains the scanning and/or physical inspection of the suspicious container (OECD, 2005). In addition some experts have called for scanning all import cargo containers. The conducted research by OECD (2005) revealed that 100% scanning is not a realistic option and it would make little sense to seek to scan all import cargo containers since not all containers pose the same risk. In fact much containerised trade is repetitive (i.e. same shippers, same shipment, and same consignee), involves large and well known trades, operating in predictable patterns and can be screened (OECD, 2005). Furthermore, an over-emphasis on security may result in policies destabilizing the economic benefits brought about by containerisation (Thibault, *et al.*, 2006).

6.2.1. Maritime Transportation Security Act

Based on IMO (2003, Codes 2.9-2.11, Part A), individual governments are required to assess the risk facing their ports and establish a three-tier security system as follows:

1. *Security level 1* means the level for which minimum appropriate protective security measures shall be maintained at all times (i.e. normal level of security threats).
2. *Security level 2* means the level for which appropriate additional protective security measures shall be maintained for a period of time as a result of heightened risk of security incident (i.e. medium level of security threats).
3. *Security level 3* means the level for which further specific proactive security measures shall be maintained for a limited period of time when a security incident is probable or imminent, although it may not be possible to identify the specific target (i.e. high level of security threats).

Based on the ISPS Code the parties (i.e. ports, ship operators, and vessels) should establish three-tier security plans that correspond with the three levels of security assessment. These security plans should indicate the operational and physical measures required to comply with each of the three security levels.

6.2.2. Declaration of Security (DOS)

Based on IMO (2003, Code 5.1, Part A) "contracting government shall determine when a declaration of security (DOS) is required by assessing the risk the ship/port interface or ship to ship activity poses to person, property or the environment".

The following can be revealed by a review of the IMO (2003, Part B, Codes 5.2, 5.3, 9.50, 16.55, and 16.57):

- It is likely that a DOS will be requested at higher security levels, when a ship has a higher security level than the one of the port facility, or another ship with which it interfaces.
- A port facility security officer (PFSO) may also initiate a DOS prior to ship/port interfaces that are identified in the approved port facility security assessment

(PFSA) as being of particular concern.

- The ship security plan (SSP) should establish details of the procedures and security measures the ship could adopt if the ship is at a higher security level than that applying to a port facility.
- The port facility security plan (PFSP) should establish details of the procedures and security measures the port facility could adopt if the port facility is at lower security level than that applying to a ship.
- The PFSP should establish the procedure to be followed when, on the instruction of the contracting government, the PFSO requests a DOS or when a DOS is requested by a ship.

The following can be revealed by review of the form recommended in IMO (2003, Appendix to Part B) for documenting the DOS between a ship and a port facility:

- The security levels of the ship and port facility.
- The activity covered by the DOS (i.e. loading, discharging, mooring, bunkering, etc.).
- The agreement between the ship security officer (SSO) and PFSO to carry out a variety of specific activities in accordance with the relevant approved plan.
- The period of validity of the DOS.

6.2.3. Indicator of Port Security (IPS)

Within Chapter 5 (Section 5.4.12) and based on the assessment of an independent competent body such as a reputable classification society the methodology for evaluating the reliability of a port from the security point of view was explained. Furthermore, to indicate the accuracy of audit result for measuring a port's reliability (i.e. R_{Port}^{Audit}) and its deviation on a timely basis an indicator of port security (IPS) can be defined as follows:

Total number of accidents / claims involving pilferage and/or tampering incidents observed on the annual basis at the port = N_t

Total number of bill of ladings / manifests handled by the port annually = N_j

$$
\begin{aligned}
IPS &= \frac{N_i}{N_j} \\
LIPS &= -\log(IPS) \qquad (6.1) \\
RLIPS &= \textit{Round up LIPS to an integer value}
\end{aligned}
$$

Based on Equation 6.1, for instance, if a port (e.g. port of Singapore) is handling 30 million TEUs annually (i.e. N_j) and N_i is evaluated as 3, then *RLIPS* can be evaluated as 7 and the reliability of the port can be estimated as high. Furthermore, if the value of N_i is evaluated as 30, 300, 3000, or 30000, then *RLIPS* can be evaluated as 6, 5, 4, or 3 respectively, thus, the reliability of the port can be estimated as fairly high, medium, fairly low, or low. Accordingly a quantitative criterion (i.e. *RLIPS*), as shown in Figure 6.2, can be transformed to a qualitative criterion (i.e. reliability of a port) by exploiting the membership functions. Based on the value of *RLIPS* and Figure 6.2 a fuzzy set for a port's reliability can be assessed. Furthermore by help of Equations 3.14-3.19, the reliability of a port based on the indicator of its security (i.e. R_{Port}^{IS}) can be evaluated. As a result the reliability of a port (i.e. R_{Port}) can be evaluated as follows:

$$R_{Port} = \min(R_{Port}^{Audit}, R_{Port}^{IS}) \qquad (6.2)$$

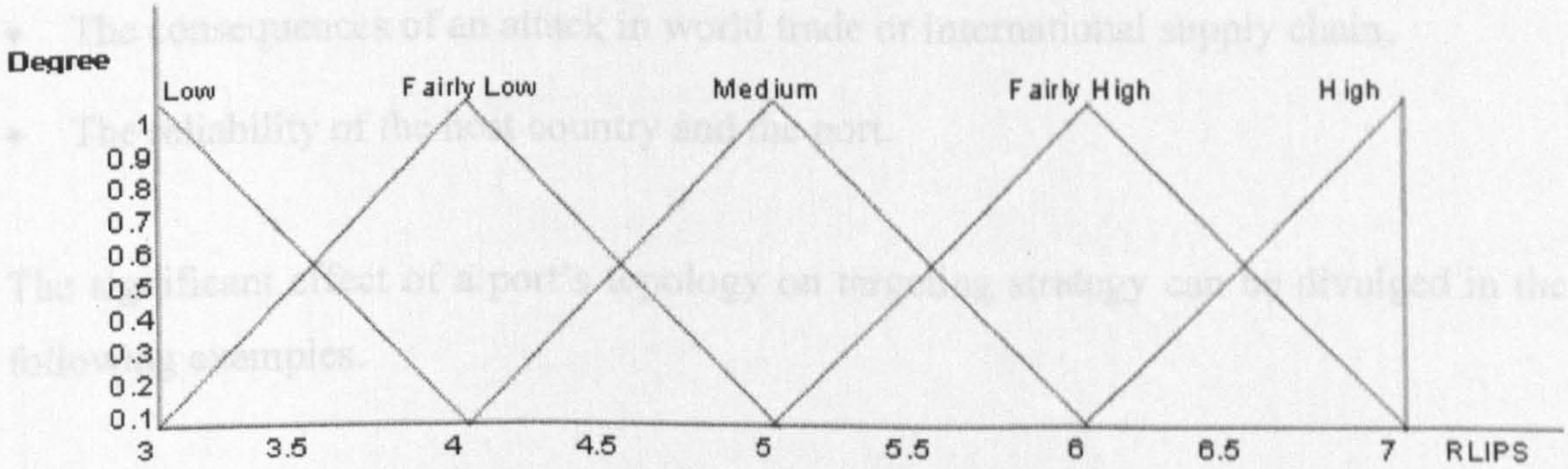

Figure 6.2: Membership Functions of Port

6.3. Targeting strategy

Prior to 9/11, port authorities focused their security effort on preventing criminal activities within their jurisdiction. After attacks, they become very concerned that a terrorist attack at one of their terminals or facilities could have local, national, and international inferences (Thibault, *et al.*, 2006). Based on experts' opinion, to enhance the security of a port the best option is to exploit an integrated, carefully planned approach that incorporates the best elements of technical, physical, procedural and information security disciplines into a comprehensive strategy (Goslin, 2008). Moreover, the hourly waiting cost of a containership arriving at port of disembarkation is tens of thousands of dollars. Thus, the strategy must be developed in a way that does not slow down world trade. In other words, instead of inspecting cargo containers at random, rational inspection should be carried out. Thus, to enhance the probability that targeted cargo proves to be compliant with regulations or contains no contraband; firstly the topology of a port should be investigated. Analysis of a port's topology should reveal the following:

- The availability of illicit materials or contraband at the host country.
- The flow of containers on daily/monthly or annual basis.
- The number of cargo containers that remain on board a vessel or vessels within a port territory on daily/ monthly or annual basis.
- The willingness of terrorist organisations to attack the port or its host country.
- The damage capability and recall difficulties after an attack.
- The consequences of an attack in world trade or international supply chain.
- The reliability of the host country and the port.

The significant effect of a port's topology on targeting strategy can be divulged in the following examples.

Firstly, assume that an authorised group is uncertain regarding availability of illicit materials within a batch of containers (e.g. 100 containers). To detect the illicit materials the authorised group decided to scan 20% of the batch at random. The probability of detecting an unknown container that contains illicit materials given that within all scanned containers (i.e. 20% of the batch) no illicit material was found can be calculated as 1/80 = 0.0125, therefore, the authorised group is not able to gain any certainty pertaining to the remaining containers (i.e. 80% of the batch). As it is obvious a targeting strategy based on random inspection cannot be a successful tactic.

Secondly, based on Figure 6.1, four states (i.e. import, export, transhipment, and ROB) for containers can be alleged. Based on the surveillance of a port's topology and through consultancy with the host government officials a conditional probability table (CPT), as shown in Table 6.1, can be illustrated.

Table: 6.1: CPT (Illicit Material | Cargo Container)

Container / Illicit Material	Export	Import	Transhipment	ROB
Present	σ_{EX}	σ_{IM}	σ_{TS}	σ_{ROB}
Absent	$1-\sigma_{EX}$	$1-\sigma_{IM}$	$1-\sigma_{TS}$	$1-\sigma_{ROB}$

Assume N_{EX} , N_{IM} and N_{TS} stand for the total numbers of export, import and transhipment cargo containers flowing through a port on daily basis respectively and N_{ROB} stands for the number of cargo containers remaining on board a vessel or vessels within a port territory on a daily basis. As a result:

$$
\begin{aligned}
&N_T = N_{EX} + N_{IM} + N_{TS} + N_{ROB} \\
&P(Container = EX) = \frac{N_{EX}}{N_T} \\
&P(Container = IM) = \frac{N_{IM}}{N_T} \\
&P(Container = TS) = \frac{N_{TS}}{N_T} \\
&P(Container = ROB) = \frac{N_{ROB}}{N_T}
\end{aligned}
\qquad (6.3)
$$

Based on the Bayesian's chain rule, Table 6.1 and Equation 6.3 the marginal probability of the presence of illicit material can be calculated as follows:

$$P(Illicit\_material = \Pr esent) = \frac{\sigma_{EX} N_{EX} + \sigma_{IM} N_{IM} + \sigma_{TS} N_{TS} + \sigma_{ROB} N_{ROB}}{N_T} \quad (6.4)$$

If the presence of illicit material is known with 100% certainty (i.e. instantiation of illicit material), then by using Bayesian's rule the posterior probabilities can be calculated as follows:

$$P(Container = EX) = \frac{N_{EX}\sigma_{EX}}{N_{EX}\sigma_{EX} + N_{IM}\sigma_{IM} + N_{TS}\sigma_{TS} + N_{ROB}\sigma_{ROB}}$$

$$P(Container = IM) = \frac{N_{IM}\sigma_{IM}}{N_{EX}\sigma_{EX} + N_{IM}\sigma_{IM} + N_{TS}\sigma_{TS} + N_{ROB}\sigma_{ROB}}$$

$$P(Container = TS) = \frac{N_{TS}\sigma_{TS}}{N_{EX}\sigma_{EX} + N_{IM}\sigma_{IM} + N_{TS}\sigma_{TS} + N_{ROB}\sigma_{ROB}} \quad (6.5)$$

$$P(Container = R.O.B) = \frac{N_{ROB}\sigma_{ROB}}{N_{EX}\sigma_{EX} + N_{IM}\sigma_{IM} + N_{TS}\sigma_{TS} + N_{ROB}\sigma_{ROB}}$$

Assume that, after surveillance of a port's topology, the following data is illustrated by experts (Table 6.2):

Table 6.2: Experts' Opinion based on the Port's Topology

σ_{EX}	σ_{IM}	σ_{TS}	σ_{ROB}	$\frac{N_{EX}}{N_T}$	$\frac{N_{IM}}{N_T}$	$\frac{N_{TS}}{N_T}$	$\frac{N_{ROB}}{N_T}$
0.3	0.7	0.5	0.2	15%	40%	20%	25%

Based on Equation 6.4 the marginal probability of the presence of illicit materials can be calculated as 47.5% (i.e. 52.5% absent). Based on Equation 6.5 the posterior probabilities of the export, import, transhipment and ROB cargo containers containing illicit materials are evaluated as 9.74%, 58.95%, 21.05% and 10.53% respectively. Therefore, the probability that the import cargo containers contain contraband is higher than the others. Within Chapter 5 based on measuring a container's security score, a targeting strategy that specifies which containers are required to be scanned and where to scan them (i.e. at overseas port of embarkation, at the domestic port of disembarkation, or both) was developed. If the targeting strategy developed in Chapter 5 is utilized by authorities at the discharge port (i.e. disembarkation) and in cooperation with the authorities at an overseas loading port (i.e. embarkation), then the value of σ_{IM} may approach zero. As a result, based on Equation 6.4 the marginal probability of the presence of illicit materials can be calculated as 19.5% (i.e. 80.5% absent). In addition the gain in certainty is evaluated as (80.5% − 52.5%) 28%. Thus, to enhance the probability that targeted cargo proves to be compliant with regulations or contains no contraband, the best tactic is to analyse a port's topology and define a different methodology for targeting, screening, and scanning export, import, transhipment, and ROB cargo containers. The symbols and abbreviations are presented in Table 6.3.

Table 6.3: Table of Symbols and Abbreviations

R	Reliable
$\overline{R}$	Unreliable
CSS	A container's security score.
$P(C=R)=CSS$	Probability that a container does not contain illicit materials.
$P(IM=R)=R_{IM}$	Probability that an importer is reliable and does not cooperate with criminals.
$P(EX=R)=R_{EX}$	Probability that an exporter is reliable and does not cooperate with criminals.
$P(WH=R)$	Probability that a warehouse is reliable.
$P(CO=R)=R_{CO}$	Probability that a country of origin or a host country is reliable.
$P(LP=R)$	Probability that a loading port is reliable.
$P(OC=R)=R_{OC}$	Probability that an ocean carrier is reliable.
$P(CC=R)$	Probability that a container consolidation centre is reliable.
$P(WH=R \mid CO=R)=R_{WH}$	Probability that a warehouse is reliable given that its host country is reliable.
$P(LP=R \mid CO=R)=R_{LP}$	Probability that a loading port is reliable given that its host country is reliable.
$P(CC=R \mid CO=R)=R_{CC}$	Probability that a container consolidation centre is reliable given that its host country is reliable.

6.3.1. Evaluating the Security Score of Export Cargo Containers

Once the container is stuffed and it leaves the manufacturing site, the container is vulnerable to being interrupted and having its contents tampered with. Ideally, seals should only be placed on containers by the party directly responsible for stuffing and/or visually verifying the content of the container. Thus, it is noteworthy to mention that the party responsible for stuffing and sealing the container is the first, and most important, link in a secure container supply chain (OECD, 2005). Based on OECD (2005)'s research, seals are only valuable when referencing a document (manifest, bill of lading, etc.) that provides a picture of what was in the container and when it was sealed. The commercial operators (may physically come into contact with an export cargo container and its contents) and premises after being transported by road or rail directly to a port (i.e. at the port's gate) can be listed as follows:

- Manufacturer or exporter.
- Container consolidation facility.
- Warehouse or an intermediary's premises.
- Inland carrier.

As a result, firstly an authorised group should gain sufficient information regarding a manufacturer or an exporter. The information can be provided by evaluating the reliability of a manufacturer or an exporter (Appendix 4 Section A.4.2). Secondly by scanning a limited number of an exporter's cargo containers (Equations 5.1-5.8) and accruing sufficient evidence that the exporter is not cooperating with criminals the exporter's name can be documented within the low risk exporters.

To gain sufficient information regarding inland carriers and accruing sufficient evidence that they are not cooperating with criminals, the method developed in Chapter 5 (Section 5.4.11) can be used. Furthermore, it can be combined with a technology. For instance, Duos Technologies has developed a system, Intermodal Container Exit System (ICES) that can identify and track containers and link them to transport companies, drivers and specific vehicles. ICES will capture and store the following information in a simple user interface (Goslin, 2008):

- Container number.
- Trailer number.
- Front and rare licence plates.
- Driver's licence data.
- Video of vehicle and container.
- Video and audio of driver and guard interaction at the port.
- Biometric capture of fingerprint.

To achieve sufficient information concerning a security score of an export cargo container that is stuffed in a consolidation centre (i.e. *CC*) and is stored in a warehouse (i.e. *WH*) and accruing sufficient evidence concerning performance of *CC* and *WH* from the security point of view, firstly, based on the audit result (Appendix 4, Section A.4.1) their reliability (i.e. R_{WH} and R_{CC}) should be evaluated. Secondly, due to uncertainty and avoiding any preconceived notion the probability that an export cargo container is reliable given either CC, WH, or both are unreliable / reliable can be assigned as follows:

$$\begin{aligned} &P(C=R \mid CC=\overline{R}, WH=\overline{R})=0 \\ &P(C=R \mid CC=R, WH=\overline{R})=0.5 \\ &P(C=R \mid WH=R, CC=\overline{R})=0.5 \\ &P(C=R \mid WH=R, CC=R)=1 \end{aligned} \qquad (6.6)$$

As discussed in Chapter 5, the reliability of a warehouse, loading port and container consolidation's perimeter depends upon their host country (i.e. country of origin). Thus, the marginal probability of a warehouse, loading port and container consolidation's perimeter can be formulated as follows:

$$\begin{aligned} &P(WH=R)=P(WH=R \mid CO=R)\times P(CO=R)+P(WH=R \mid CO=\overline{R})\times P(CO=\overline{R}) \\ &P(CC=R)=P(CC=R \mid CO=R)\times P(CO=R)+P(CC=R \mid CO=\overline{R})\times P(CO=\overline{R}) \\ &P(LP=R)=P(LP=R \mid CO=R)\times P(CO=R)+P(LP=R \mid CO=\overline{R})\times P(CO=\overline{R}) \end{aligned} \qquad (6.7)$$

Based on OECD (2005)'s research "in many cases of container related crime, internal conspiracies between criminals and inside personnel (belonging to warehouse managers, carriers, forwarders and even customs) have been involved". Thus, the assessment of a container consolidation facility, loading port and warehouse's reliability, based on the audit result (Appendix 4, Section A.4.1), is only valid if their host country is found to be reliable (Section 5.4.9). In other words, the probability that a warehouse, loading port and container consolidation centre is reliable given that their country of origin (i.e. their host country) is unreliable should be assigned to zero (i.e. to avoid bias). As a result, based on Table 6.3, Equation 6.7 can be simplified as follows:

$$\begin{aligned} P(WH = R) &= R_{WH} \times R_{CO} \\ P(CC = R) &= R_{CC} \times R_{CO} \qquad (6.8) \\ P(LP = R) &= R_{LP} \times R_{CO} \end{aligned}$$

Based on the Bayesian's chain rule and Equations 6.6 and 6.8, the marginal probability that an export cargo container is reliable and does not contain illicit materials (i.e. at the port's gate) can be evaluated as follows:

$$\textit{CSS for an export cargo container} = P(C_{EX} = R) = \frac{1}{2} \times R_{CC} \times R_{CO} + \frac{1}{2} \times R_{WH} \times R_{CO} \qquad (6.9)$$

As discussed in Chapter 5, if the value of the CSS is less than 75% (i.e. acceptable limit), then the container should be physically inspected or scanned. Furthermore, based on Equation 6.9, if the reliability of a country of origin (i.e. host country) is evaluated as 75% or less, then the value of the CSS (i.e. for all values of R_{WH} and R_{CC}) can be evaluated as 75% or less. Accordingly the container should be physically inspected or scanned at a transhipment hub or port rather than the country of origin. As discussed in Chapter 5, the reliability of the host country for a transhipment hub or port has to be more than 75% reliable. As a result it is possible to designate some foreign ports through which containers are transhipped, for piloting an integrated scanning system to include non-intrusive inspection (NII) and radiation detection.

6.3.2. Evaluating the Security Score of Import Cargo Containers

The methodology for evaluating the security score of an import cargo container was explained in Chapter 5. The best strategy is to identify and examine or search marine containers that pose a security risk (i.e. the value of CSS is not within the acceptable limit) before loading such containers at a loading port for shipment, either directly at the loading port or through a transhipment hub or port.

6.3.3. Evaluating the Security Score of Transhipment and ROB Cargo Containers

Containers during their passage through the supply chain may transit through several countries, be loaded onto several different modes of transport, transferred between several different firms, handled several times, and wait in some location for an extended period of time. Thus, evaluating the security score of a transhipment or ROB cargo container depends upon many variables and is complex. Furthermore, transhipment cargo containers moved from one vessel to another are only available for scanning for a short period of time and may be difficult to access. Similarly, it may be difficult to scan cargo containers that remain on board a vessel as it passes through a foreign seaport. Based on GAO (2007)'s research "currently containers such as these that are designated as high-risk at CSI ports are not scanned unless specific threat information is available regarding the cargo in that particular container".

To simplify the evaluation of a security score of a transhipment and ROB cargo container the following hypotheses are useful:

1. The probability of detecting an export cargo container (Section 6.3.1) that contains illicit materials at an effectively reliable loading port (i.e. *LP*) given that its host country (i.e. *CO*) is sufficiently reliable can be evaluated as high.
2. As soon as a container is loaded on board an ocean carrier (i.e. *OC*) at an effectively reliable loading port, the containership will often stop at various seaports to discharge and load containers. Furthermore, the containership transits through various routes and ports pose different levels of security risk. As discussed in Chapter 5 (Sections 5.4.10 and 5.7), if the reliability of an ocean carrier is evaluated as 80% or more, then the ship staff are adequately reliable (i.e. vigilance) and the probability of tampering with its cargo containers at various seaports can be evaluated as low.

Based on the above hypotheses and the Bayesian's chain rule, the marginal probability that a transhipment or ROB cargo container is reliable and does not contain illicit materials can be evaluated as follows:

$$P(C=R)=P(C=R\mid LP=R,OC=R)\times P(LP=R)\times P(OC=R)+$$
$$P(C=R\mid LP=\overline{R},OC=R)\times P(LP=\overline{R})\times P(OC=R)+$$
$$P(C=R\mid LP=R,OC=\overline{R})\times P(LP=R)\times P(OC=\overline{R})+ \quad (6.10)$$
$$P(C=R\mid LP=\overline{R},OC=\overline{R})\times P(LP=\overline{R})\times P(OC=\overline{R})$$

As a result of uncertainty and avoiding any preconceived notion the probability that a transhipment or ROB cargo container is reliable given either OC, LP, or both are unreliable / reliable can be assigned as follows:

$$P(C=R\mid OC=\overline{R},LP=\overline{R})=0$$
$$P(C=R\mid OC=R,LP=\overline{R})=0.5$$
$$P(C=R\mid OC=\overline{R},LP=R)=0.5 \quad (6.11)$$
$$P(C=R\mid OC=R,LP=R)=1$$

Based on Table 6.3 and Equations 6.8, 6.10, and 6.11, the marginal probability that a transhipment or ROB cargo container is reliable and does not contain illicit materials can be evaluated as follows:

$$\textit{CSS for a transhipment / ROB cargo container} = P(C=R)$$

$$P(C=R)=P(LP=R)\times P(OC=R)+0.5\times P(LP=\overline{R})\times P(OC=R)+$$
$$0.5\times P(LP=R)\times P(OC=\overline{R})=P(LP=R)\times P(OC=R)+$$
$$0.5\times[(1-P(LP=R))\times P(OC=R)]+0.5\times[P(LP=R)\times(1-P(OC=R))]= \quad (6.12)$$
$$0.5\times P(OC=R)+0.5\times P(LP=R)=0.5\times R_{OC}+0.5\times R_{LP}\times R_{CO}$$

It is noteworthy to mention that based on the mentioned hypotheses, Equation 6.12 (i.e. simplified formula) can only be used, if the reliability of an ocean carrier, a loading port and a country of origin is 80% (Section 5.7), 75% (Section 6.2.3), and 75% (Section 6.3.1) or more respectively. Otherwise a container's security score should be measured by the elaborated methodology in Chapter 5 (i.e. accurate method). However, if the sufficient data is not available CSS can be estimated as follows:

- If the reliability of an ocean carrier is more than 80% (i.e. the probability of tampering with the ocean carrier's cargo containers at various seaports can be evaluated as low) and reliability of loading port is less than 75%, then the container should be categorised as medium or high risk and, based on a series network terminology with two components, the probability that a transhipment or ROB cargo container is reliable and does not contain illicit materials can be evaluated as follows:

$$P(C = R) = R_{LP} \times R_{CO} \tag{6.13}$$

- If the reliability of an ocean carrier is less than 80% and reliability of loading port is less than 75%, then the container should be categorised as medium or high risk and, based on a series network terminology with three components, the probability that a transhipment or ROB cargo container is reliable and does not contain illicit materials can be evaluated as follows:

$$P(C = R) = R_{LP} \times R_{CO} \times R_{OC} \tag{6.14}$$

6.4. Methodology

The aim of this study is to exploit a *FBN* decision making model for evaluating the security level of a port, based on the security scores of a ship's cargo containers. The methodology in stepwise orders is described as follows:

Firstly, based on Sub-Sections 6.2.3 and 5.4.9 the reliability of a port and its host country can be evaluated.

Secondly, prior to a ship / port interface, the numbers of import, transhipment, and ROB cargo containers on board a ship are assessed by an authorised group.

Thirdly, based on Sub-Sections 6.3.2 and 6.3.3 security scores of import, transhipment and ROB cargo containers are evaluated. Based on the value of CSS, as shown in Table 6.4, three states (i.e. low risk, medium risk, and high risk) for a container are alleged.

Fourthly, based on experts' opinion a *CPT*, as shown in Table 6.5, is formulated.

Fifthly, based on the *BN* decision making model, as shown in Figure 6.3, the likelihood of security level 1 (i.e. L_1), security level 2 (i.e. L_2), and security level 3 (i.e. L_3) is evaluated.

Sixthly, the security level based on the likelihood of security levels, as shown in Table 6.6, is evaluated. Mathematically no more possibilities exist.

Seventhly, based on Section 6.3, a targeting strategy is developed.

Finally, the sensitivity of the model is analysed.

Table 6.4: Risk level based on the value of CSS

if $0.75 \le CSS \le 1$	*if* $0.5 \le CSS < 0.75$	*if* $0 \le CSS < 0.5$
Low Risk	*Medium risk*	*High Risk*

Table 6.5: CPT (Illicit Material | a Container's Security Score)

CSS / *Illicit Material*	*Low Risk*	*Medium Risk*	*High Risk*
Present	ε_1	η_1	μ_1
Absent	ε_2	η_2	μ_2
Uncertain	$1-(\varepsilon_1+\varepsilon_2)$	$1-(\eta_1+\eta_2)$	$1-(\mu_1+\mu_2)$

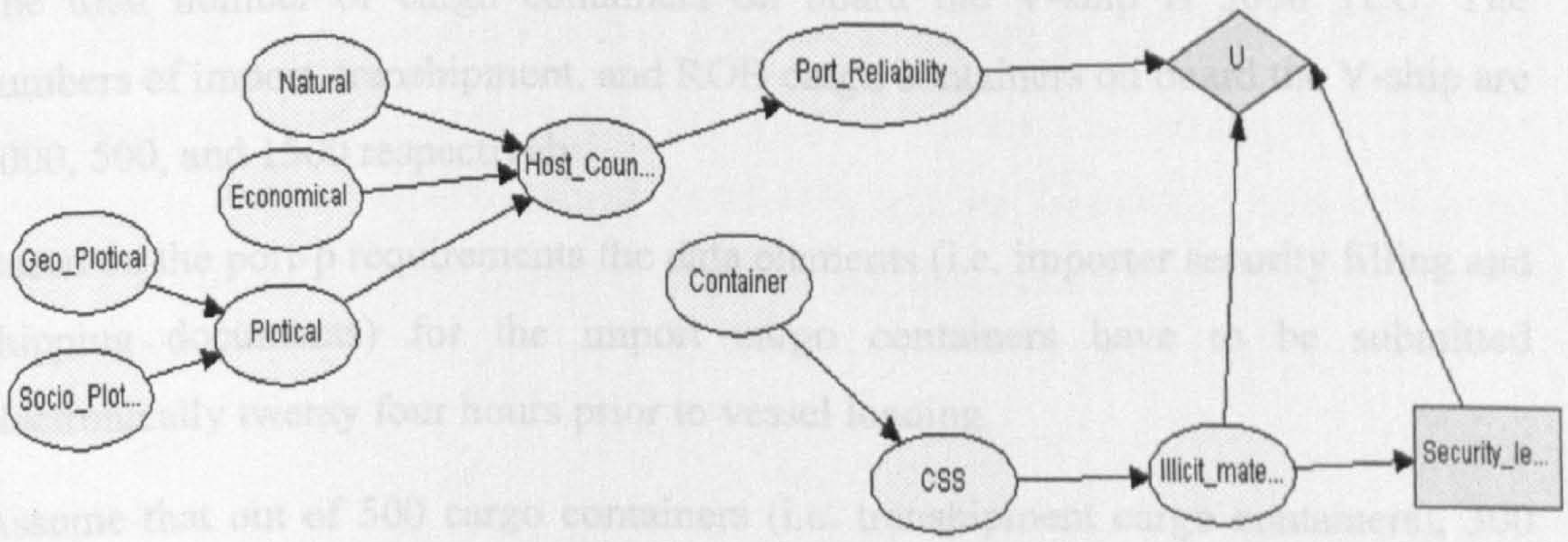

Figure 6.3: BN Decision Making Model for Evaluating the Security Level

Table 6.6: Likelihood of Security Levels versus Security Level

if $L_2 + L_3 < L_1$ $L_3 \le L_1$ $L_2 \le L_1$ *then* Level 1	*if* $L_2 + L_3 \ge L_1$ $L_3 \le L_1$ $L_2 \le L_1$ *then* Level 2	*if* $L_2 > L_3$ $L_2 > L_1$ *then* Level 2	*if* $L_3 \ge L_2$ $L_3 > L_1$ *then* Level 3

6.5. Test Case

Based on IMO rules (2003, Codes 2.9-2.11, Part A) and the following information an authorised person in country-þ would like to assess the security level of port-þ , based on the security scores of the V-ship's cargo containers, prior to V-ship / port-þ interface.

- The reliability of country-þ from an economical point of view is evaluated as 58% reliable. From the natural and political point of view the country-þ is 100% reliable.
- The audit score for the port-þ is evaluated as 152. The value of *RLIPS* for port-þ is evaluated as 7.
- Based on the latest audit result provided by the assessments of port state control and port facility security officers the reliability of the V-ship is evaluated as 80.76% reliable (Figure 5.11, Sub-Section 5.6.5).
- The total number of cargo containers on board the V-ship is 3000 TEU. The numbers of import, transhipment, and ROB cargo containers on board the V-ship are 1000, 500, and 1500 respectively.
- Based on the port-þ requirements the data elements (i.e. importer security filling and shipping documents) for the import cargo containers have to be submitted electronically twenty four hours prior to vessel loading.
- Assume that out of 500 cargo containers (i.e. transhipment cargo containers), 300 were loaded at the 60% reliable port (sited at the 80% reliable country) and 200 were loaded at the 70% reliable port (sited at the 90% reliable country).

- Assume that out of 1500 cargo containers (i.e. ROB cargo containers), 1000 were loaded at the 90% reliable port (sited at the 80% reliable country), 200 were loaded at the 65% reliable port (sited at the 75% reliable country) and 300 were loaded at the 74% reliable port (sited at the 75% reliable country).

By help of the proposed methodology (Section 6.4) the security level of the port-þ can be measured as follows:

6.5.1. Step 1

Based on the given information the audit score for the port-þ is evaluated as 152 and based on Figure A4.2 (Appendix 4) and Equation 3.20 the reliability of the port-þ in terms of a fuzzy set can be assessed as follows:

$$\text{port - }\tilde{\text{þ}} = \{(0.75, High), (0.25, Fairlyhigh), (0, Medium), (0, Firlylow), (0, Low)\}$$

By means of Equations 3.14-3.19, the reliability of port-þ based on the audit result (i.e. R_{Port}^{Audit}) can be evaluated as 93.75% reliable. Furthermore, based on the given information (i.e. *RLIPS = 7)* and Figure 6.2, the reliability of the port-þ in terms of a fuzzy set can be assessed as follows:

$$\text{port - }\tilde{\text{þ}} = \{(1, High), (0, Fairlyhigh), (0, Medium), (0, Firlylow), (0, Low)\}$$

By means of Equations 3.14-3.19, the reliability of port-þ based on an indicator of security (i.e. R_{Port}^{IS}) can be evaluated as 100% reliable. As a result and based on Equation 6.2, the reliability of the port-þ (i.e. R_{Port}) can be evaluated as (93.75% ≈ 94%) 94% reliable. Based on the given information the reliability of the host country (i.e. country-þ), as shown in Figure 6.4, is evaluated as 85.97% reliable. Based on Equation 6.8 the marginal probability that the port-þ is reliable can be evaluated as (0.94 × 0.8597) 80.81% reliable.

6.5.2. Step 2

Based on the given information the percentages of import, transhipment, and ROB cargo containers on board the V-ship can be evaluated as follows:

$$import = \frac{1000}{3000} = 33.33\%$$

$$transhipment = \frac{500}{3000} = 16.67\%$$

$$ROB = \frac{1500}{3000} = 50\%$$

6.5.3. Step 3

Based on the port-þ requirements the data elements for the import cargo containers have to be submitted electronically twenty four hours prior to a vessel loading. Therefore, if the elaborated methodology in Chapter 5 is followed by the authorities at port-þ, then the value of CSS for all the import cargo containers on board the V-ship is within the acceptable limit (i.e. CSS $\geq$ 0.75).

Based on the given information and Equation 6.13 out of 500 transhipment cargo containers, the value of CSS for 300 containers is evaluated as 0.48 (i.e. 0.8×0.6) and for the remainder is evaluated as 0.63 (i.e. 0.70×0.9).

Based on the given information and Equations 6.12-6.13 out of 1500 ROB cargo containers, the value of CSS for 1000 containers is evaluated as 0.7638 (i.e. $0.5 \times 0.8076 + 0.5 \times 0.9 \times 0.8$), the value of CSS for 200 containers is evaluated as 0.4875 (i.e. 0.65×0.75) and for the remainder is evaluated as 0.555 (i.e. 0.74×0.75).

Based on Table 6.4 and the above results Table 6.7 is illustrated.

Table 6.7: Containers' Security Score of V-ship's Cargo Containers

Container / *CSS*	*Import*	*Transhipment*	*ROB*
Low Risk	1000	0	1000
Medium Risk	0	200	300
High Risk	0	300	200

6.5.4. Step 4

Based on experts' opinion a condition probability table is illustrated (Table 6.8).

Table 6.8: CPT (Illicit Material | Low, Medium, and High Risk Cargo Containers)

CSS / *Illicit Material*	*Low Risk*	*Medium Risk*	*High Risk*
Present	0	0.5	0.9
Absent	0.75	0	0
Uncertain	0.25	0.5	0.1

6.5.5. Step 5

The likelihood of security level 1 (i.e. L_1), security level 2 (i.e. L_2), and security level 3 (i.e. L_3), as shown in Figure 6.4, is evaluated as 0.40, 0.22, and 0.38 respectively.

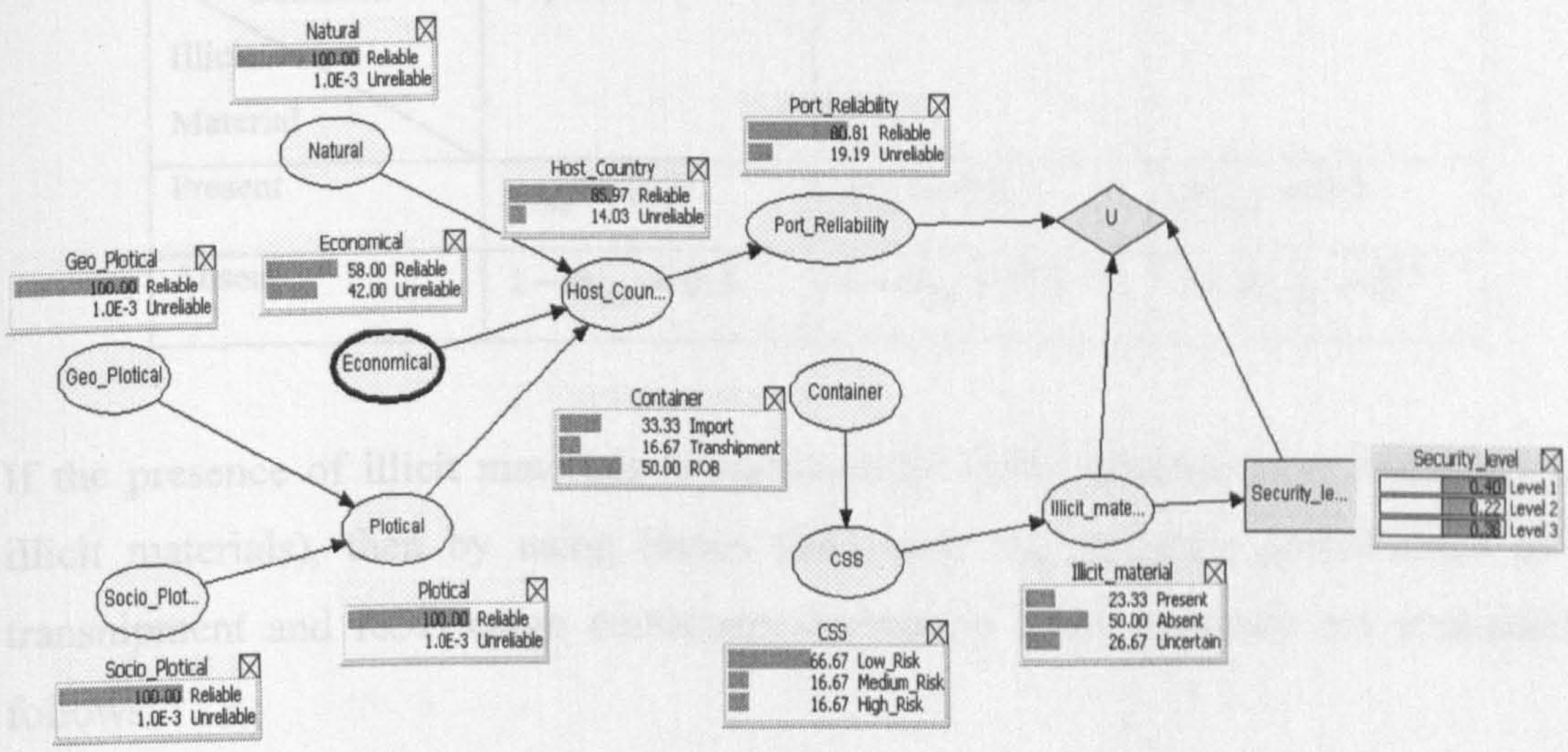

Figure 6.4: BN Decision Making Model for Evaluating the Security Level

6.5.6. Step 6

Based on Step 5 the value of L_1 (i.e. 0.4) is greater than the individual values of L_2 (i.e. 0.22) and L_3 (i.e. 0.38) and is lesser than the combination of both (i.e. 0.6). In other words additional protective measures should be maintained. Consequently, based on Table 6.6, the security level is evaluated as Level 2.

6.5.7. Step 7

Based on Table 6.7, 500 transhipment cargo containers and 500 ROB cargo containers on board the V-ship are categorised as medium and high risk. Most security experts think that, if terrorists were to use a container, they would be involved in the container stuffing origin of the shipment, and almost certainly affix appropriate container seals or devices to the container (Maritime Security Expo, 2006). Thus, the probability that an import cargo container contains illicit materials is higher than the transhipment and ROB cargo containers. Assume that after surveillance of port-þ's topology (Section 6.3) a *CPT*, as shown in Table 6.9, is illustrated by security experts.

Table 6.9: Experts' Opinion based on the Topology of Port-þ

Illicit Material \ Container	Import	Transhipment	ROB
Present	$\sigma_{IM}=0.7$	$\sigma_{TS}=0.5$	$\sigma_{ROB}=0.3$
Absent	$1-\sigma_{IM}=0.3$	$1-\sigma_{TS}=0.5$	$1-\sigma_{ROB}=0.7$

If the presence of illicit materials is known with 100% certainty (i.e. instantiation of illicit materials), then by using Bayes chain rule the posterior probabilities of the transhipment and ROB cargo containers containing illicit materials are evaluated as follows:

$$P(Container=TS)=\frac{N_{TS}\sigma_{TS}}{N_{TS}\sigma_{TS}+N_{ROB}\sigma_{ROB}}=\frac{500\times 0.5}{500\times 0.5+500\times 0.3}=62.5\%$$

$$P(Container=ROB)=\frac{N_{ROB}\sigma_{ROB}}{N_{TS}\sigma_{TS}+N_{ROB}\sigma_{ROB}}=\frac{500\times 0.3}{500\times 0.5+500\times 0.3}=37.5\%$$

Based on the above calculations and since the posterior probability of the transhipment cargo containers (i.e. 62.5%) is greater the posterior probability of the ROB cargo containers (i.e. 37.5%), therefore, all transhipment cargo containers (i.e. 500TEU) should be scanned or physically inspected.

6.5.8. Sensitivity Analysis (*Final Step)*

A sensitive analysis is used to test the logicality of the delivery of the analysis result. To carry out the research the percentage of low, medium, and high risk containers, as shown in Table 6.10, is decreased and increased by a certain amount respectively. Accordingly the obtained results (i.e. security level) are found to be realistic.

Table 6.10: Sensitive Analysis

CSS	*Likelihood of security level*	*Result*
90% Low risk 0% Medium risk 10% High risk	$L_1 = 0.54$ $L_2 = 0.19$ $L_3 = 0.27$	Level 1
85% Low risk 0% Medium risk 15% High risk	$L_1 = 0.51$ $L_2 = 0.18$ $L_3 = 0.31$	Level 1
84% Low risk 0% Medium risk 16% High risk	$L_1 = 0.50$ $L_2 = 0.18$ $L_3 = 0.32$	Level 2
76.67% Low risk 10% Medium risk 13.33% High risk	$L_1 = 0.46$ $L_2 = 0.21$ $L_3 = 0.33$	Level 2
73.33% Low risk 10% Medium risk 16.67% High risk	$L_1 = 0.44$ $L_2 = 0.20$ $L_3 = 0.36$	Level 2
71% Low risk 0% Medium risk 29% High risk	$L_1 = 0.43$ $L_2 = 0.17$ $L_3 = 0.41$	Level 2
70% Low risk 0% Medium risk 30% High risk	$L_1 = 0.42$ $L_2 = 0.16$ $L_3 = 0.42$	Level 3
66.67% Low risk 16.67% Medium risk 16.67% High risk	$L_1 = 0.40$ $L_2 = 0.22$ $L_3 = 0.38$	Level 2
60% Low risk 20% Medium risk 20% High risk	$L_1 = 0.36$ $L_2 = 0.22$ $L_3 = 0.42$	Level 3

6.6. Results and Discussion

In an ideal condition by scanning all import cargo containers loaded at an overseas port of embarkation (e.g. port-A) and to be discharged at a port of disembarkation (e.g. port-E), the probability that an import cargo container does not contain illicit material can be increased but cannot approach 100% certainty. The reason is that as soon as the cargo is loaded on board a vessel it passes through different ports (i.e. B, C, and D) with different reliabilities and each of them poses different levels of security risk. Thus the only practical way to clear from this dilemma, due to lack of information and number of variables, is to enhance the ocean or sea carriers' reliability through enhancing their ship staff's reliability. The methodology for selection of and control options for improving the ship staff's reliability were shown in Chapters 3 and 4. To analyse the cost and benefit (i.e. CBA), the following decision making scenario is developed:

To increase a shipping company's profit, its manager has to make a decision to take an action or not. The manager is uncertain whether the performance of the company's employees (i.e. ship staff's performance or SSP) is high, average or low. The cost of an action is C_1. It is believed that by taking an action and enhancing the performance of the employees (i.e. with average performance) the reliability of the company's vessels will increase and accordingly the profit and the net profit associated with an action can be estimated as B_1 and $(B_1 - C_1)$ respectively. Similarly for the employees with low performance, the profit and the net profit associated with an action can be estimated as B_2 and $(B_2 - C_1)$ respectively. An assessment programme (i.e. Audit) will help the manager to determine the company's performance (i.e. CP). The cost of an assessment programme (i.e. Audit) is C_2. The manager assumes that 50%, 30%, and 20% of the company's employees are with high, average and low performances respectively. Based on experts' opinion a CPT, as shown in Table 6.11, can be illustrated.

Table 6.11: CPT (Company performance | Performance of Ship Staff)

SSP / *CP*	*High (H)*	*Average (A)*	*Low(L)*
High (H)	0.8	0.1	0.1
Average (A)	0.1	0.8	0.2
Low (L)	0.1	0.1	0.7

Based on the Bayes chain rule the following equations can be evaluated:

$$
\begin{aligned}
&P(CP=H)=0.8\times 0.5+0.1\times 0.3+0.1\times 0.2=0.45\\
&P(CP=A)=0.1\times 0.5+0.8\times 0.3+0.2\times 0.2=0.33\\
&P(CP=L)=0.1\times 0.5+0.1\times 0.3+0.7\times 0.2=0.22\\
&P(SSP=H\mid CP=H)=\frac{0.8\times 0.5}{0.45}=0.89\\
&P(SSP=A\mid CP=H)=\frac{0.1\times 0.3}{0.45}=0.07\\
&P(SSP=L\mid CP=H)=\frac{0.1\times 0.2}{0.45}=0.04\\
&P(SSP=H\mid CP=A)=\frac{0.1\times 0.5}{0.33}=0.15\\
&P(SSP=A\mid CP=A)=\frac{0.8\times 0.3}{0.33}=0.73\\
&P(SSP=L\mid CP=A)=\frac{0.2\times 0.2}{0.33}=0.12\\
&P(SSP=H\mid CP=L)=\frac{0.1\times 0.5}{0.22}=0.22\\
&P(SSP=A\mid CP=L)=\frac{0.1\times 0.3}{0.22}=0.14\\
&P(SSP=L\mid CP=L)=\frac{0.7\times 0.2}{0.22}=0.64
\end{aligned}
\tag{6.13}
$$

A decision tree is a diagram that represents, in a special organised way, the decisions and the main external or other events that influence uncertainty, as well as possible outcomes of all those decision and events. Figure 6.5 shows a decision tree representation and solution to this problem. In Figure 6.5, squares represent decisions and the lines coming out of each square show all available distinct options that can be selected at the decision analysis point. For instance, as shown in Figure 6.5, to perform an assessment programme (i.e. Audit) or not to perform, two lines coming out of "audit square" show all available distinct options (i.e. Yes or No) that can be selected by the manager. In Figure 6.5, circles show various circumstances that have uncertain outcomes and the lines that come out of each circle denote a possible outcome of that uncertainty. For instance, as shown in Figure 6.5, the "circle R" shows the result of an assessment program and the lines that come out of "circle R" denote possible outcomes of that uncertainty (i.e. a company's performance is high, average, or low). Based on

Equation 6.13 the probability of each outcome is written on each respective line. Based on Figure 6.5, the manager can calculate the overall desirability of those choices. For instance, if the manager makes a decision to perform the audit and based on the audit's result the company's performance found to be high, then the desirability for taking an action can be calculated as follows:

$$\begin{aligned} &-0.89\times(C_1+C_2)+0.07\times[B_1-(C_1+C_2)]+0.04\times[B_2-(C_1+C_2)] \\ &=0.07\times B_1+0.04\times B_2-(C_1+C_2) \end{aligned} \quad (6.14)$$

If the assessment (i.e. evaluated by Equation 6.14) is lesser than "$-C_2$", then no action has to be taken. Thus:

$$\begin{aligned} &0.07\times B_1+0.04\times B_2-(C_1+C_2)<(-C_2) \\ &\mathit{or} \\ &0.07\times B_1+0.04\times B_2<C_1 \end{aligned} \quad (6.15)$$

If the manager makes a decision to perform the audit, with similar techniques Equations 6.14 and 6.15 are evaluated, the desirability for the other choices can be assessed. Thus, the three conditions can be summarised as follows:

1. If a company's performance is high and $C_1 > 0.07\times B_1+0.04\times B_2$, then take no action.
2. If a company's performance is average and $C_1 > 0.73\times B_1+0.12\times B_2$, then take no action.
3. If a company's performance is low and $C_1 > 0.14\times B_1+0.64\times B_2$, then take no action.

As an illustrative example, assume the company owns 10 vessels and the total loss of the company due to low reliability of its vessels (i.e. delay, accidents, and detention) is estimated as £2,400,000. Assume $B_2 = 2\times B_1$. Thus:

$$B_1 + B_2 = £2{,}400{,}000$$
$$B_2 = 2 \times B_1$$
$$B_1 = £800{,}000$$
$$B_2 = £1{,}600{,}000$$

The manager may take an action to increase the manning scale of all the vessels by employing additional Second Officers. The total cost of this action (i.e. C_1) is estimated as £480,000 (i.e. 12 × 10 × £4000). The cost of an assessment programme (i.e. C_2) is estimated as £100,000. As a result, the condition 1 is satisfied and conditions 2 and 3 are not satisfied. Consequently and based on Figure 6.5, the expected profit associated with this strategy is calculated as:

$$\begin{aligned}
&-0.45\times(C_2)+\\
&0.33\times\{-0.15\times(C_1+C_2)+0.73\times[B_1-(C_1+C_2)]+0.12\times[B_2-(C_1+C_2)]\}+\\
&0.22\times\{-0.22\times(C_1+C_2)+0.14\times[B_1-(C_1+C_2)]+0.64\times[B_2-(C_1+C_2)]\}=\\
&0.2717\times B_1+0.1804\times B_2-0.55\times C_1-C_2\approx\\
&0.27\times B_1+0.18\times B_2-0.55\times C_1-C_2=£140{,}000
\end{aligned} \tag{6.16}$$

Based on Figure 6.5, the expected profit associated with taking an action and not performing the audit is calculated as:

$$\begin{aligned}
&0.5\times(-C_1)+0.3\times(B_1-C_1)+0.2\times(B_2-C_1)=\\
&0.3\times B_1+0.2\times B_2-C_1=£80{,}000
\end{aligned} \tag{6.17}$$

Based on Equations 6.16 and 6.17, the optimal strategy is to perform a crew assessment programme; take no action if the company's performance is high, and take an action if an assessment programme reveals the company's performance either average or low.

For the above example and by assuming that the utility function is a linear function of the monetary profit, a *BN* decision making model, as shown in Figure 6.6, is illustrated. In Figure 6.6, squares represent decisions and diamonds (i.e. U_1 and U_2) represent utilities. The values for U_1 and U_2 are shown in Tables 6.12 and 6.13. In Figures 6.6, the expected profits associated with taking an action and performing the audit (i.e. yes) or not performing the audit (i.e. no) are estimated as £140,000 and £80,000 respectively.

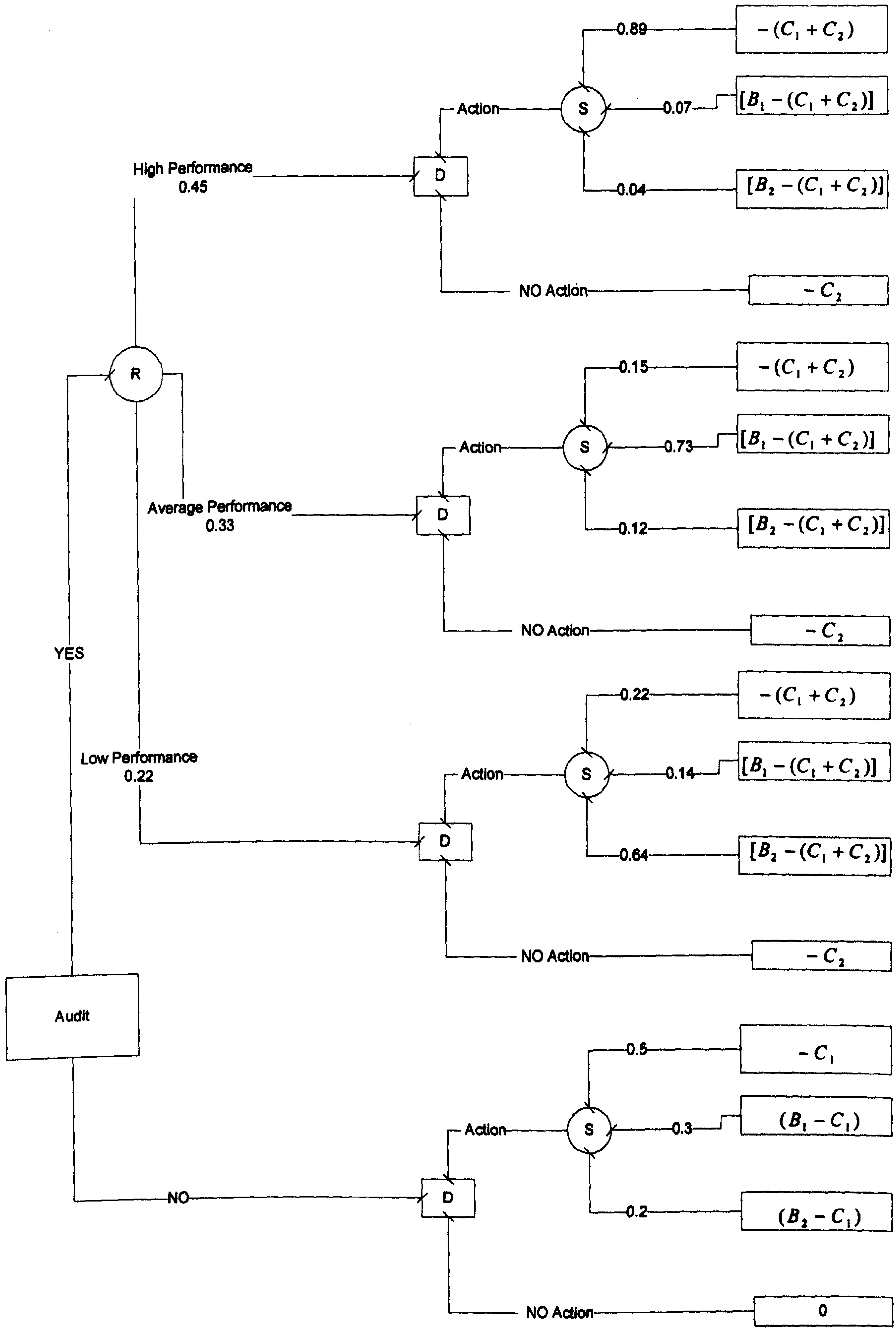

Figure 6.5: Decision Tree for the Shipping Company

Table 6.12: Values of U_1

Audit	Yes	No
U_1	-£100,000	0

Table 6.13: Values of U_2

Action	Yes			No		
SSP	High	Average	Low	High	Average	Low
U_2	-£480,000	£320,000	£1,120,000	0	0	0

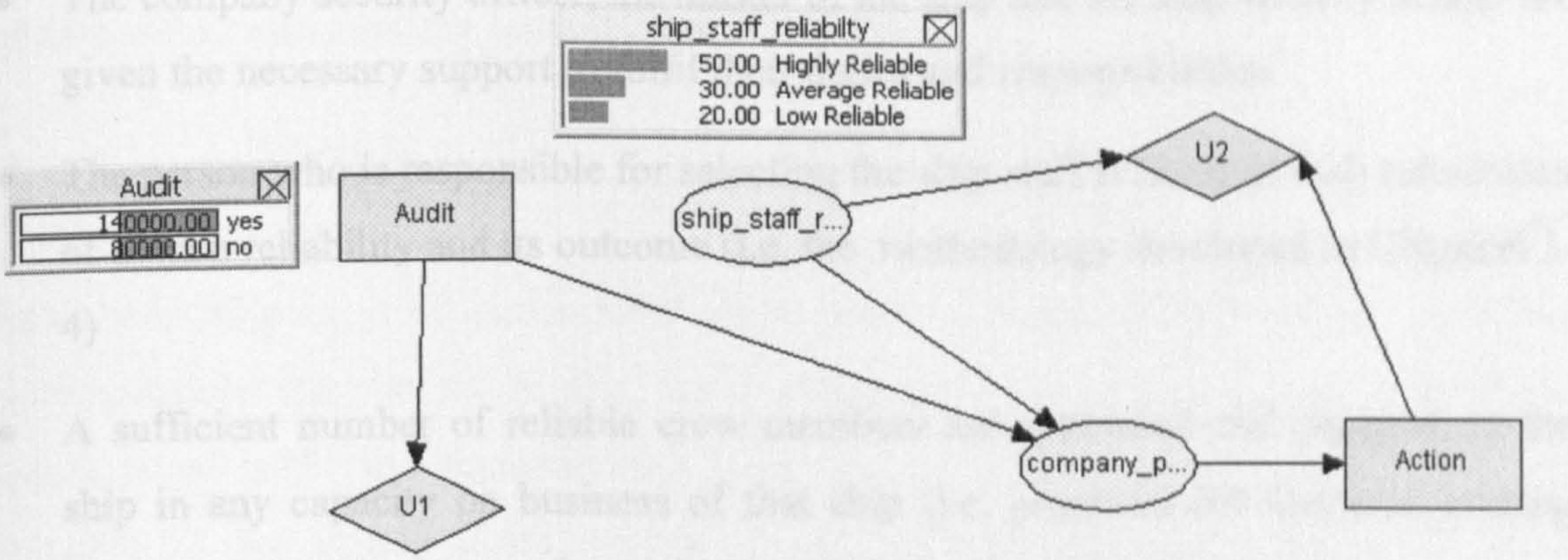

Figure 6.6: BN Decision Making Model for Evaluating the Shipping Company's Profit

6.7. Conclusion

Within the previous chapter a *FBN* model for evaluating a container security score was developed. The output of the newly developed model (i.e. security scores of containers) is used within this chapter to evaluate the security level of a port, prior to ship / port interface.

This chapter generates a new approach to pre-processing of input data that allows the use of standard *BN* techniques and software tools for evaluating the security level of a port. Based on the developed *FBN* decision making model, port authorities are able to assess the level of security risk prior to a containership's arrival at anchorage and making decisions accordingly (i.e. the ship permitted, further inspection is required, or not entitled to enter the port).

Based on the analysis, the significant influence of the ship staff's reliability on the level of security risk is revealed within this chapter. As a result, if a shipping company would like to expand its security effort to maintain its profit and reputation, the company should not only identify its weakness, including human factors in the infrastructure, policies and procedure but also ensure that:

- The company security officer, appropriate shore-based company personnel and ship security officer receive the necessary training.
- The company security officer, the master of the ship and the ship security officer are given the necessary support to fulfil their duties and responsibilities.
- The person who is responsible for selecting the ship staff is familiar with calculation of human reliability and its outcome (i.e. the methodology developed in Chapters 3-4)
- A sufficient number of reliable crew members are appointed and engaged on the ship in any capacity on business of that ship (i.e. proposed *BN* Decision making model, within this chapter, for evaluating the shipping company's profit).
- Internal audits are carried out at planned intervals, findings are reviewed and the appropriate corrective measures are taken, where necessary.

Chapter Seven

Conclusions and Further Research

Summary

Within this chapter the reliability assessment and decision making approaches and techniques that would be valuable in safety/security of CLSC operation are outlined. Furthermore, the areas, which require more effort to be paid for the enhancement of the developed approaches, are summarised.

7.1. Research Contribution

More than 90 percent of international cargo passes through seaports, which contribute approximately 99 percent to the world economy. Thus, smooth operation of the international trade and transportation infrastructure is essential to global trade. The integrity of the supply chain system is highly dependent on the reliability of its components (i.e. importers, exporters, manufacturers, manufacturing sites, inland carriers, warehouses, ports, containerships, container consolidation and deconsolidation facilities, etc.). Additionally the challenges in appropriately assessing the reliability of the supply chain are associated with uncertainty.

There are two types of threat related to ports: direct attacks, or the transport of containers containing illicit materials through ports for use in terrorist plot elsewhere in a country. If a port is closed to counteract a significant incident or in response to an attack, then trading partners are no longer trusted, consumer choices are reduced with fewer goods, and possibly higher prices. To prevent the relevant commercial dilemma, commercial operators can respond by attempting to mitigate risk. Mitigation can consist of attempting to reduce the damage caused by supply chain disruptions, or taking actions to prevent or reduce the possibility of supply chain disruptions. If the sources of vulnerabilities are known, then an early warning system can focus on these sources and help to generate timely awareness of potential and actual disruptions, allowing for earlier mitigation and reduction of losses. Mitigation systems can also assign responsibility, detailing who should focus on which areas of security threats.

The work presented in this thesis has developed four new analytical models capable of performing reliability assessments of a *CLSC's* components and security/safety management under high uncertainties. Such frameworks have been demonstrated by four corresponding test cases with regards to safety/security of *CLSC* operations. The frameworks have been developed in a generic sense to be applicable to deal with operational and management problems and as a foundation for generation of various risk analysis methods and decision making procedures. In summary, the newly developed methods and techniques can be summarised as follows:

- Based on the detailed and comprehensive review of root causes for human error a generic model with a hierarchical structure for evaluating the seafarers' reliability, by using fuzzy logic and *ER* approach has been constructed and the methodology for evaluating the seafarers' reliability developed.
- A novel frame of reference (i.e. benchmark) for selection of seafarers, based on their reliability, has been created and tested.
- A new approach to pre-processing of input data that allows the use of standard *BN* techniques and software tool for evaluating the seafarers' reliability has been developed and constructed.
- A *FBN* model to evaluate the reliability of a complex system and to deal with the dependent relationships between input variables has been developed.
- A new *symmetric model* to enable the wider application of *FBN* in a generic mode has been created.
- A new *FBN* methodology has been proposed that allows researchers in the field of expert systems to unify possibility and probability approaches to the decision making process.
- A general equation for the prediction of reduction of human reliability attributable to a person's continuous hours of wakefulness, acute sleep loss and cumulative sleep debt has been formulated.
- Methodologies for evaluating the reliability of commercial operators (i.e. importer, exporter, manufacturer, etc.) and premises (i.e. ports, warehouses, manufacturing sites, container consolidation and de-consolidation centres) has been developed.

Furthermore, by using *FBN* and symmetric model the methodology for evaluating a container's security score has been developed. The new *FBN* methodology can be used for targeting those containers which pose high level of risk to the container supply chains. Additionally, the new methodology can be used to identify the commercial operators that do not act appropriately to secure their supply chains.

- The need to formulise port security level decision making has been identified. Consequently a new *FBN* decision making model for evaluating the security level of a port, based on security scores of a ship's cargo containers prior to ship / port interface, has been developed. Based on the proposed *FBN* decision making model, port authorities are now able to assess the level of security risk prior to a containership's arrival at anchorage and making decisions accordingly (i.e. the ship permitted, further inspection is required, or not entitled to enter the port).
- *A BN* Decision making model has been formulated. The model can be used to analyse the company's costs, benefits and potential company's profit.

It is believed that these newly developed methods can be adapted to the practical application of dealing with safety/security problems in other industries, particularly in situations where a high level of uncertainty exists. More specifically:

- The fuzzy logic and Bayesian probability inferences are two major uncertainty reasoning theories. Because of their flexibility and prediction capabilities, both fuzzy logic and *BNs* have shown much potential in the field of risk assessment including broad risk analysis, risk prediction and risk based decision making. The *FBN* methodologies developed within this thesis on the basis of the two theories can be considered as the contribution to the absence of the literature of risk and reliability studies in the context of *CLSCs* and the transference of the knowledge of uncertainty treatment to the area of risk assessment.
- In risk assessment and safety/security management the tactic for managing uncertainty is a main concern. Irrespective of what approach to be applied it is always dependent on human judgment to manage the uncertainties. In other words, the deficiencies of risk modelling resulting from the lack of data or a high level of uncertainty as a result of intrinsic feature of complex systems must be made up by

means of general evaluation capacity of humans, who are able to grasp the essence of an object even if it is vague and unclear. In modelling realistic safety/security scenarios using *BNs*, the converging connections are more popular than diverging and serial connections. This point can be supported by many widely used hierarchical risk analysis approaches such as *FTA*. The converging connections are more difficult to handle appropriately compared to the diverging and serial connections in *BNs*; they are not friendly enough for human knowledge and may be too specific for any expert. A novel "*Symmetric Model*" has been developed within this thesis to have the capability of dealing with such a problem, thus helping the wider applications of *BNs* in a generic mode.

Since the test cases in this study provide reasonable results, the analytical models developed have the potential to improve the safety of *CLSC* operation by enabling and facilitating the decision makers to evaluate the reliability of a seafarer prior to his/her designation to any activities and during his/her seafaring period, and evaluating the outcome (i.e. *CBA*). The new methods have the potential to improve the security of *CLSC* operation by targeting those containers with high or medium level of risk particularly in circumstances where the lack of data exists or such information is associated with a high level of uncertainty without jeopardising the efficiency of operation. Furthermore, they can be used for evaluating the security level of a port, based on security scores of a ship's cargo containers prior to ship / port interface. Such that port authorities are able to assess the level of security risk prior to a containership's arrival at anchorage and making decisions accordingly (i.e. the ship permitted, further inspection is required, or not entitled to enter the port).

7.2. Implication for Future Research

Although this programme of research provides a comprehensive analysis related to the risk assessment and decision making of the *CLSC* operation, further opportunities for the application of the ideas developed have been identified. Further research opportunities are listed as follows:

Firstly, within Chapter 2 under heading of historical failure data and statistical analysis, the data was collected for *UK* merchant vessels via the *MAIB*. However, for further research there is the possibility of using international databases such as Australian Transport Safety Bureau (*ATSB*), National Transportation Safety Board (*NTSB*) and Marine Accident Investigators' International Forum (*MAIF*). This will provide a more extensive input data set.

Secondly, within this thesis an *AHP* methodology was used to obtain the relative importance of each criterion or attribute. In order to conduct the assessment, a group of three experts were employed. However, for further research the number of experts could be increased and they could be selected from a range of different maritime industries (e.g. port state controls, ship owners, ship staff, marine academia, and marine superintendents). This would further increase the applicability of the newly developed techniques and may give rise to further interesting findings.

Thirdly, in Chapter 4 a general equation (i.e. Equation 4.31) for the prediction of loss of human reliability as a function of a person's continuous hours of wakefulness, acute sleep loss and cumulative sleep debt was formulated. Furthermore, Equation 4.31 was validated by help of two test cases (i.e. Lindbergh's Flight to Paris and Guantanamo Bay Aviation Accident). For complete validation of Equation 4.31, further research under simulation laboratory conditions can be conducted as follows:

- Firstly, in a simulation laboratory a person should be designated to operate a gantry crane for four consecutive hours. Such an experiment will test the effects of fatigue on coordination and concentration during the loading and unloading of container vessels.

- Secondly, the number of the operations (i.e. the number of consecutive movements for loading and discharging) and the number of errors (i.e. the number of incidents and accidents) should be recorded. The number of errors divided by the number of operations can indicate a person's unreliability value. Accordingly the designated person's reliability value can be calculated.

- Thirdly, an identical test should be carried out by the same person and with different percentages of sleep loss (i.e. in a 24- hour period).

- Fourthly, the difference of his/her reliability value in steps 2 and 3 can indicate the reduction of his/her reliability due to continuous hours of wakefulness, acute sleep loss and cumulative sleep debt.
- Fifthly, Steps 1-4 should be repeated with at least ten different persons, the associated deviation should be studied accordingly.

Such a series of tests could also be a carried out on selected deck officers through the use of a ship/bridge simulator.

Fourthly, in Chapter 5 a general equation (i.e. Equation 5.4) for evaluating the increment of an importer's reliability (i.e. δ) due to observation of no violation with customs laws and regulations through inspection or scanning of "N" consecutive containers at the port of embarkation was formulated. Based on the security requirement, the value of C in Equation 5.4 was assigned by the author. To evaluate a rational value for C, based on the following, further research in different ports can be conducted.

- The availability of illicit materials or contraband at the host country.
- The willingness of terrorist organisations to attack the port or its host country.
- The damage capability and recall difficulties after an attack.
- The consequences of an attack in world trade or international supply chain.
- The reliability of the host country and the port.

Fifthly, The complexity of container line supply chains leads to a lack of transparency which interferes with the ability to monitor their safety/security. Based on the physical security requirements and procedural security standards identified within this thesis, it was suggested that the commercial operators and premises be certified by an independent competent body such as a reputable classification society. As a result, the effectiveness of the check lists which have been constructed in Appendix 4 should be further investigated by the classification societies. Furthermore, the security score of commercial operators and premises should be included within classification societies' audits.

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Appendices

Appendix 1

Summary of Security Initiative, Conventions, Rules and Regulations

A1.1. Special Measure to Enhance Maritime Security

International Ship and Port Facilities Security Code *(i.e. ISPS Code)* enforced from 1st of July 2004. *Part A* of the Code is mandatory and *part B* contains guidance as how to comply with the mandatory requirements. The regulation requires administrations to set security levels and ensure the provision of security level information to ships entitled to fly their flag. Prior to entering a port, or whilst in a port, within the territory of a contracting government, a ship shall comply with the requirements for the security level set by that contracting government, if that security level is higher than the security level set by the administration for that ship. Regulation *XI-2/8* confirms the role of the Master in exercising his professional judgement over decisions necessary to maintain the security of the ship. It says he shall not be constrained by the company, the chatterer or any other person in this respect. Regulation *XI-2/5* requires all ships to be provided with a ship security alert system. When activated the ship security alert system shall initiate and transmit a ship-to-shore security alert to a competent authority designated by the administration, identifying the ship, its location and indicating that the security of the ship is under threat or it has been compromised. The system will not raise any alarm on-board the ship. The ship security alert system shall be capable of being activated from the navigation bridge and in at least one other location. Regulation *XI-2/6* covers requirements for port facilities, providing among other things for contracting governments to ensure that port facility security assessments are carried out and that port facility security plans are developed, implemented and reviewed in accordance with the *ISPS Code*. Other regulations in this chapter cover the provision of information to *IMO*, the control of ships in port, (including measures such as the delay, detention, restriction of operations including movement within the port, or expulsion of a ship from port), and the specific responsibility of companies (IMO, 2003).

A1.2. Twenty-Four Hour Advanced Cargo Rule

The rule requires all sea carriers (with the exception of bulk carriers and approved break bulk cargo) to provide proper cargo descriptions and valid consignee addresses twenty-four hours before cargo is loaded at the foreign port for shipment to the United States. Prior to this requirement, many cargo manifests would simply declare that the container had *"Freight All Kind"* or *"General Merchandise"* (Kelly, 2007).

A1.2.1. Automated Targeting System (ATS)

ATS takes manifest information provided in accordance with the twenty-four hour rule and uses a system that integrates enforcement and commercial databases. The system is designed to detect anomalies and determines which cargo is high-risk and should be subject to additional scrutiny. ATS accomplishes this by analysing the data and rank ordering it based on certain rules and algorithms. Upon reaching certain thresholds, cargo may be targeted for further action by Customs and Border Protection (CBP), including physical inspection of the container (Kelly, 2007).

A1.3. Container Security Initiative (CSI)

Under CSI, teams of CBP and Immigration and Customs Enforcement (ICE) personnel are assigned to (currently) fifty-four ports around the world that collectively account for about ninety per cent of the containerised freight destined for the U.S. The program calls for CBP to work with host nation customs officials to examine high-risk containers at foreign seaports before they are loaded on vessels bound for the U.S. The three core elements of CSI are (Kelly, 2007):

1. Identify high-risk containers. CBP uses automated targeting tools to identify containers that pose a potential risk for terrorism, based on advance information and strategic intelligence.
2. Pre-screen and evaluate containers before they are shipped. Containers are screened as early in the supply chain as possible, generally at the port of departure.

3. Use technology to pre-screen high-risk containers to ensure that screening can be done rapidly without slowing down the movement of trade. This technology includes large-scale X-ray and gamma ray machines and radiation detection devices.

A1.3.1. Secure Freight Initiative (SFI)

SFI is a pilot program designed to test high-volume scanning at six ports in Pakistan, Honduras, UK, Oman, Singapore and South Korea. Containers arriving at participating ports are scanned with both non-intrusive radiographic imaging and passive radiation detection equipment placed at terminal arrival gates to screen incoming containers. Transhipment cargo containers (i.e. those being transferred from ship to ship) would also be scanned. Sensor and image data concerning U.S. bound containers will be transmitted in near real-time to the National Targeting Centre where it will be combined with other available risk data to improve risk scoring and targeting of high-risk containers; thus enhancing the opportunity to conduct further scrutiny of suspect cargo while still overseas (Kelly, 2007).

A1.3.2. Customs-Trade Partnership Against Terrorism (C-TPAT)

C-TPAT is a "public-private partnership" that is designed to strengthen the global supply chain by the voluntary agreement of the private sector program participants to adopt a wide range of security measures. For example, in the area of container and trailer security, members are required to take certain measures to ensure that containers and truck trailers are protected against the introduction of unauthorized material and/or persons. At the point-of-stuffing, containers and trailers must be sealed using an approved "high security" seal and an inspection must be conducted to assure the physical integrity of the box. Other *C-TPAT* requirements include personnel security, procedural security, information technology security, physical security and security training/threat awareness. *C-TPAT* is open to a wide range of industries in the trade community including importers, sea, air and land carriers, airfreight consolidators, port/terminal operators, and foreign manufacturers and warehousing operators. In return for their participation, *C-TPAT* members are extended certain benefits that reduce the level of inspection that participant's shipments are subjected to when entering the United States. Because of their certification as a *C-TPAT* member, the risk profile on their shipments is reduced; thus subjecting it to a far lower likelihood of extensive documentary and physical inspection. Additionally, they receive access to *FAST* lanes on the Canadian and Mexican border and expedited cargo processing at *FAST* lanes. *C-TPAT* members are certified by CBP based on self-reported compliance with mandated security measures and are vetted, in part, based on prior history concerning violations and compliance with customs regulations. Critics of *C-TPAT* question whether CBP has sufficient procedures and personnel to validate that members are indeed compliant with mandated security measures (Kelly, 2007).

A1.3.3. Mega Ports Initiative

The initiative provides early detection of possible illegal trafficking of nuclear materials through foreign ports. Under this program, the National Nuclear Security Administration (*NNSA*) installs radiation detection equipment at foreign ports to strengthen the detection and exclusion capabilities of officials within the partner nations. The program is designed to provide the foreign governments with the ability to screen incoming, outbound and transhipped cargo while posing a minimal threat of delay to port operations. *NNSA* has identified seventy ports of interest in some thirty-five countries based on the volume of U.S. bound containers. To date, however, it is only operational in Greece, Bahamas, Sri Lanka, Spain, Singapore and the Netherlands (Kelly, 2007).

A1.4. Conventions & Regulations

Based on Singapore Shipping Association (SSA, 2008)'s research the following conventions and regulations regarding minimum standards expected for planning, loading, transportation and discharge of containers with the aim of preventing further accident are listed.

A1.4.1. International Convention for Safe Containers 1972 (CSC Convention)

The stated objective of the *CSC* Convention is to maintain a high level of safety of human life in transport and handling of containers by providing acceptable test procedures and related strength requirements and to facilitate the international transportation of containers through uniform international safety regulations equally applicable to all modes of surface transport. There are two annexes to the Convention. Annex 1 provides, over the course of five chapters, the regulatory framework by which administrations may approve containers as conforming to the maintenance and examination criteria of the instrument. Annex 2 concerns the structural safety requirements and tests for containers and provides a number of test loads and procedures for containers in operational contexts such as lifting, stacking, transverse racking, etc. It should be noted that the *CSC* does allow for the approval of containers that do not meet the structural norms of the *ISO* standards upon which most vessel stowage systems are bound.

A1.4.2. Code of Safe Practice for Cargo Stowage and Securing (CSS)

The *CSS* code aims to provide an international standard to promote the safe stowage and securing of cargoes, including containers, by a number of means, and establishes the general principles of cargo stowage and securing. The code is divided into seven chapters that set out securing systems and appropriate actions to be taken in heavy weather following the shifting of the cargo. There are 13 annexes to the code that address safe stowage and securing procedures for specific types of cargo.

A1.4.3. International Maritime Dangerous Goods (IMDG) Code

The *IMDG* code is the instrument under *SOLAS* that governs dangerous goods transported in the marine environment. Importantly, the code does not only concern itself with the carriage of dangerous goods in packaged form in containers, but also with terminology, packaging, labeling, placarding, markings, stowage, segregation, handling, and emergency response. It therefore extends beyond the ship to shore side operations concerning the packaging and transport of dangerous good in containers. The code is divided into two volumes and a supplement. The first volume covers general provisions, definitions and training, classifications of dangerous goods, packing and tank provisions, consignment procedures, construction and testing of cargo receptacles and provisions concerning transport operations. The second volume consists of the dangerous goods list and limited quantities exemptions. The code is under permanent review and amendments are published on annual basis.

A1.4.4. Containers Regulations (ISO standards)

All containers destined for carriage by sea should comply with both the international regulations detailed below, as well as the *ISO* Standards contained at Appendix X of International Convention for Safe Containers (*CSC*). All containers presented for carriage by sea must comply with the Container Safety Convention 1984 as noted below:

1. The International Convention for Safe Containers (*CSC*) requires that all those operating containers internationally by sea have in place a system of examination, maintenance and record keeping to ensure that they operate their container fleets safely; their system must be approved by their competent authority, and in particular that:

    - All containers are *CSC* plated.
    - All containers have a Next Examination Date (*NED*), which is a date in the future, or / and *ACEP* approval decal.
    - Records are kept of CSC examinations and *NED*.
    - An Approved Container Examination Procedure (*ACEP*) is in place.

Table A1.1: Summary of International Rules and Regulations for Containerships

Title, Alphabetical order	*Source*	*Code*	*version*
Automatic Identification system	SOLAS	AIS	2004
Cargo Securing Manual	SOLAS MSC.69(69)	CSM	2002
Code of Safe Practice for Cargo Stowage and Securing		CSS	1992
Code on Alarms and Indicator	IMO Resolution A.830(XIX)	ISM	
Convention on International Regulations for Preventing Collisions at Sea		COLREG	1972/2002
Explanatory notes to the standards for ship manoeuvrability	MSC Circ.1053	ISM	
Fire Test Procedure Code	MSC.80(43)	FTP	2002
Guidance for implementation of SOLAS chapter XI-2 and ISPS code	MSC circ.1097	ISM	
Guidelines for the control and management of ship's ballast water to minimise the transfer of harmful aquatic organisms and pathogen	IMO resolution A.868(XX)	ISM	
Harmonised System of Surveys and Certification	SOLAS MSC.88(71)	HSSC	2001
Inspection of water tight bulkheads	SOLAS MSC.69(69)		2002
Interim guideline for Open Top Containership	MSC/Circ.608		1994,Rev.1
Interim Standards for Ship Manoeuvrability	IMO resolution A.751(18)	ISM	
International Code for Fire Safety System	MSC.98(73)	FSS	2002
International Code for the Safe carriage of packaged irradiated nuclear fuel, plutonium and high –level radioactive waste on board ships	SOLAS MSC.88(71)	INF	2001
International Convention for Safety of life at sea		SOLAS	2004
International Convention on Load lines	MSC.143(77)	ILLC 66/68	2005
International convention on tonnage measurement of ships, amended by IMO resolution A.493(XII) and A.494(XII)			1969
International convention on standards of Training, Certification and watch keeping for seafarers		STCW	1978
International Convention for prevention of pollution from ships including annex VI prevention of air pollution from ships 1997		MARPOL	1973/78,1991 Plus amendments
International Life-Saving Appliances Code		LSA	2003
International Management code for the safe operation of ships and for pollution prevention amended by IMO resolution A. 741(18)	SOLAS MSC.99(73)	ISM	1994/2002
International Maritime dangerous Goods Code	SOLAS MSC.123(75)	IMDG	2004/2006
Issues to be considered when introducing new technology on board ships	MSC circ.1091	ISM	
Prevention of air pollution on ships	IMO resolution A.719(XVII)	ISM	
Principles relating to bridge design	MSC/Circ.982	ISM	
Provision and display of manoeuvring information onboard ships	IMO resolution A.601(XV)	ISM	
Safe Access to working in large Cargo tanks and ballast Spaces	IMO resolutions A.272(VIII)and A.330(IX)	ISM	
Special measure to enhance Maritime Security	SOLAS chapter XI-2		2004

Appendix 2

Solution to Test Case (Chapter 3)

By help of the proposed methodology (Section 3.9) and the following information, the Master of a container vessel can assess the reliability of a Third Officer under his command and evaluate the variation of the Third Officer's reliability value by alteration of each criterion's value.

A2.1. Information

- The Third Officer is 30 years old.
- He holds an approved "officer in charge of navigational watch" certificate of competency (STCW 95) with the level of competency as a second mate and does not hold a BSc degree in nautical science.
- He has a valid medical fitness certificate, and 31.2 months of qualifying sea service.
- He holds the following approved certificates:

  1. Ethic and leadership certificate.
  2. Basic safety training (BST) certificate.
  3. Advanced fire prevention & fire fighting certificate.
  4. Radar simulation training certificate.
  5. Global maritime distress safety system (GMDSS) certificate.
  6. First aid training certificate.
  7. Survival craft and rescue boat training certificate.
  8. Automated radar plotting aids (ARPA) training certificate.
  9. ISM attendance course certificate.
  10. Bridge resource management (BRM) attendance course certificates.

- Pursuant to his statements, the quality of the foods, which are served on board, is "not bad".
- He had 8 hours rest in previous night.
- Based on his statements, the level of his stress is "moderate" and he is "healthy".

- The values of Beaufort number for the last two days are indicated as 4 and 5 respectively.
- The vessel is partially loaded and the value of metacentric height (GM) is 3 meters.
- Based on the available data (during design and construction) and pursuant to ABS guidance notes for the application of ergonomics to marine systems, the design & layout grade is estimated as 100% very good.
- The design & habitability grade for the last two days is estimated as 100% good.
- Based on the Master's observation, he is punctual, needs supervision occasionally, and is enthusiastic.
- Based on the Master's judgement, the grade of his communication and language skill is medium, his teamwork is good, and the grade of his decision-making is medium.
- To estimate his situation awareness, the Master has demonstrated a scenario. The Master asked him to elucidate his actions regarding the presented scenario. Accordingly, the grade of his situation awareness is evaluated as good.

A2.2. Qualification

Based on the previous discussion (Section 3.4.1) the decision makers have assigned the following fuzzy rules for a deck officer's qualification:

- If a person holds a BSc degree in nautical science and an approved chief mate/master certificate of competency (STCW 95) with the level of competency as a master, then his qualification is 100% excellent.
- If a person holds an approved chief mate/master certificate of competency (STCW 95) with the level of competency as a master, then his qualification is 20% excellent and 80% very good.
- If a person holds a BSc degree in nautical science and an approved chief mate/master certificate of competency (STCW 95) with the level of competency as a chief mate, then his qualification is 100% very good.

- If a person holds an approved chief mate/master certificate of competency (STCW 95) with the level of competency as a chief mate, then his qualification is 20% very good and 80% good.
- If a person holds a BSc degree in nautical science and an approved officer in charge of a navigational watch certificate of competency (STCW 95) with the level of competency as a third or second mate, then his qualification is 100% good.
- If a person holds an approved officer in charge of a navigational watch certificate of competency (STCW 95) with the level of competency as a third or second mate, then his qualification is 20% good and 80% average.
- If a person does not hold any certificate of competency, then his qualification is 100% low (e.g. fake certificate) and his or her reliability value is zero.

Based on the given information and the stated rules, the Third Officer's qualification set is assessed as follows:

$$\tilde{Q} = \{(\text{Excellent}, 0), (\text{Very good}, 0), (\text{Good}, 0.2), (\text{Average}, 0.8), (\text{Low}, 0)\}$$

The decision makers have assigned the following fuzzy rules for mapping from qualification to technical proficiency (Figure A2.1):

- If a person qualification is excellent, then his/her technical proficiency is 100% very good.
- If a person's qualification is very good, then his/her technical proficiency is 20% very good and 80% good.
- If a person's qualification is good, then his/her technical proficiency is 10% good and 90% average.
- If a person's qualification is average, then his/her technical proficiency is 20% average and 80% fairly low.
- If a person's qualification is low, then his/her technical proficiency is 100% low.

Based on Equations (3.3-3.5), the following is obtained:

$u^2 = 0.2 \times 0.1 = 0.02$, $u^3 = 0.2 \times 0.9 + 0.8 \times 0.2 = 0.34$, $u^4 = 0.8 \times 0.8 = 0.64$

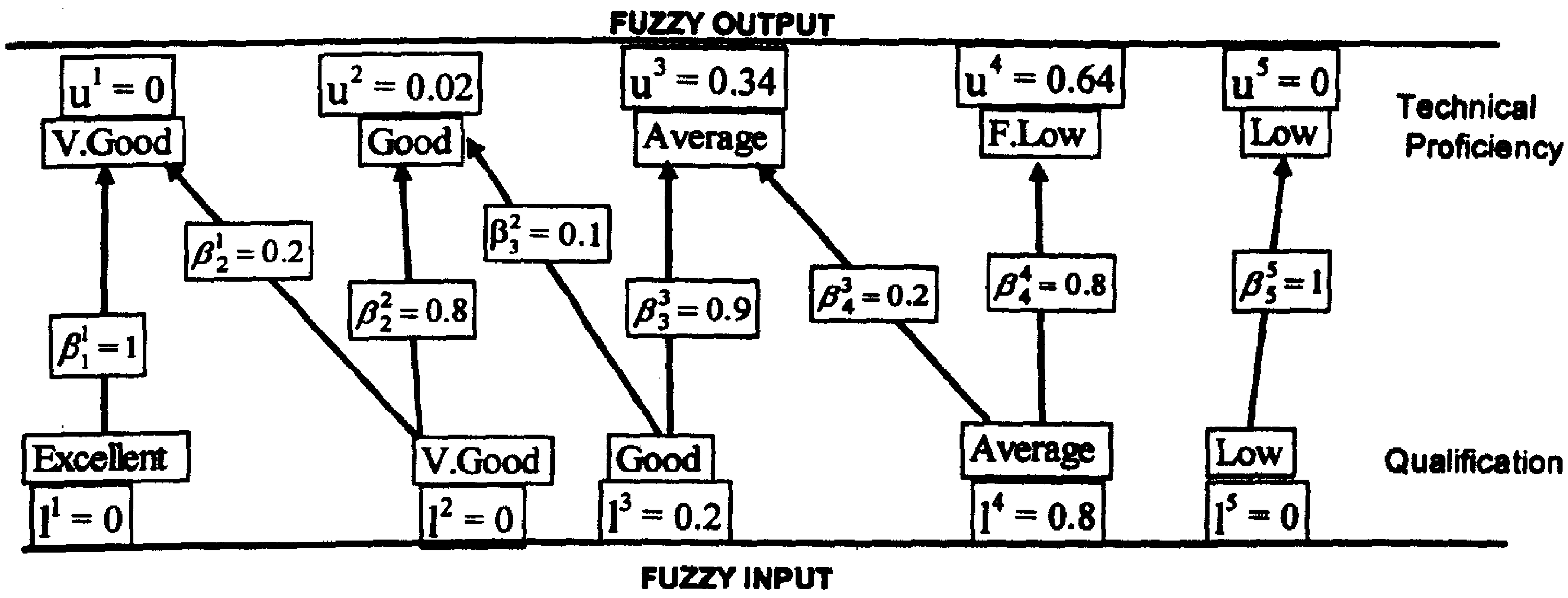

Figure A2.1: Mapping from Qualification to Technical Proficiency

The fuzzy output set is assessed as follows:

$\tilde{T}_Q$ = {(Very Good, 0), (Good, 0.02), (Average, 0.34), (Fairly Low, 0.64), (Low, 0)}

A2.3. Experience

Based on the given information, the Third Officer has 31.2 months of qualifying sea service. Based on Figure 3.6 and Equation (3.20), the belief degrees are calculated as follows:

- H_{n+1} stands for Average grade.
- H_n stands for Low grade.
- $h_i = 31.2$, $h_{n,i} = 30$, and $h_{n+1,i} = 36$.

Thus, $\beta_{n,i} = (36 - 31.2)/(36 - 30) = 0.8$ with the Low grade and $\beta_{n+1,i} = 1 - 0.8 = 0.2$ with the Average grade. Therefore, the Third Officer's experience set is assessed:

$\tilde{E}$ = {(Very Low, 0), (Low, 0.8), (Average, 0.2), (Good, 0), (Very Good, 0)}

The mapping process, as shown in Figure A2.2, is elucidated and elaborated. Accordingly, the fuzzy output set is evaluated as follows:

$\widetilde{T}_E$ = {(Very Good, 0), (Good, 0), (Average, 0.28), (Fairly Low, 0.72), (Low, 0)}

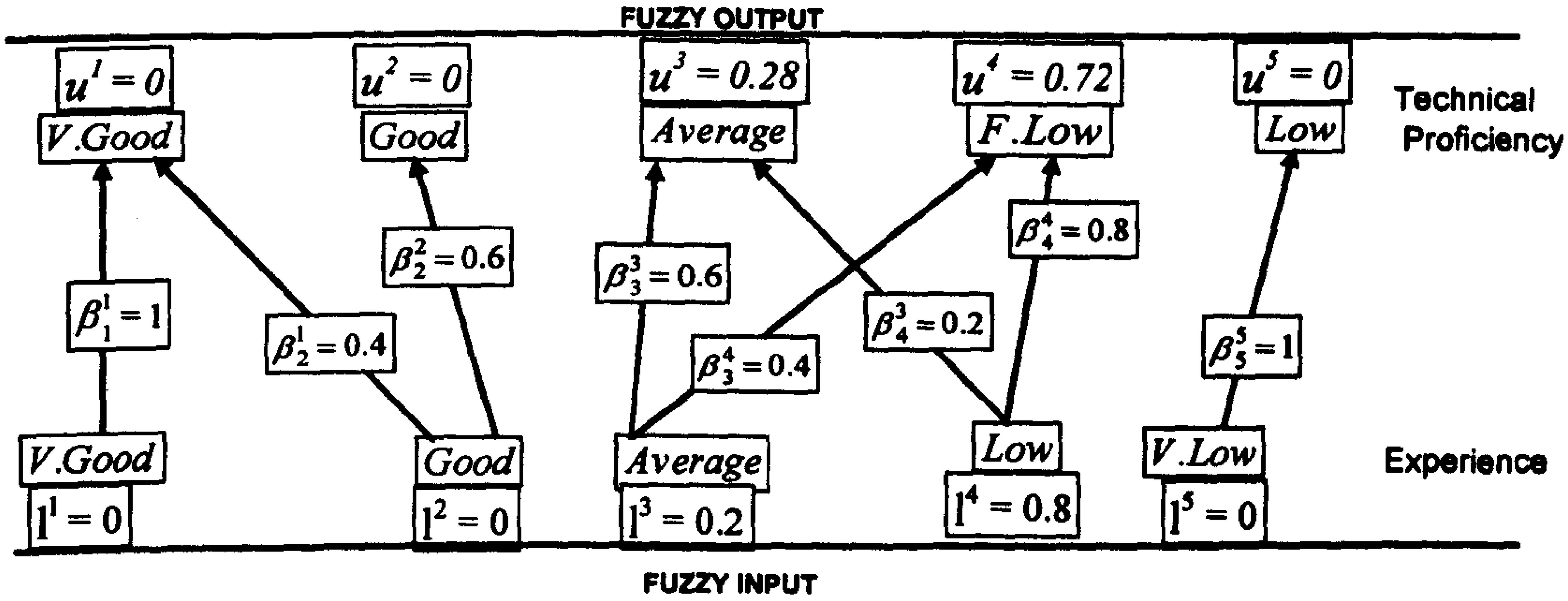

Figure A2.2: Mapping from Experience to Technical Proficiency

A2.4. Specific Training

Based on the previous discussion (Section 3.4.2) the decision makers have assigned the following fuzzy rules for a deck officer's specific training. It is noteworthy to mention that for special vessels (i.e. LNG, Tanker, RORO, passenger, etc) additional requirements have to be considered.

- If a person holds the following certificates, then his/her specific training is 100% excellent.

  1. Ethic and leadership certificate.
  2. Advanced medical training certificate.
  3. Basic safety training (BST) certificate.
  4. Advanced fire prevention & fire fighting certificate.
  5. Radar simulation training certificate.
  6. Global maritime distress safety system (GMDSS) certificate.
  7. First aid training certificate.
  8. Survival craft and rescue boat training certificate.
  9. Automated radar plotting aids (ARPA) training certificate.
  10. ISM attendance course certificate.
  11. Bridge resource management (BRM) attendance course certificates.

- If a person holds the following certificates, then his/her specific training is 20% excellent and 80% very good.

  1. Ethic and leadership certificate.
  2. BST certificate.

3. Advanced fire prevention & fire fighting certificate.
4. Radar simulation training certificate.
5. GMDSS certificate.
6. First aid training certificate.
7. Survival craft and rescue boat training certificate.
8. ARPA training certificate.
9. ISM attendance course certificate.
10. BRM attendance course certificates.

- If a person holds the following certificates, then his/her specific training is 100% good.

1. BST certificate.
2. Advanced fire prevention & fire fighting certificate.
3. Radar simulation training certificate.
4. GMDSS certificate.
5. First aid training certificate.
6. Survival craft and rescue boat training certificate.
7. ARPA training certificate.
8. ISM attendance course certificate.
9. BRM attendance course certificates.

- If a person holds the following certificates, then his/her specific training is 20% good and 80% average.

1. BST certificate.
2. Advanced fire prevention & fire fighting certificate.
3. Radar simulation training certificate.
4. GMDSS certificate.
5. First aid training certificate.
6. Survival craft and rescue boat training certificate.
7. ARPA training certificate.
8. ISM attendance course certificate.

- If a person does not hold any certificate, then his/her specific training is 100% low (e.g. fake certificate) and his or her reliability value is zero.

Based on the stated rules and the given information, the Third Officer's specific training set is assessed as follows:

$$\tilde{S} = \{(\text{Excellent}, 0.2), (\text{Very good}, 0.8), (\text{Good}, 0), (\text{Average}, 0), (\text{Low}, 0)\}$$

The mapping process is elucidated as shown in Figure A2.3, and the fuzzy output set is evaluated as follows:

$\widetilde{T}_S$ = {(Very Good, 0.2), (Good, 0.64), (Average, 0.16), (Fairly Low, 0), (Low, 0)}

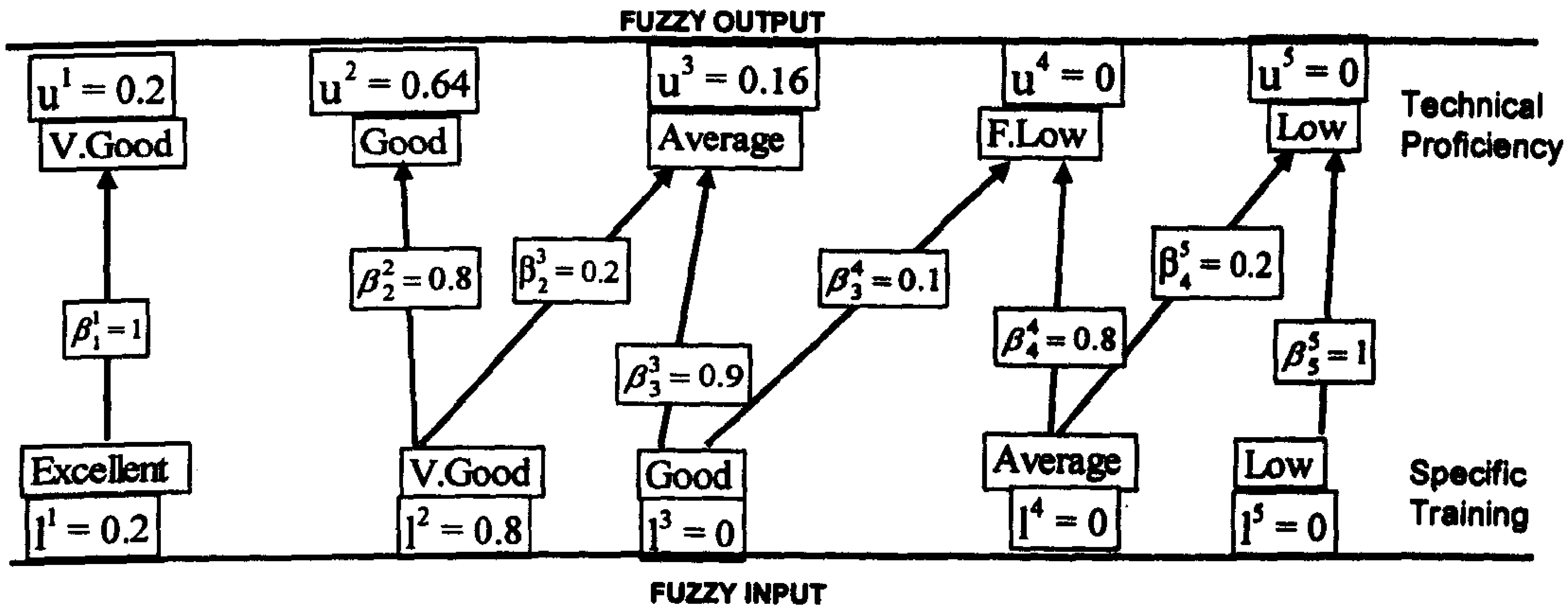

Figure A2.3: Mapping from Specific Training to Technical Proficiency

A2.5. Aggregation of Sub-Criteria

The weight of each sub-criterion can be extracted from Table 3.8. Moreover, by help of the IDS software, as shown in Figure A2.4, $\widetilde{T}_Q$, $\widetilde{T}_E$ and $\widetilde{T}_S$ are aggregated and the result is presented in Table A2.1.

Table A2.1: Aggregation of Sub-Criteria (Technical Proficiency)

Technical Proficiency	Very Good	Good	Average	Fairly Low	Low	Weight
$\widetilde{T}_Q$	0	0.02	0.34	0.64	0	0.3708
$\widetilde{T}_E$	0	0	0.28	0.72	0	0.3408
$\widetilde{T}_S$	0.2	0.64	0.16	0	0	0.2884
Aggregation Result	0.0474 ≈ 0.05	0.1605 ≈ 0.16	0.2712 ≈ 0.27	0.5209 ≈ 0.52	0	

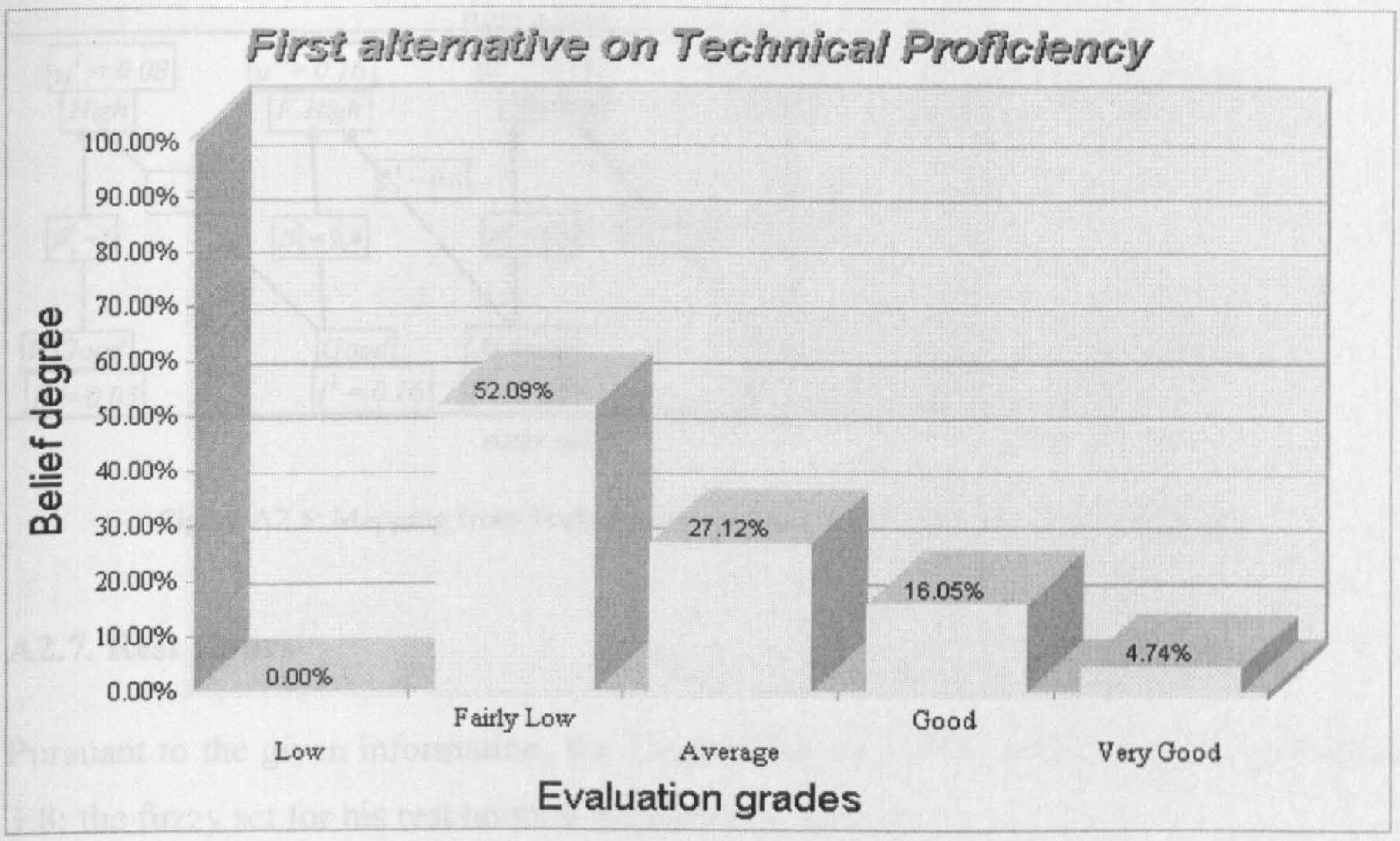

Figure A2.4: Technical Proficiency Aggregation Result

A2.6. Mapping from Main Criterion (Technical proficiency) to Goal

The main criterion (i.e. technical proficiency) can be transformed to the goal (i.e. Third Officer's reliability) by formulating a mapping process. Based on Table A2.1, the fuzzy set for the Third Officer's technical proficiency can be written as follows:

$\widetilde{T}$ = {(Very Good, 0.05), (Good, 0.16), (Average, 0.27), (Fairly Low, 0.52), (Low, 0)}

The mapping process, as shown in Figure A2.5, is elaborated and elucidated. The fuzzy output set is evaluated as follows:

$\widetilde{G}_T$ = {(High, 0.08), (Fairly High, 0.16), (Medium, 0.34), (Fairly Low, 0.42), (Low, 0)}

where $\widetilde{G}_T$ stands for fuzzy output set that is evaluated by mapping from technical proficiency to the Third Officer's reliability.

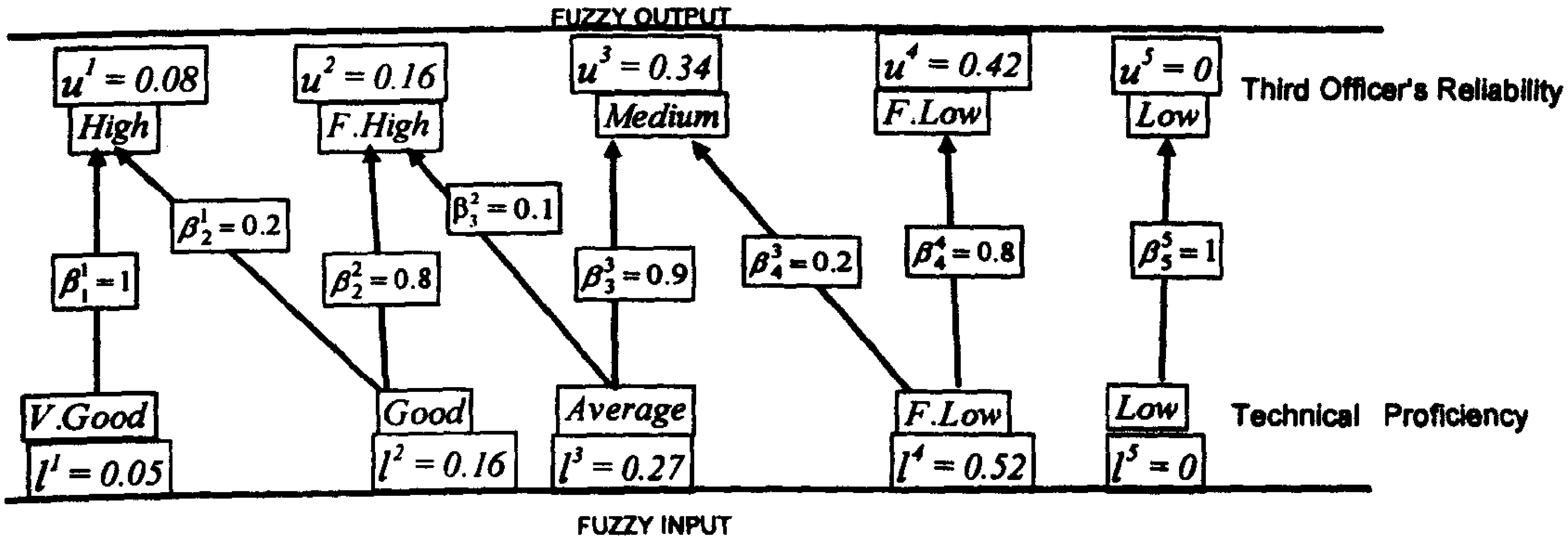

Figure A2.5: Mapping from Technical Proficiency to the Third Officer's Reliability

A2.7. Rest Hours

Pursuant to the given information, the Third Officer had 8hrs rest/day, based on Figure 3.8; the fuzzy set for his rest hours is evaluated as follows:

$$\widetilde{R} = \{(\text{Very Good}, 1), (\text{Good}, 0), (\text{Average}, 0), (\text{Low}, 0), (\text{Very Low}, 0)\}$$

The mapping process is illustrated in Figure A2.6, and the fuzzy out put set is evaluated as below:

$$\widetilde{H}_R = \{(\text{Very Low}, 1), (\text{Low}, 0), (\text{Medium}, 0), (\text{High}, 0), (\text{Very High}, 0)\}$$

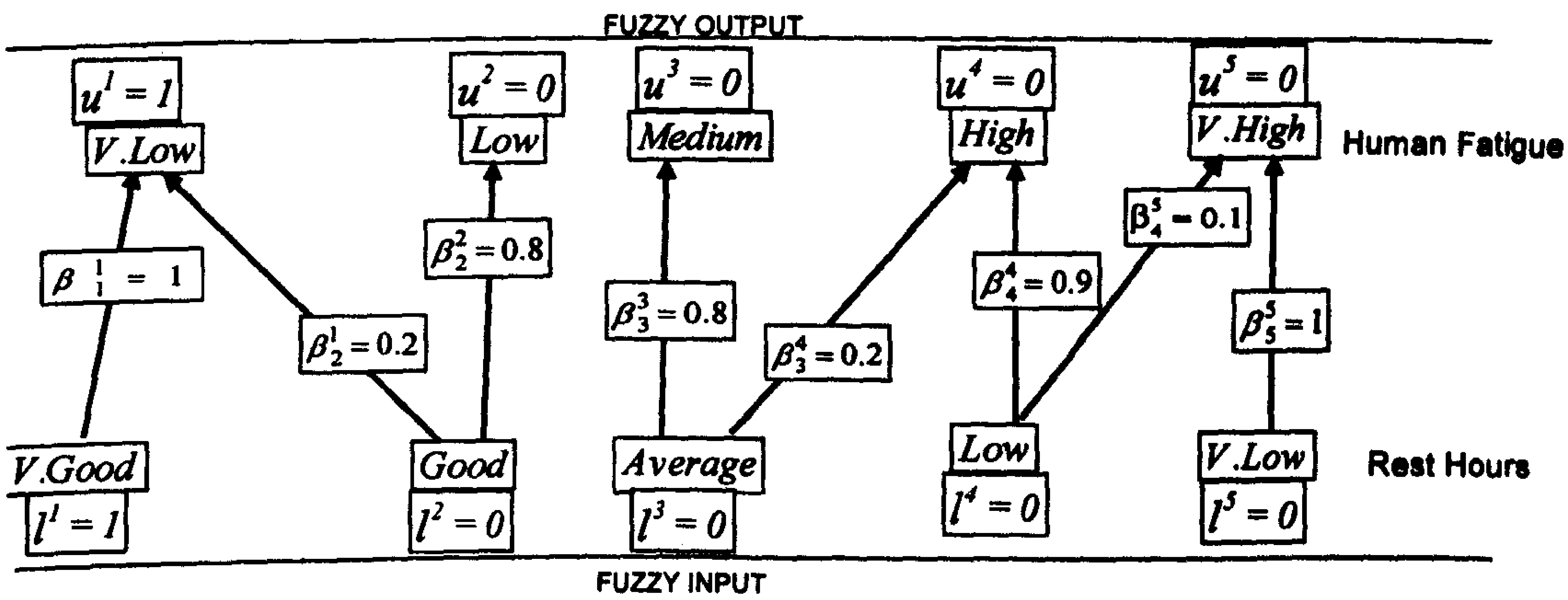

Figure A2.6: Mapping from Rest Hours to Human Fatigue

A2.8. Environmental State

Pursuant to the given information and Sub-Section 3.10.3.1, the average Beaufort number is 4.5, based on Figure 3.5 and Equation 3.20, the fuzzy set for Environmental State can be evaluated as follows:

$$\widetilde{ES} = \{(\text{Very Calm}, 0), (\text{Calm}, 0.5), (\text{Moderate}, 0.5), (\text{Rough}, 0), (\text{Very Rough}, 0)\}$$

The mapping process is illustrated in Figure A2.7, and the fuzzy out put set is evaluated as follows:

$$\widetilde{H}_{ES} = \{(\text{Very Low}, 0.1), (\text{Low}, 0.4), (\text{Medium}, 0.4), (\text{High}, 0.1), (\text{Very High}, 0)\}$$

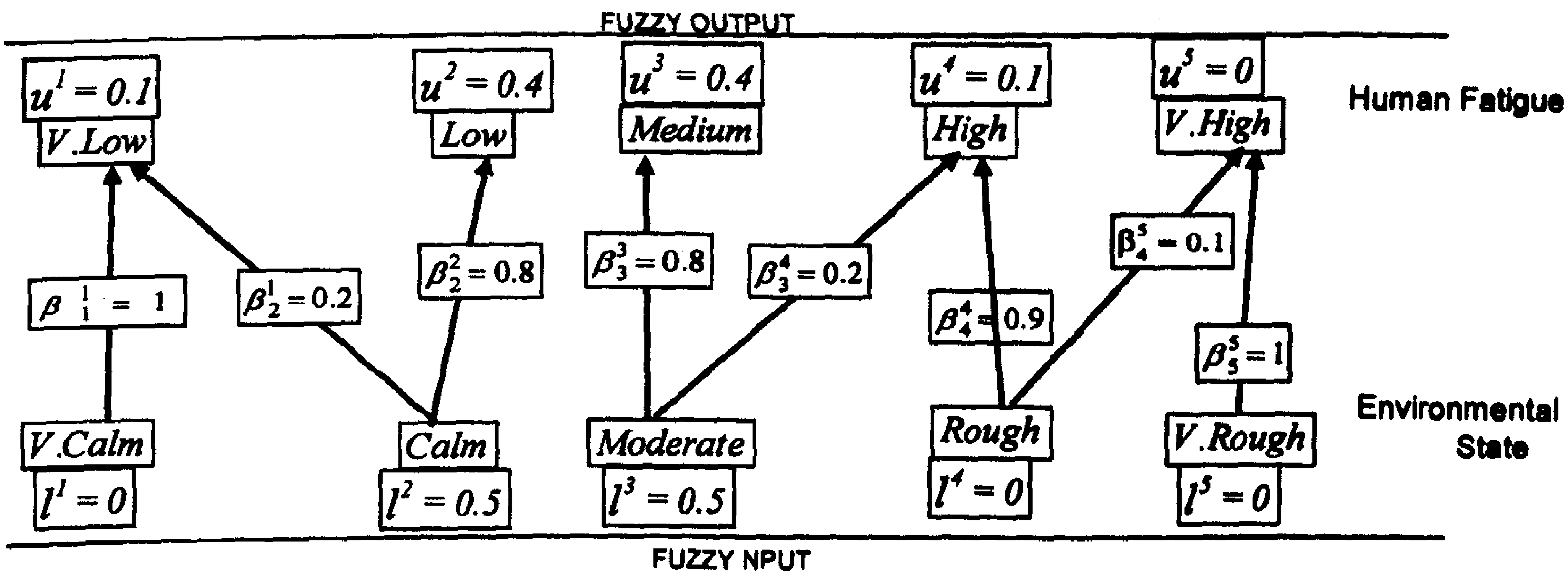

Figure A2.7: Mapping from Environmental State to Human Fatigue

A2.9. Design & Habitability

Based on the given information, the fuzzy set for Design & Habitability is evaluated as follows:

$$\widetilde{DH} = \{(\text{Very Good}, 0), (\text{Good}, 1.0), (\text{Average}, 0), (\text{Bad}, 0), (\text{Very Bad}, 0)\}$$

The mapping process is shown in Figure A2.8, and the fuzzy out put set is evaluated as follows:

$$\widetilde{H}_{DH} = \{(\text{Very Low}, 0.2), (\text{Low}, 0.8), (\text{Medium}, 0), (\text{High}, 0), (\text{Very High}, 0)\}$$

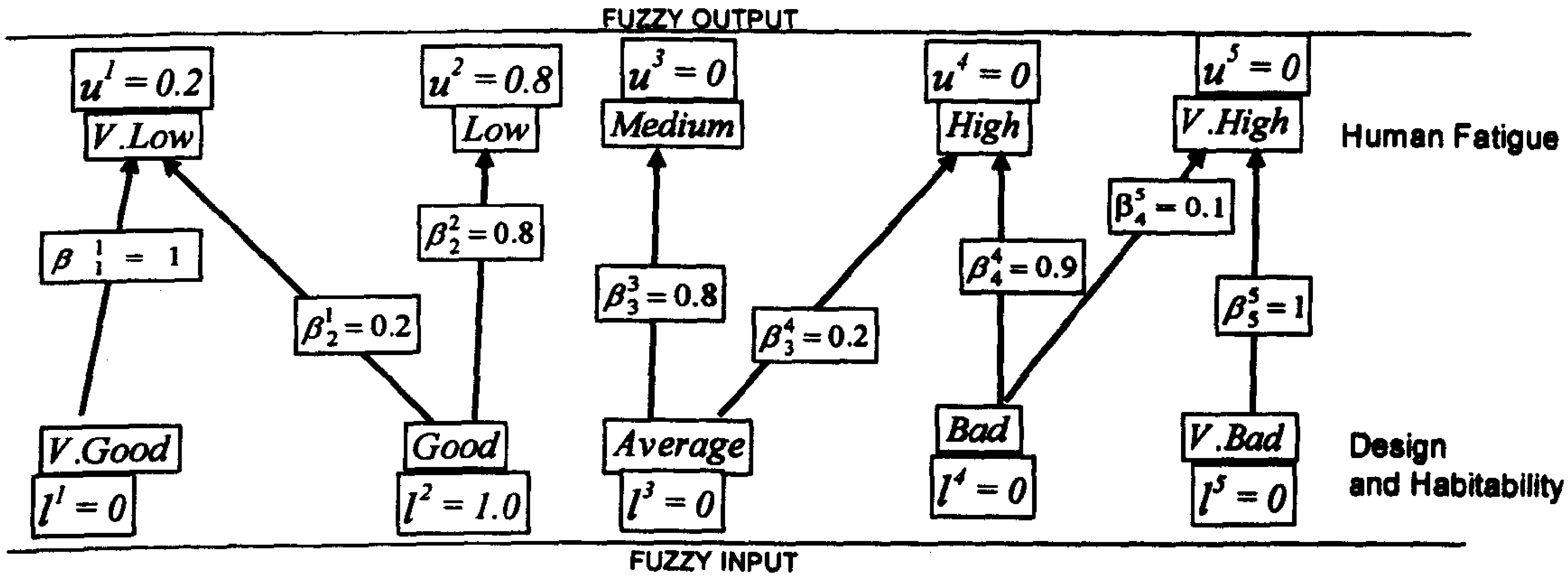

Figure A2.8: Mapping from Design &Habitability to Human Fatigue

A2.10. Aggregation of Sub-Criteria

The weight of each sub-criterion can be extracted from Table 3.10. Moreover, by help of the IDS software, as shown in Figure A2.9, $\widetilde{H}_R$, $\widetilde{H}_{ES}$, and $\widetilde{H}_{DH}$ are aggregated and the result is presented in Table A2.2.

Table A2.2: Aggregation of Sub-Criteria of Human Fatigue

Human fatigue	Very low	Low	Medium	High	Very high	Weight
$\widetilde{H}_R$	1	0	0	0	0	0.4491
$\widetilde{H}_{ES}$	0.1	0.40	0.40	0.1	0	0.2880
$\widetilde{H}_{DH}$	0.2	0.8	0	0	0	0.2629
Aggregation Result	0.5954 ≈ 0.6	0.2870 ≈ 0.28	0.0941 ≈ 0.1	0.0235 ≈ 0.02	0	

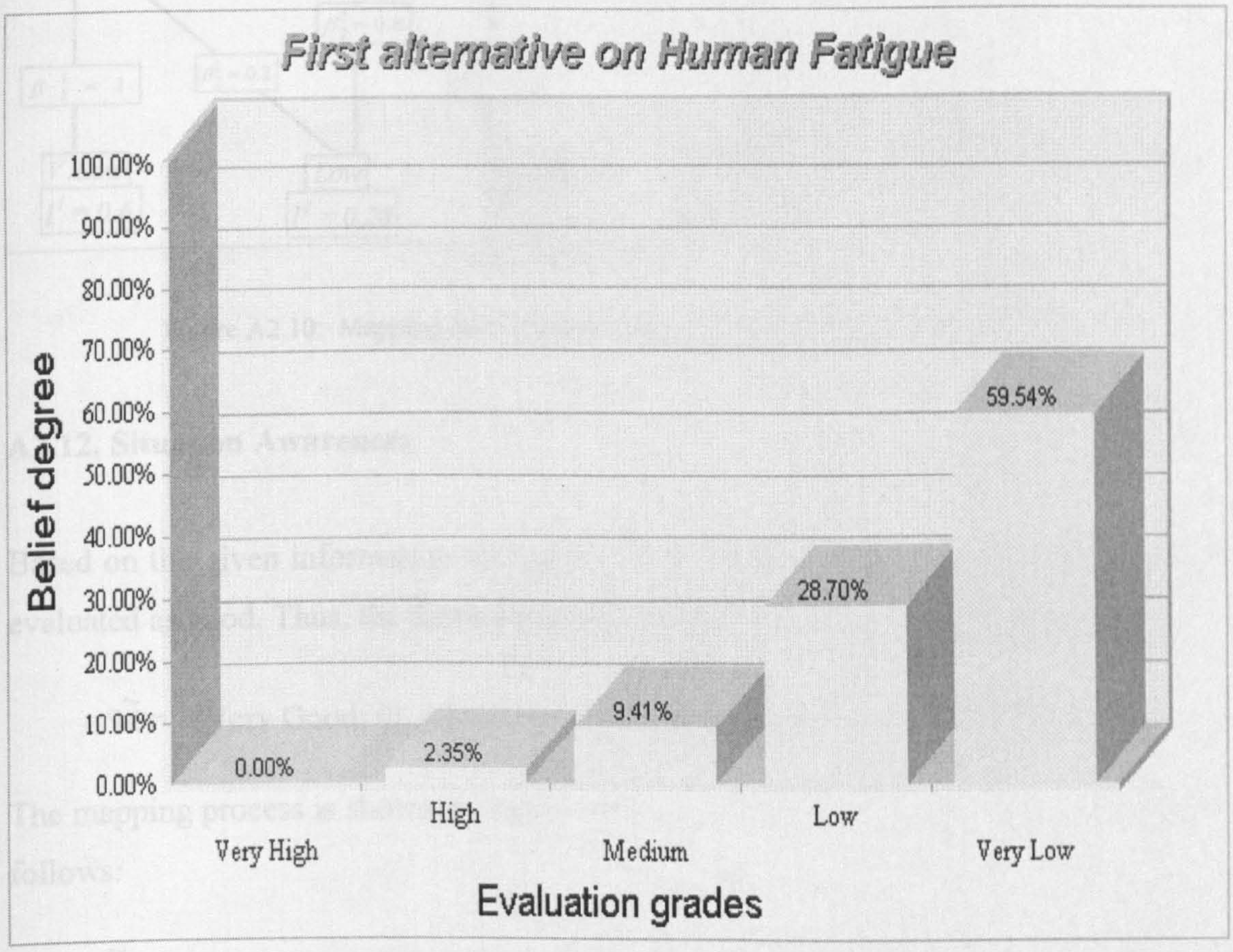

Figure A2.9: Human Fatigue Aggregation Result

A2.11. Mapping from Main Criterion (Human Fatigue) to Goal

The main criterion (i.e. human fatigue) can be transformed to the g oal (i.e. Third Officer's reliability) by formulating a mapping process. Based on Table A2.2, the fuzzy set for the Third Officer's fatigue can be written as follows:

$\widetilde{H}$ = {(Very Low, 0.6), (Low, 0.28), (Medium, 0.1), (High, 0.02), (Very High, 0)}

The mapping process is shown in Figure A2.10, and the fuzzy out put set is evaluated as follows:

$\widetilde{G}_H$ = {(High, 0.656), (Fairly High, 0.224), (Medium, 0.1), (Fairly low, 0.016), (Low, 0.004)}

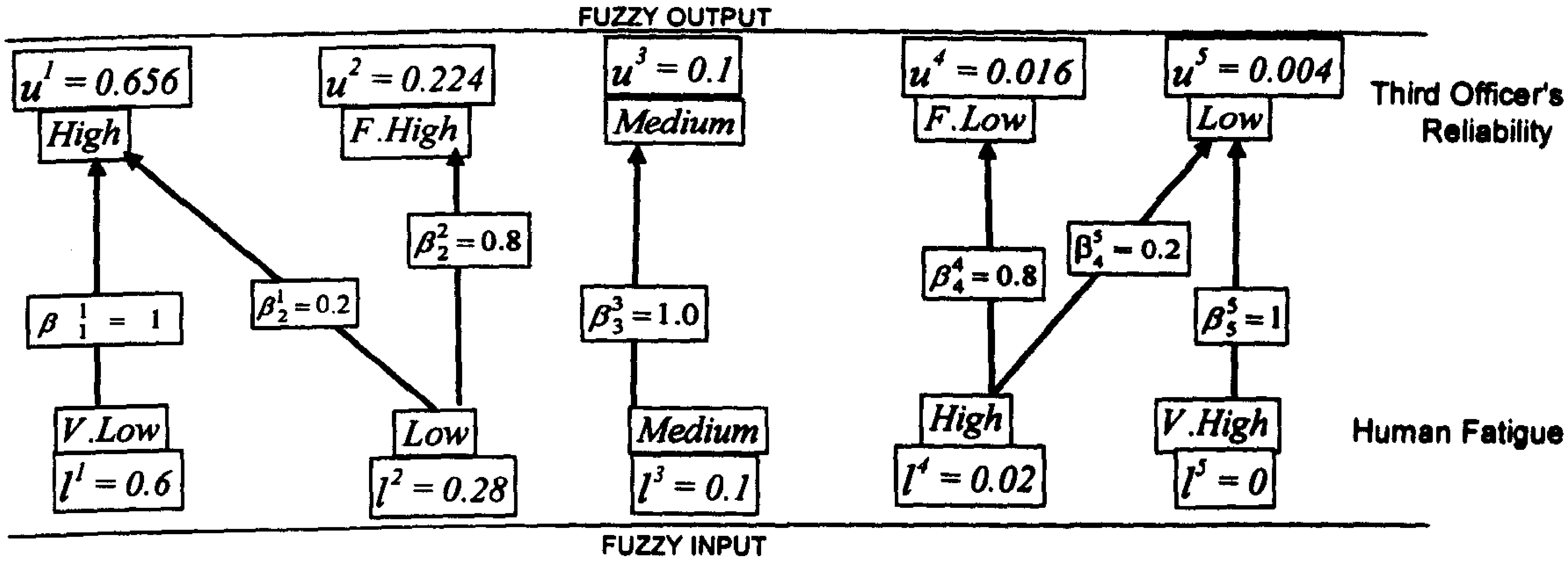

Figure A2.10: Mapping from Human Fatigue to the Third Officer's Reliability

A2.12. Situation Awareness

Based on the given information the grade of the Third Officer's situation awareness is evaluated as good. Thus, the fuzzy set can be evaluated as follows:

$$\widetilde{SA} = \{(\text{Very Good}, 0), (\text{Good}, 1.0), (\text{Medium}, 0), (\text{Low}, 0), (\text{Very Low}, 0)\}$$

The mapping process is shown in Figure A2.11, and the fuzzy out put set is evaluated as follows:

$$\widetilde{NT}_{SA} = \{(\text{Very Good}, 0.2), (\text{Good}, 0.8), (\text{Average}, 0), (\text{Fairly low}, 0), (\text{Low}, 0)\}$$

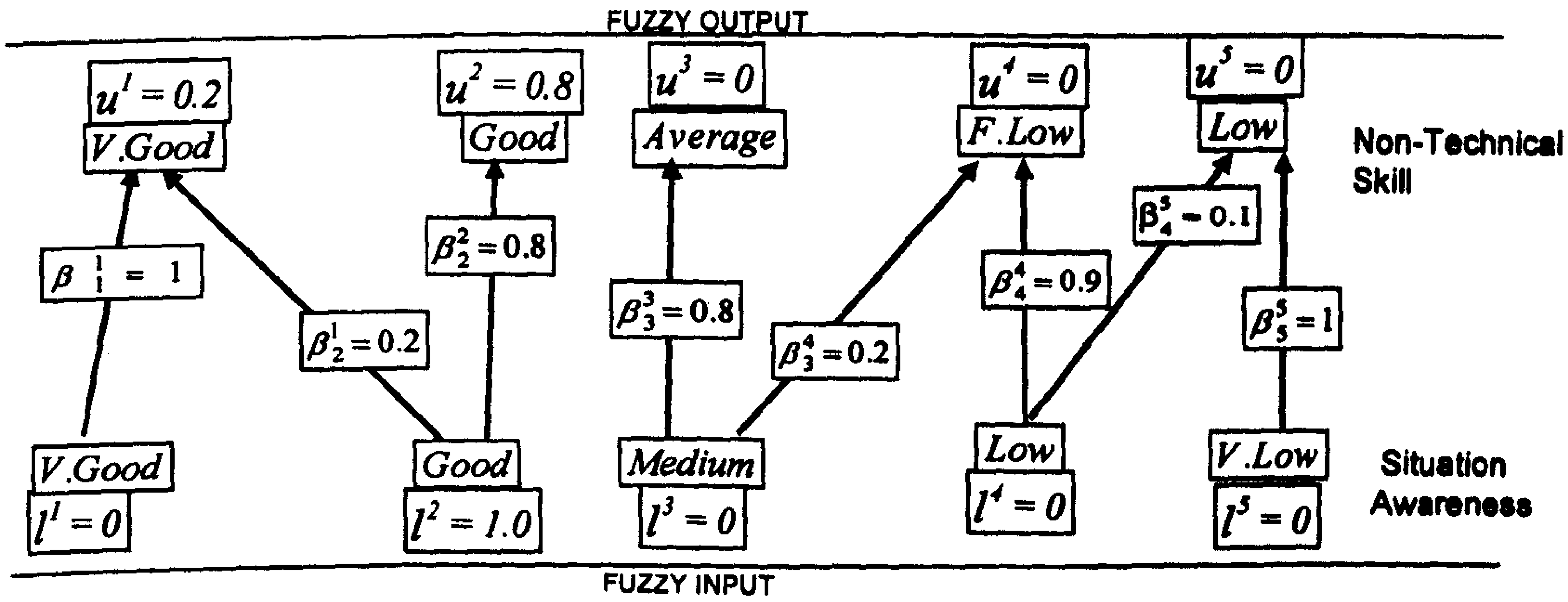

Figure A2.11: Mapping from Situation Awareness to Non-Technical Skill

A2.13.Communication & Language Skill

Based on the given information, the Third Officer's communication & language skill is Medium. Thus, the fuzzy set can be evaluated as follows:

$$\widetilde{CL} = \{(\text{Very Good}, 0), (\text{Good}, 0), (\text{Medium}, 1.0), (\text{Low}, 0), (\text{Very Low}, 0)\}$$

The mapping process is shown in Figure A2.12, and the fuzzy output set can be evaluated as follows:

$$\widetilde{NT}_{CL} = \{(\text{Very Good}, 0), (\text{Good}, 0), (\text{Average}, 0.8), (\text{Fairly low}, 0.2), (\text{Low}, 0)\}$$

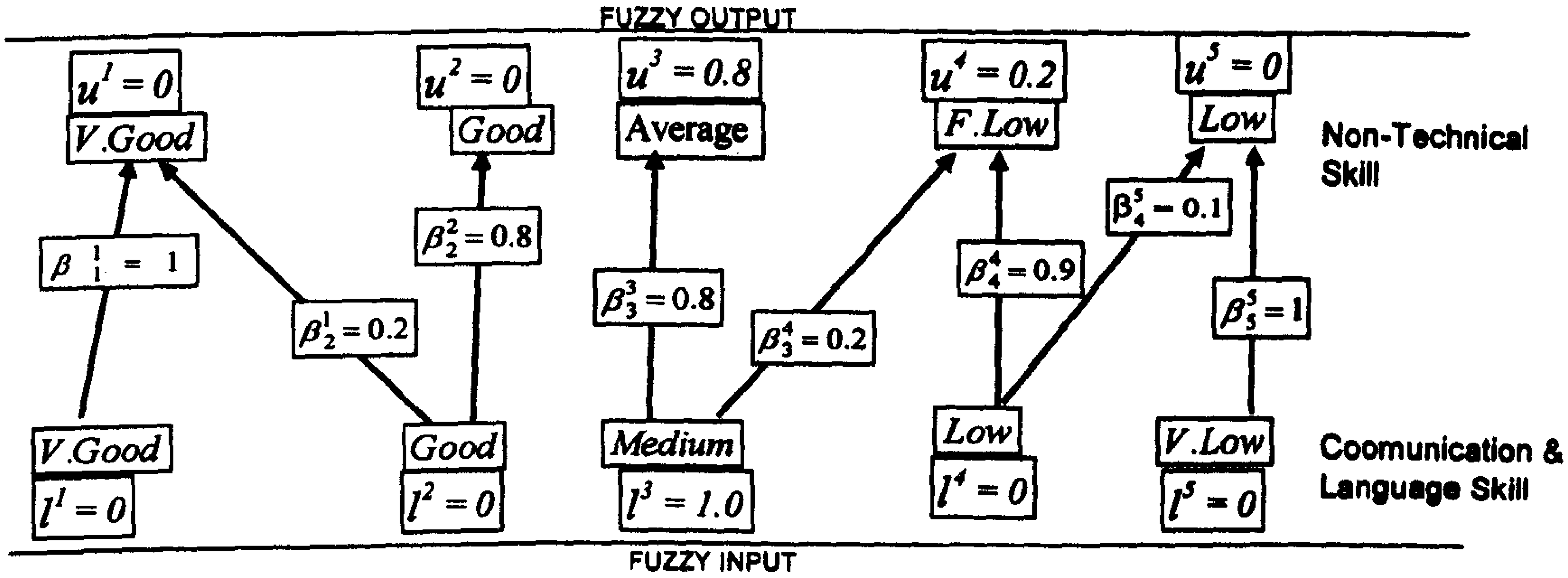

Figure A2.12: Mapping from Communication & Language Skill to Non-Technical Skill

A2.14. Teamwork

Based on the given information and the Master's observation the grade of the Third Officer's teamwork is evaluated as good. Therefore, the fuzzy set can be evaluated as follows:

$$\widetilde{TW} = \{(\text{Very Good}, 0), (\text{Good}, 1.0), (\text{Medium}, 0), (\text{Low}, 0), (\text{Very Low}, 0)\}$$

The mapping process is elucidated in Figure A2.13, and the fuzzy output set can be evaluated as follows:

$$\widetilde{NT}_{TW} = \{(\text{Very Good}, 0.2), (\text{Good}, 0.8), (\text{Average}, 0), (\text{Fairly low}, 0), (\text{Low}, 0)\}$$

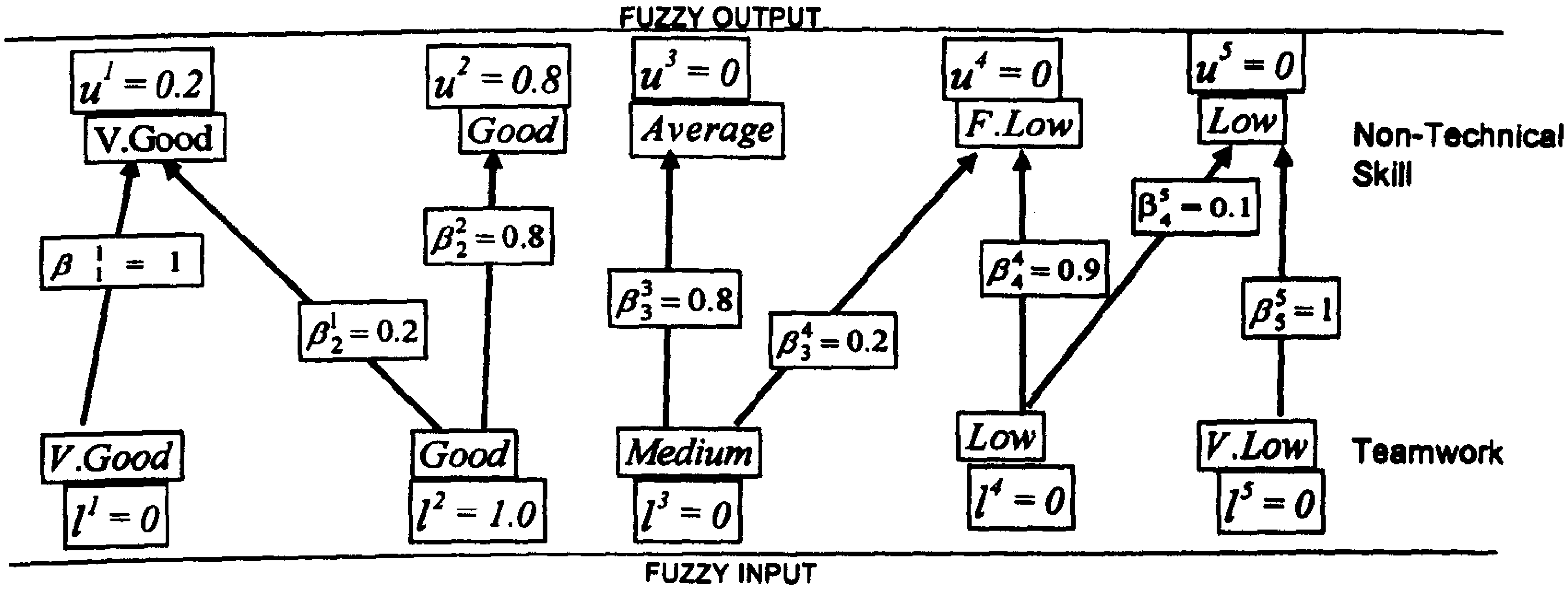

Figure A2.13: Mapping from Teamwork to Non-Technical Skill

A2.15. Decision Making

Based on the given information and Master's judgement, the grade of the Third Officer's decision making is evaluated as medium. Therefore, the fuzzy set can be evaluated as follows:

$$D\widetilde{M} = \{(\text{Very Good}, 0), (\text{Good}, 0), (\text{Medium}, 1.0), (\text{Low}, 0), (\text{Very Low}, 0)\}$$

The mapping process is elucidated in Figure A2.14, and the fuzzy output set can be evaluated as follows:

$$N\widetilde{T}_{DM} = \{(\text{Very Good}, 0), (\text{Good}, 0), (\text{Average}, 0.8), (\text{Fairly low}, 0.2), (\text{Low}, 0)\}$$

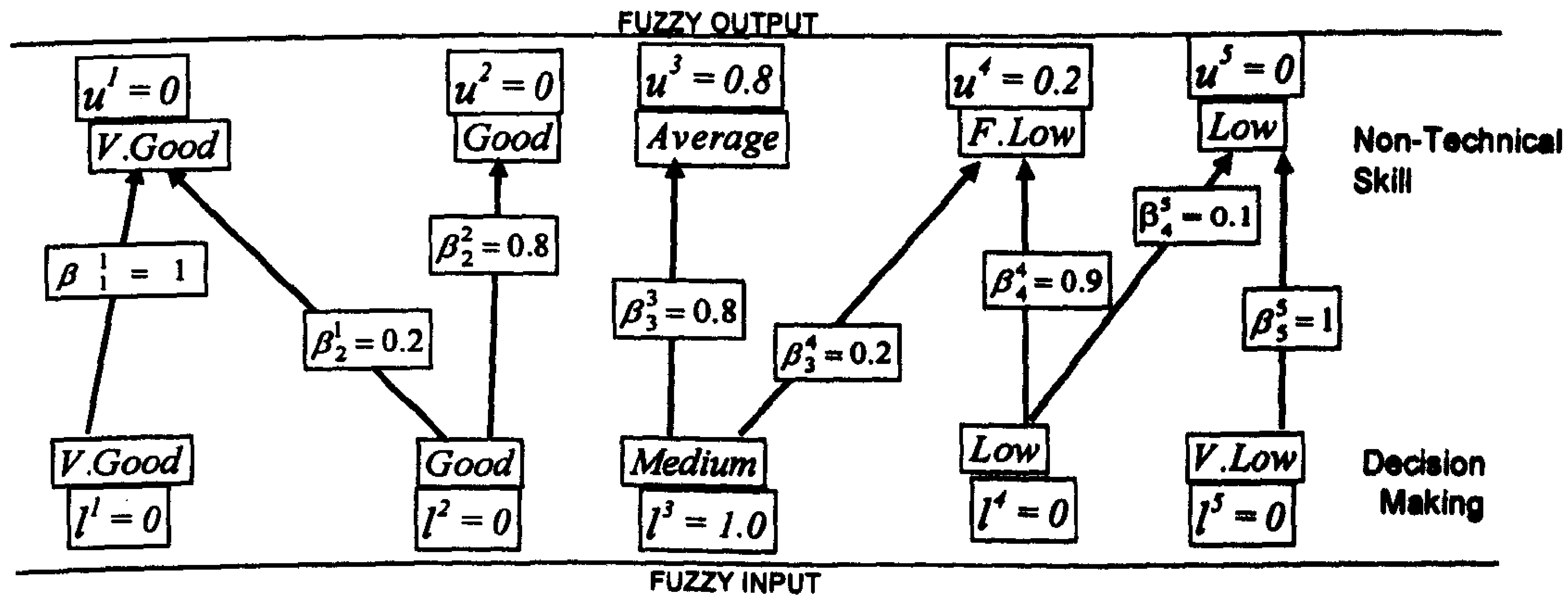

Figure A2.14: Mapping from Decision Making to Non-Technical Skill

A2.16. Aggregation of Sub-Criteria

Based on the experts' judgement, situation awareness, communication and language skill, teamwork, and decision making are equally important. Moreover, by help of IDS software, as shown in Figure A2.15, $\widetilde{NT}_{SA}$, $\widetilde{NT}_{CL}$, $\widetilde{NT}_{TW}$, and $\widetilde{NT}_{DM}$ are aggregated. The result is presented in Table A2.3.

Table A2.3: Aggregation of Sub-Criteria of Non-Technical Skill

Strength	Very Good	Good	Average	Fairly Low	Low	Weight
$\widetilde{NT}_{SA}$	0.2	0.8	0	0	0	0.25
$\widetilde{NT}_{CL}$	0	0	0.8	0.2	0	0.25
$\widetilde{NT}_{TW}$	0.2	0.8	0	0	0	0.25
$\widetilde{NT}_{DM}$	0	0	0.8	0.2	0	0.25
Result	$0.0928 \approx 0.1$	$0.4072 \approx 0.4$	$0.4072 \approx 0.4$	$0.0928 \approx 0.1$	0	

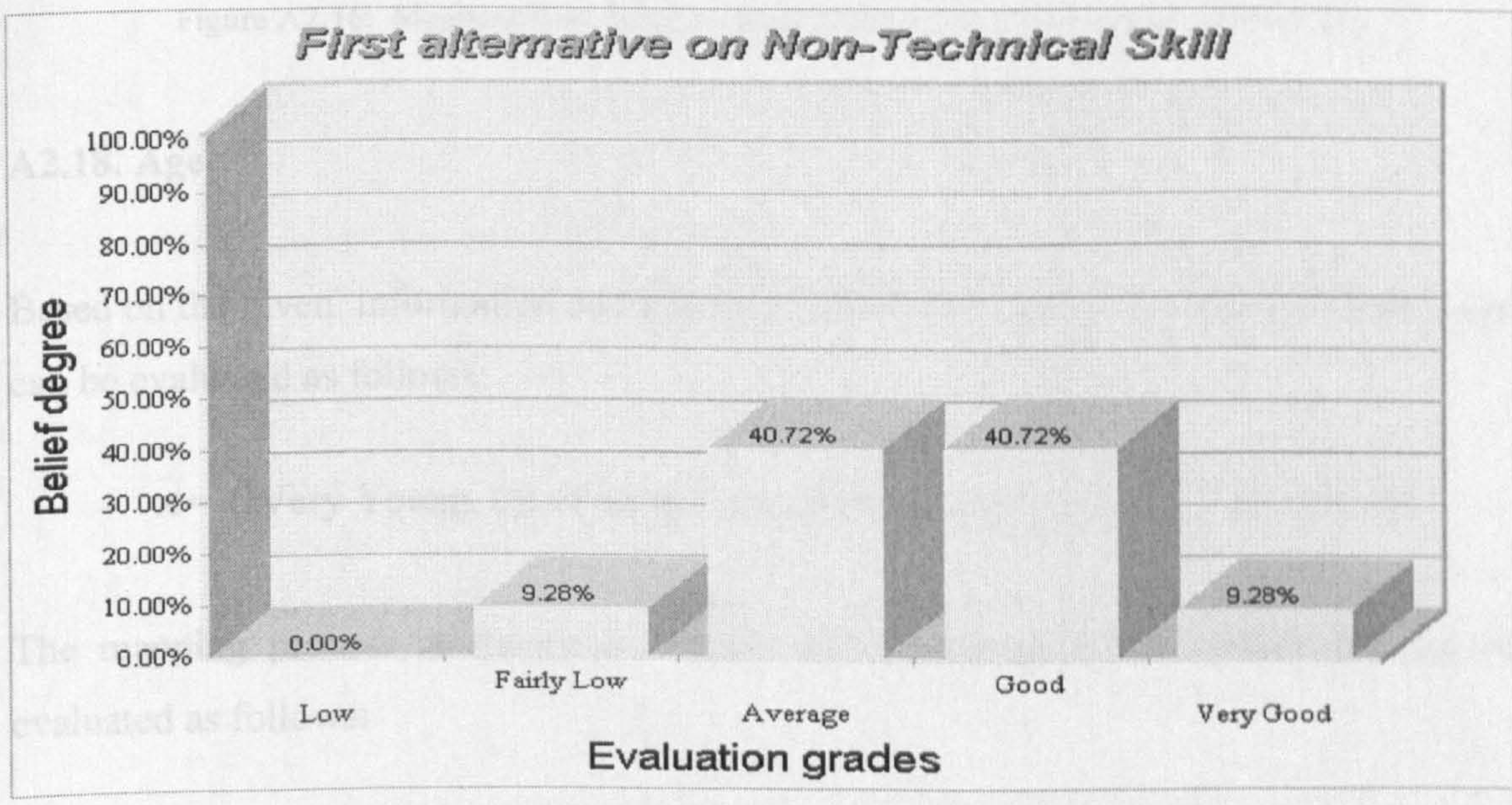

Figure A2.15: Non-Technical Skill Aggregation Result

A2.17. Mapping from Main Criterion (Non-Technical Skill) to Goal

The main criterion (i.e. Non-Technical Skill) can be transformed to the goal (i.e. Third Officer's reliability) by formulating a mapping process. Based on Table A2.3, the fuzzy set for the Third Officer's fatigue can be written as follows:

$$\widetilde{NT} = \{(\text{Very Good}, 0.1), (\text{Good}, 0.4), (\text{Average}, 0.4), (\text{Fairly low}, 0.1), (\text{Low}, 0)\}$$

The mapping process is shown in Figure A2.16, and the fuzzy output set can be evaluated as follows:

$$\widetilde{G}_{NT} = \{(\text{High}, 0.18), (\text{Fairly High}, 0.32), (\text{Medium}, 0.4), (\text{Fairly low}, 0.08), (\text{Low}, 0.02)\}$$

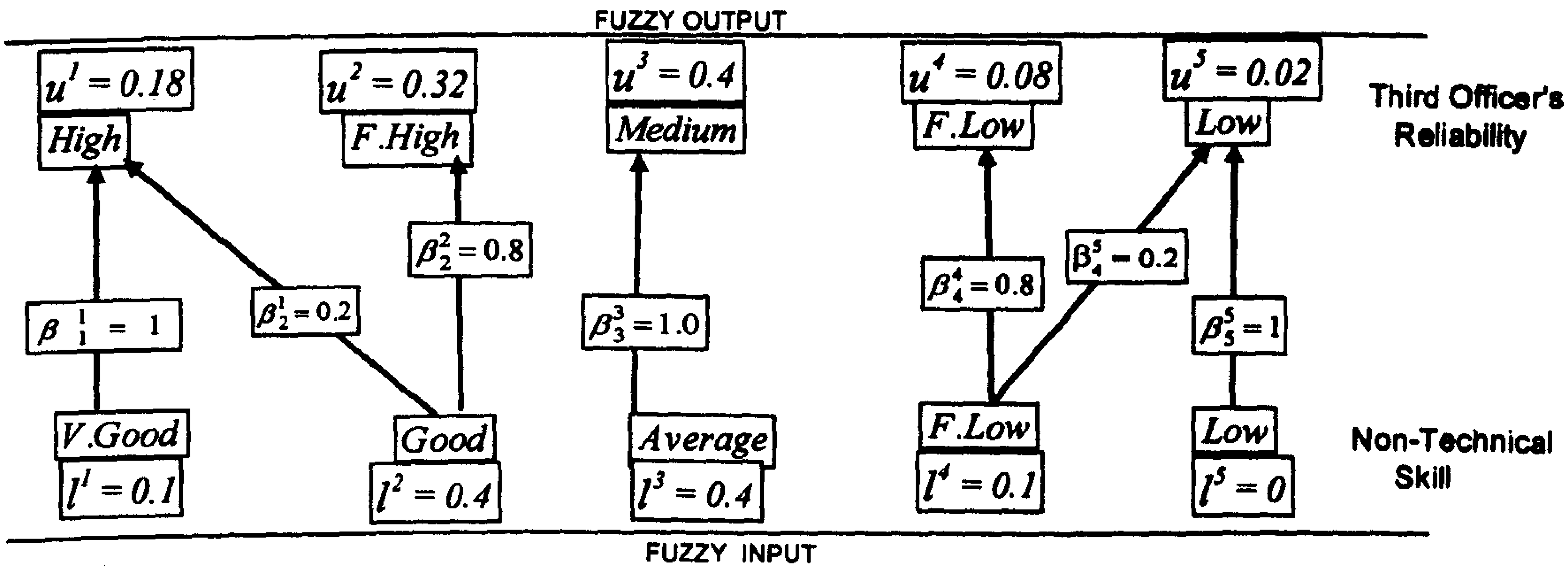

Figure A2.16: Mapping from Non-Technical Skill to the Third Officer's Reliability

A2.18. Age

Based on the given information and Figure 3.7, the fuzzy set for the Third Officer's age can be evaluated as follows:

$$\widetilde{A} = \{(\text{Very Young}, 0), (\text{Young}, 1.0), (\text{Average}, 0), (\text{Old}, 0), (\text{Very old}, 0)\}$$

The mapping process is shown in Figure A2.17, and the fuzzy output set can be evaluated as follows:

$$\widetilde{FS}_A = \{(\text{Very High}, 0.2), (\text{High}, 0.8), (\text{Medium}, 0), (\text{Low}, 0), (\text{Very Low}, 0)\}$$

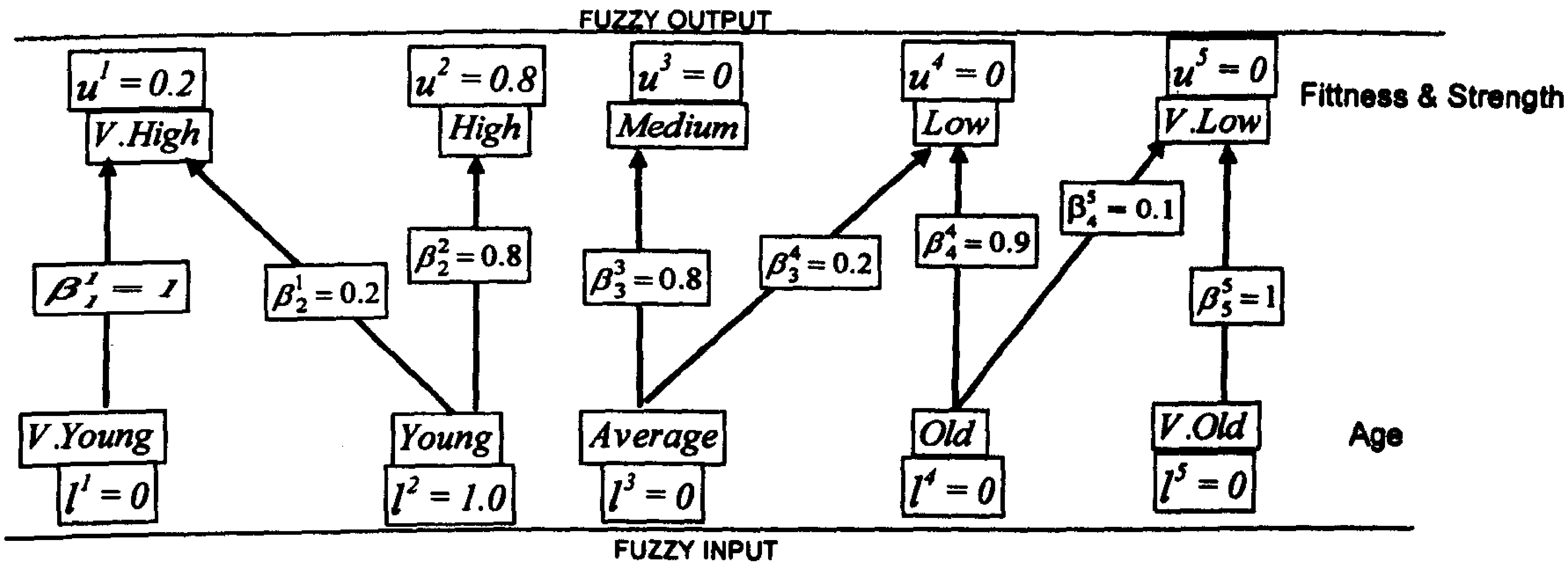

Figure A2.17: Mapping from Age to Fitness and Strength

A2.19. Health

Based on the given information, the Third Officer is holding a valid medical fitness certificate and according to his statements he is "healthy". Based on the Master's judgment he is 50% very healthy and 50% healthy .Thus, the fuzzy set for his health can be evaluated as follows:

$$\widetilde{HE} = \{(\text{Very Healthy}, 0.5), (\text{Healthy}, 0.5), (\text{Mol.Fit}, 0), (\text{Unhealthy}, 0)\}$$

The mapping process is shown in Figure A2.18, and the fuzzy output set can be evaluated as follows:

$$\widetilde{FS}_{HE} = \{(\text{Very High}, 0.6), (\text{High}, 0.4), (\text{Medium}, 0), (\text{Low}, 0), (\text{Very Low}, 0)\}$$

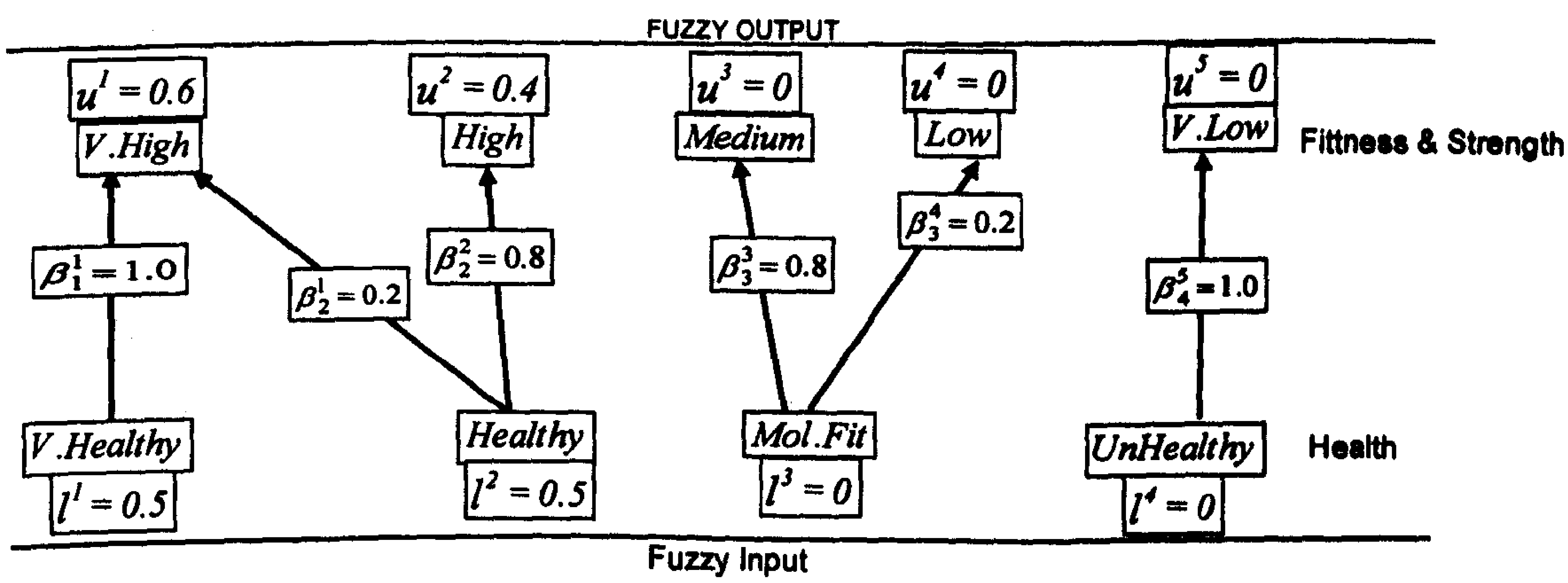

Figure A2.18: Mapping from Health to Fitness and Strength

A2.20. Stress

Based on the given information and the Third Officer's statement, his stress level is Moderate. Thus, the fuzzy set for his stress can be evaluated as follows:

$$\widetilde{ST} = \{(\text{Very High}, 0), (\text{High}, 0), (\text{Moderate}, 1), (\text{Low}, 0)\}$$

The mapping process is shown in Figure A2.19, and the fuzzy output set can be evaluated as follows:

$$\widetilde{FS}_{ST} = \{(\text{Very High}, 0.2), (\text{High}, 0.8), (\text{Medium}, 0), (\text{Low}, 0), (\text{Very Low}, 0)\}$$

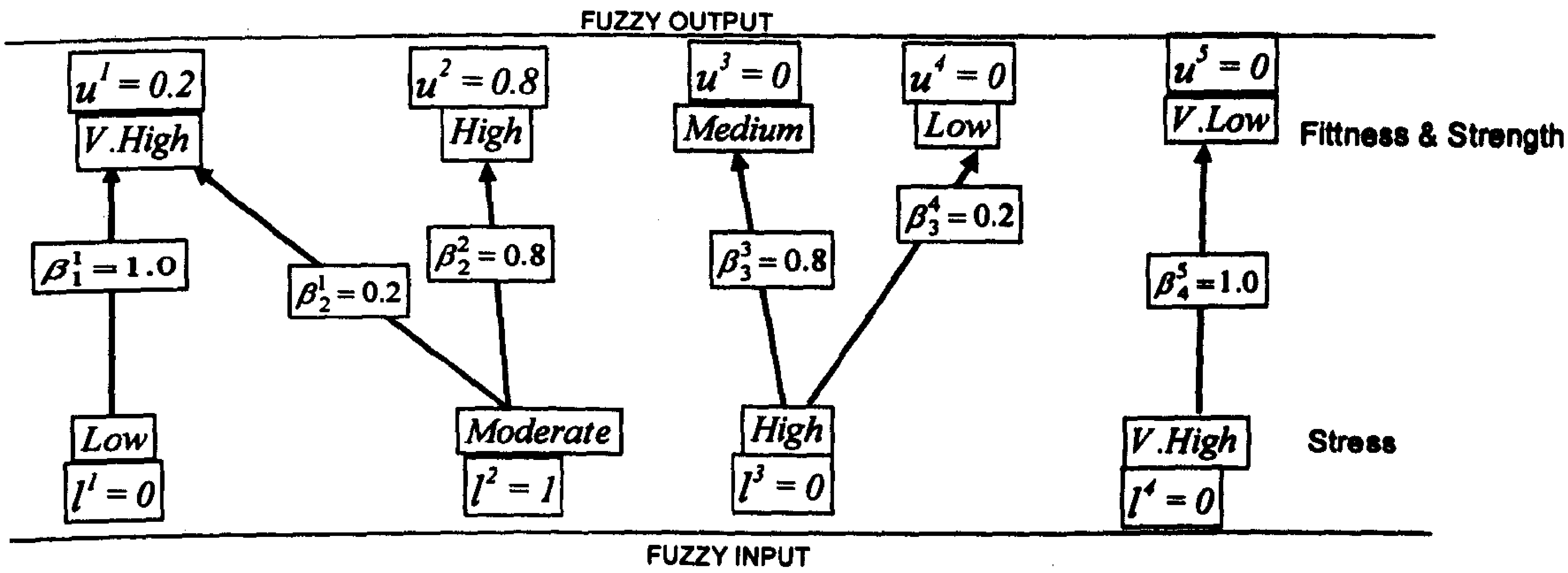

Figure A2.19: Mapping from Stress to Fitness and Strength

A2.21. Nutrition

Based on the Third Officer's statement, the quality of food is "not bad", accordingly based on expert's judgment "not bad" stands for 40% average and 60% bad. Thus, the fuzzy set for his nutrition can be evaluated as follows:

$$\widetilde{N} = \{(\text{Very Good}, 0), (\text{Good}, 0), (\text{Average}, 0.4), (\text{Bad}, 0.6), (\text{Very Bad}, 0)\}$$

The mapping process is shown in Figure A2.20, and the fuzzy output set can be evaluated as follows:

$$\widetilde{FS}_{N} = \{(\text{Very High}, 0), (\text{High}, 0), (\text{Medium}, 0.36), (\text{Low}, 0.64), (\text{Very Low}, 0)\}$$

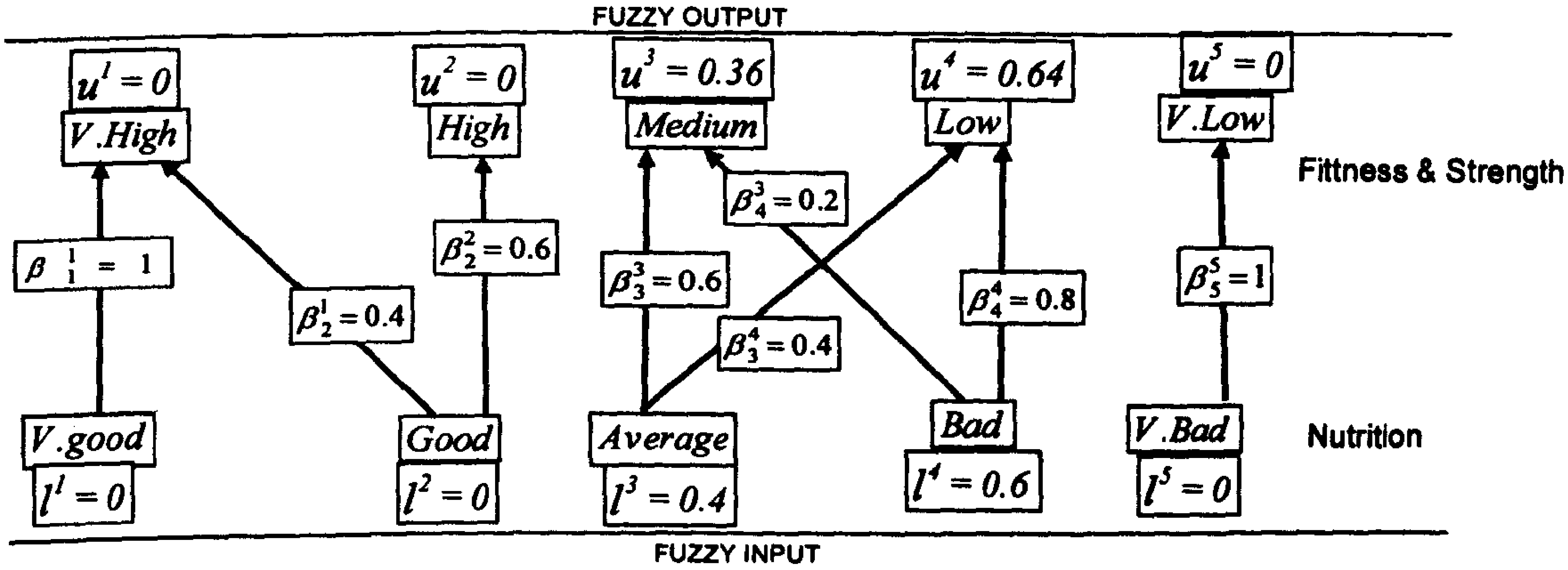

Figure A2.20: Mapping from Nutrition to Fitness and Strength

A2.22. Aggregation of Sub-Criteria

The weight of each sub-criterion can be extracted from Table 3.12. Moreover, by help of the IDS software, as shown in Figure A2.21, $\widetilde{FS}_A$, $\widetilde{FS}_{HE}$, $\widetilde{FS}_{ST}$ and $\widetilde{FS}_N$ are aggregated and the result is presented in Table A2.4.

Table A2.4: Aggregation of Sub-Criteria of Fitness and Strength

Fitness & Strength	Very high	High	Medium	Low	Very low	Weight
$\widetilde{FS}_A$	0.2	0.8	0	0	0	0.1479
$\widetilde{FS}_{HE}$	0.6	0.4	0	0	0	0.3205
$\widetilde{FS}_{ST}$	0.2	0.8	0	0	0	0.3798
$\widetilde{FS}_N$	0	0	0.36	0.64	0	0.1518
Aggregation Result	0.2907 ≈ 0.29	0.6031 ≈ 0.6	0.0382 ≈ 0.04	0.0679 ≈ 0.07	0	

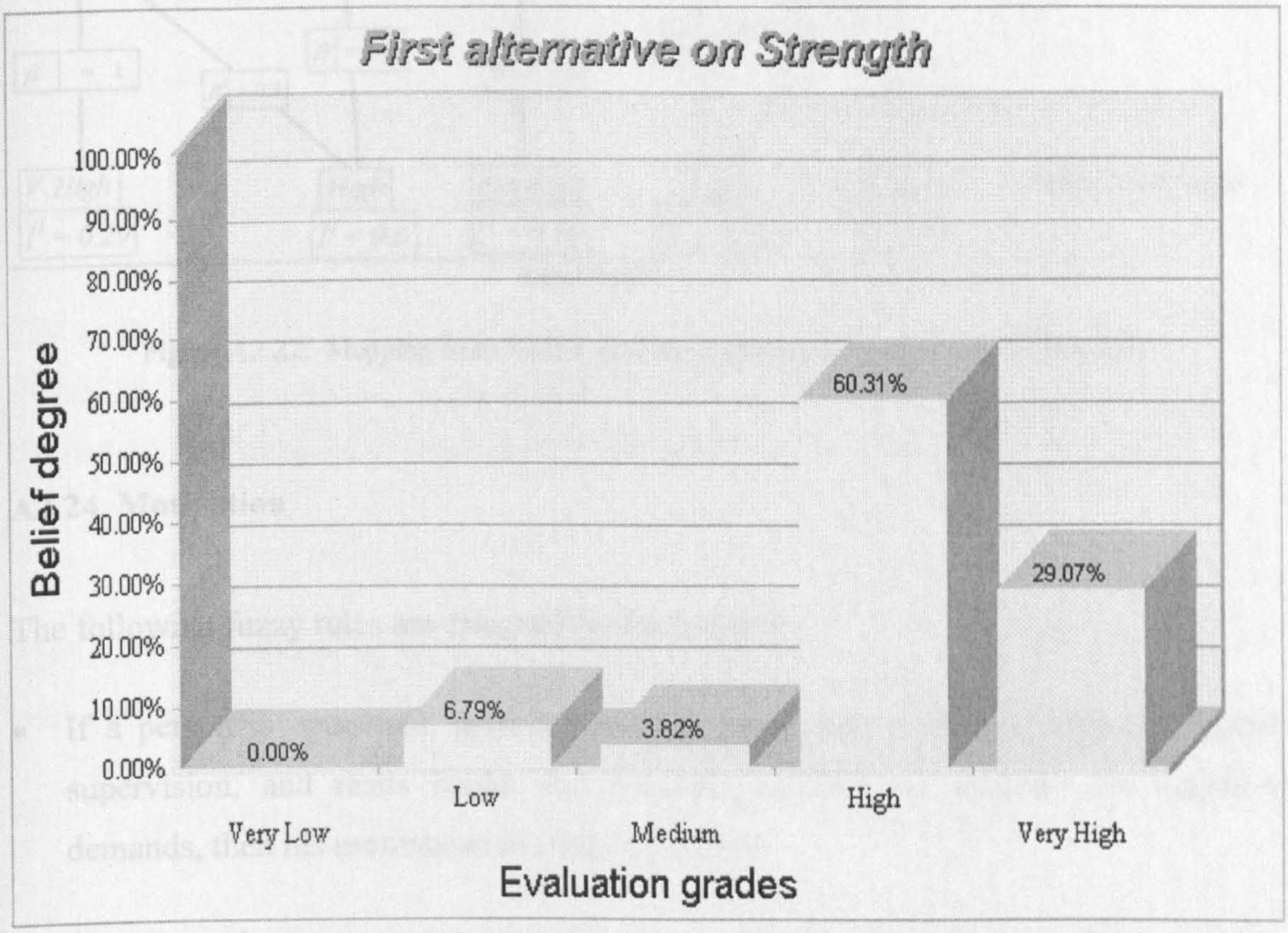

Figure A2.21: Fitness & Strength Aggregation Result

A2.23. Mapping from Main Criterion (Fitness and Strength) to Goal

The main criterion (i.e. fitness and strength) can be transformed to the goal (i.e. Third Officer's reliability) by formulating a mapping process. Based on Table A2.4, the fuzzy set for the Third Officer's fitness and strength can be written as follows:

$$\widetilde{FS} = \{(\text{Very High}, 0.29), (\text{High}, 0.6), (\text{Medium}, 0.04), (\text{Low}, 0.07), (\text{Very Low}, 0)\}$$

The mapping process is shown in Figure A2.22, and the fuzzy output set can be evaluated as follows:

$$\widetilde{G}_{FS} = \{(\text{High}, 0.53), (\text{Fairly high}, 0.36), (\text{Medium}, 0.04), (\text{Fairly low}, 0.042), (\text{Low}, 0.028)\}$$

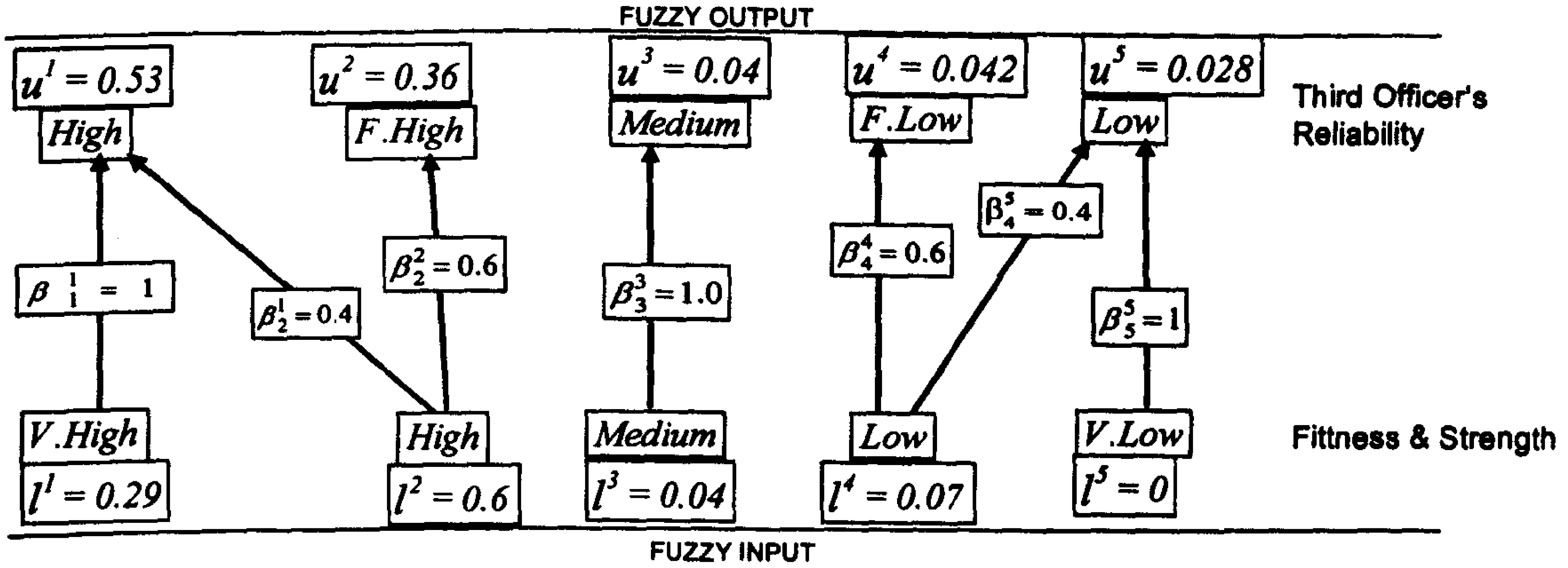

Figure A2.22: Mapping from Fitness and Strength to the Third Officer's Reliability

A2.24. Motivation

The following fuzzy rules are assigned by the experts:

- If a person is punctual, performs his job more than expected, does not require supervision, and reads books and manuals regularly to enhance his cognitive demands, then his motivation is 100% very high.
- If a person is punctual, performs his job according to his job description, requires supervision occasionally, and reads books and manuals regularly to enhance his cognitive demands, then his motivation is 70% high and 30% very high.
- If a person is punctual, performs his job according to his job description, requires supervision occasionally, and reads books and manuals occasionally to enhance his cognitive demands then his motivation is 70% medium and 30% high
- If a person is punctual, performs his job according to his job description, requires supervision frequently, and does not read books and manuals then his motivation is 70% low and 30% medium.
- If a person is not punctual, not performs his job according to his job description, requires supervision frequently, and does not read books and manuals then his motivation is 100% very low.

Based on the given information, the Third Officer is punctual, he needs supervision occasionally, and he is enthusiastic. Thus, the fuzzy set for his motivation can be evaluated as follows:

$$\tilde{M} = \{(\text{Very High}, 0), (\text{High}, 0.3), (\text{Medium}, 0.7), (\text{Low}, 0), (\text{Very Low}, 0)\}$$

A2.25. Mapping from Main Criterion (Motivation) to Goal

The main criterion (i.e. motivation) can be transformed to the goal (i.e. Third Officer's reliability) by formulating a mapping process. Based on A2.24, the fuzzy set for the Third Officer's motivation can be written as follows:

$$\tilde{M} = \{(\text{Very High}, 0), (\text{High}, 0.3), (\text{Medium}, 0.7), (\text{Low}, 0), (\text{Very Low}, 0)\}$$

The mapping process is shown in Figure A2.23, and the fuzzy output set can be evaluated as follows:

$$\tilde{G}_M = \{(\text{High}, 0.09), (\text{Fairly High}, 0.21), (\text{Medium}, 0.7), (\text{Fairly low}, 0), (\text{Low}, 0)\}$$

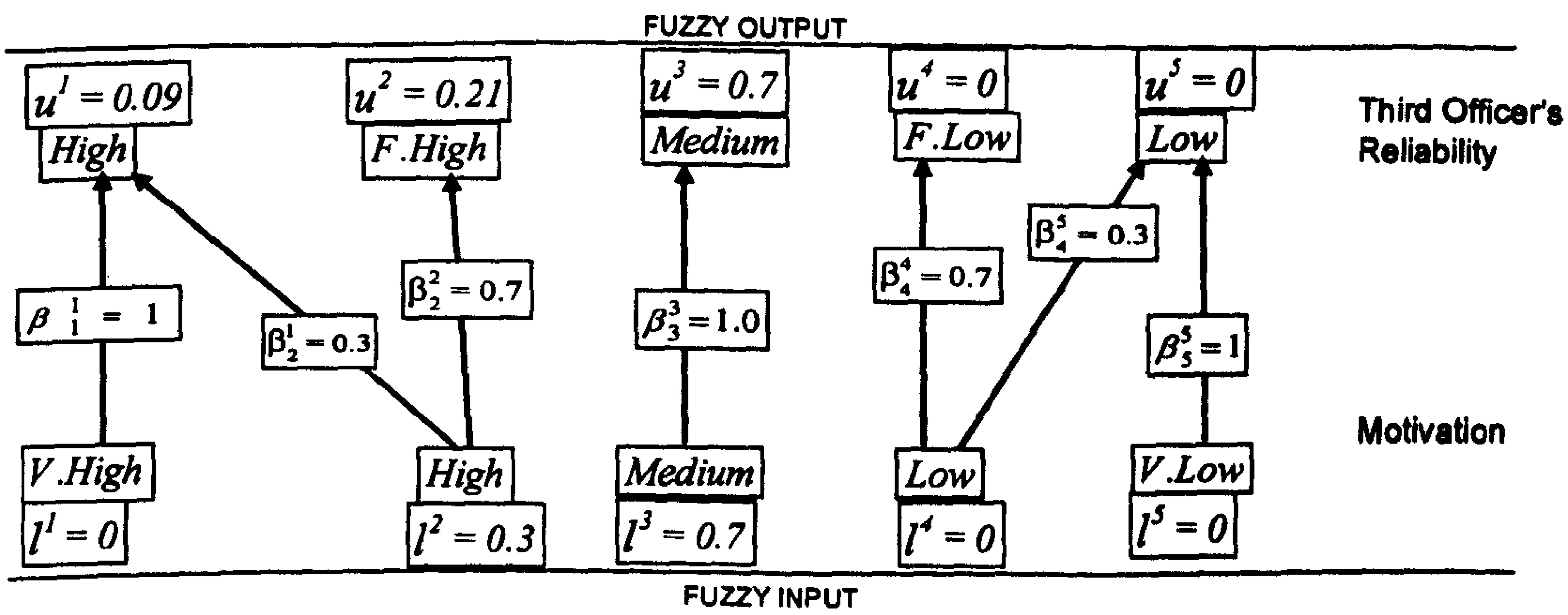

Figure A2.23: Mapping from Motivation to the Third Officer's Reliability

A2.26. Design & Layout

Based on the given information, the fuzzy set for Design & Layout is evaluated as follows:

$\widetilde{DL}$ = {(Very Good, 1), (Good, 0), (Average, 0), (Bad, 0), (Very Bad, 0)}

A2.27. Mapping from Main Criterion (Design & Layout) to Goal

The mapping process is shown in Figure A2.24, and the fuzzy output set can be evaluated as follows:

$\widetilde{G}_{DL}$ = {(High, 1), (Fairly High, 0), (Medium, 0), (Fairly low, 0), (Low, 0)}

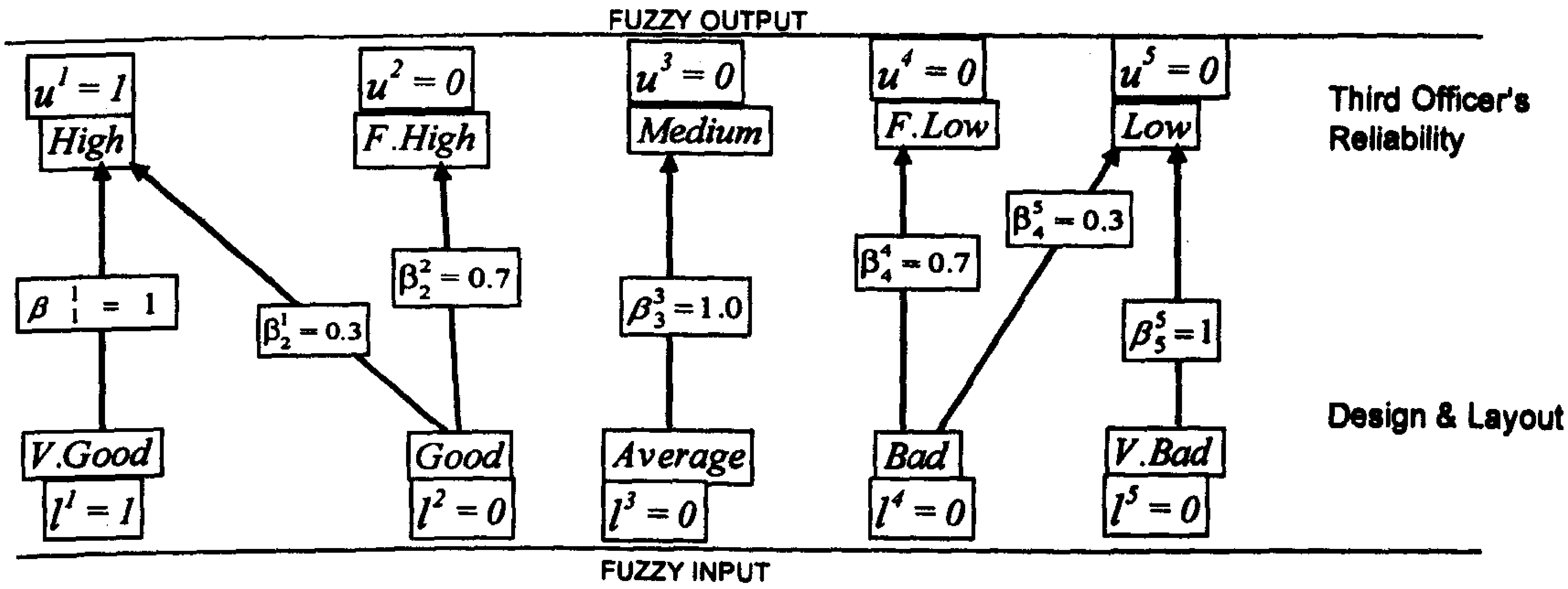

Figure A2.24: Mapping from Design & Layout to the Third Officer's Reliability

\2.28. Aggregation of Main-Criteria

}ased on the experts' judgement, the main criteria are equally important, therefore the veight distributed evenly between them (i.e. 1/6). Moreover, by help of the IDS oftware, as shown in Figure A2.25, $\widetilde{G}_T$, $\widetilde{G}_H$, $\widetilde{G}_{NT}$, $\widetilde{G}_{FS}$, $\widetilde{G}_M$, and $\widetilde{G}_{DL}$ are aggregated nd the result is presented in Table A2.5.

Table A2.5: Aggregation of Main Criteria to Goal

Ship-Staff Reliability	High	Fairly High	Medium	Fairly Low	Low	Weight
$\widetilde{G}_T$	0.08	0.16	0.34	0.42	0	1/6
$\widetilde{G}_H$	0.656	0.224	0.1	0.016	0.004	1/6
$\widetilde{G}_{NT}$	0.18	0.32	0.4	0.08	0.02	1/6
$\widetilde{G}_{FS}$	0.53	0.36	0.04	0.042	0.028	1/6
$\widetilde{G}_M$	0.09	0.21	0.7	0	0	1/6
$\widetilde{G}_{DL}$	1	0	0	0	0	1/6
Goal Result	0.4449	0.2060	0.2581	0.0834	0.0076	

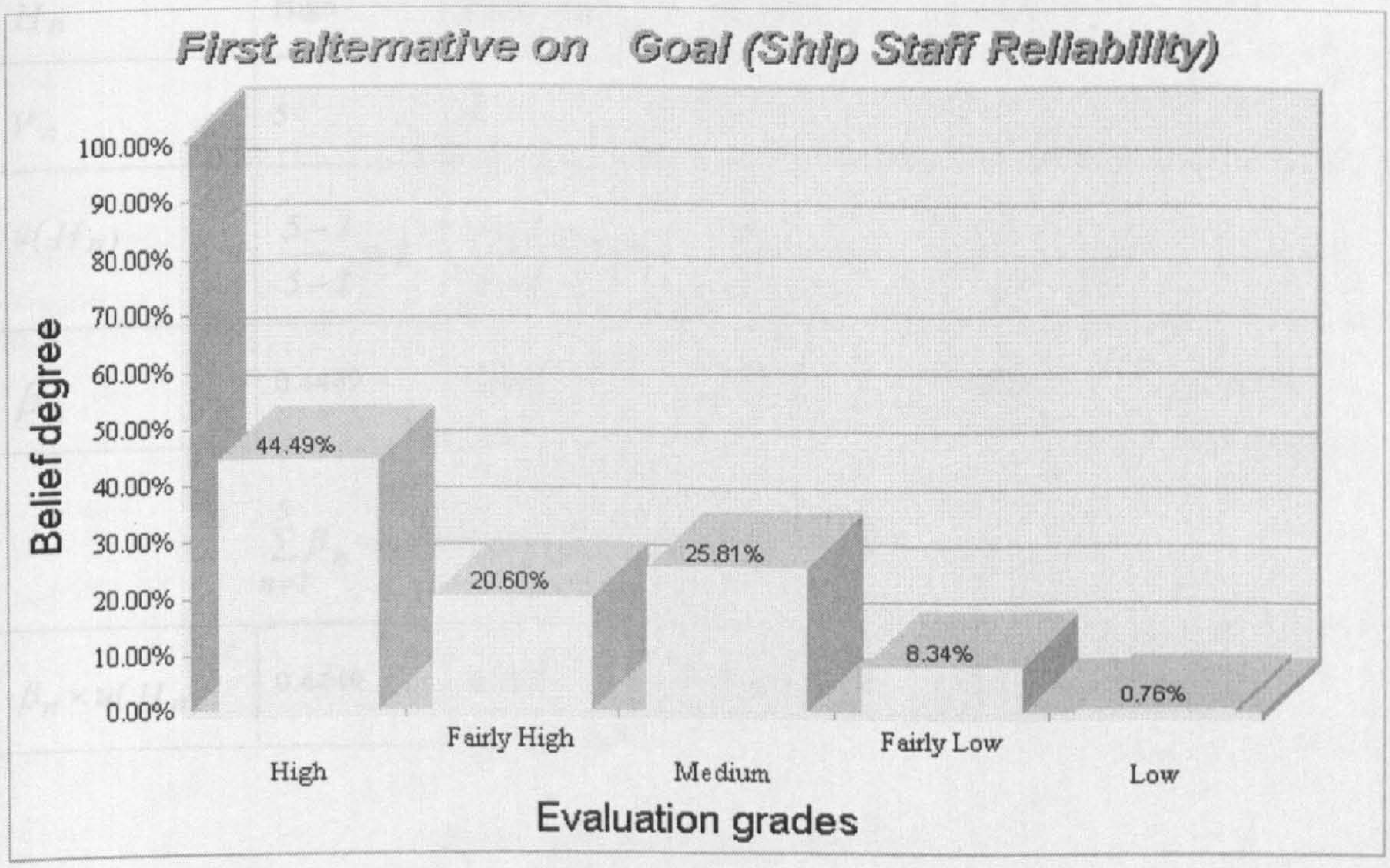

Figure A2.25: Aggregation of Main Criteria to Goal

A2.29. Utility Value

Evidently, the assessment based on a single value is much easier and more intuitive as a practical tool for a professional decision maker for ranking the alternatives. Therefore, to obtain a single crisp number for the goal, the utility value associated with each linguistic term has to be calculated. Based on Table A2.5, the fuzzy set for the Third Officer's reliability (Goal) can be written as follows:

$\tilde{G}$ = {(High, 0.4449), (Fairly High, 0.2060), (Medium, 0.2581), (Fairly Low, 0.0834), (Low, 0.0076)}

In view of the fact that the fuzzy set for the goal has been characterised by five linguistic terms, the highest preference is given to the "High" linguistic term and the lowest preference is given to the "Low" linguistic term. Thus, the ranking value is designated from five (i.e. highest preference) to one (i.e. lowest preference). The goal's assessments, as shown in Table 3.15, are complete. Based on Equations (3.14) and (3.19) the goal's utility value can be calculated as shown in Table A2.6.

Table A2.6: Calculation of Utility Value

H_n	High	Fairly high	Medium	Fairly low	Low
V_n	5	4	3	2	1
$u(H_n)$	$\frac{5-1}{5-1}=1$	$\frac{4-1}{5-1}=0.75$	$\frac{3-1}{5-1}=0.5$	$\frac{2-1}{5-1}=0.25$	$\frac{1-1}{5-1}=0$
β_n	0.4449	0.2060	0.2581	0.0834	0.0076
$\sum_{n=1}^{5}\beta_n=0.4449+0.2060+0.2581+0.0834+0.0076=1 \rightarrow \beta_H=0$					
$\beta_n \times u(H_n)$	0.4449	0.1545	0.12905	0.02085	0
$R_T = \sum_{n=1}^{5}\beta_n \times u(H_n) = 0.7493 \approx 0.75$					

Appendix 3: Mapping Process (Chapter 4)

Table A3.1: Qualification (Based on Figures A2.1 and A2.5)

Fuzzy Input	l^1	l^2	l^3	l^4	l^5			
	0	0	0.2	0.8	0			
Belief degrees in First mapping	$\beta_1^{1,1}$	$\beta_2^{1,1}$	$\beta_2^{2,1}$	$\beta_3^{2,1}$	$\beta_3^{3,1}$	$\beta_4^{3,1}$	$\beta_4^{4,1}$	$\beta_5^{5,1}$
	1	0.2	0.8	0.1	0.9	0.2	0.8	1
Belief degrees in Second mapping	$\beta_1^{1,2}$	$\beta_2^{1,2}$	$\beta_2^{2,2}$	$\beta_3^{2,2}$	$\beta_3^{3,2}$	$\beta_4^{3,2}$	$\beta_4^{4,2}$	$\beta_5^{5,2}$
	1	0.2	0.8	0.1	0.9	0.2	0.8	1
Result	g^1	g^2	g^3	g^4	g^5			
	0.004	0.05	0.434	0.512	0			
Prior Probability	0.3865							

Table A3.2: Experience (Based on Figures A2.2 and A2.5)

Fuzzy Input	l^1	l^2	l^3	l^4	l^5			
	0	0	0.2	0.8	0			
Belief degrees in First mapping	$\beta_1^{1,1}$	$\beta_2^{1,1}$	$\beta_2^{2,1}$	$\beta_3^{3,1}$	$\beta_3^{4,1}$	$\beta_4^{3,1}$	$\beta_4^{4,1}$	$\beta_5^{5,1}$
	1	0.4	0.6	0.6	0.4	0.2	0.8	1
Belief degrees in Second mapping	$\beta_1^{1,2}$	$\beta_2^{1,2}$	$\beta_2^{2,2}$	$\beta_3^{2,2}$	$\beta_3^{3,2}$	$\beta_4^{3,2}$	$\beta_4^{4,2}$	$\beta_5^{5,2}$
	1	0.2	0.8	0.1	0.9	0.2	0.8	1
Result	g^1	g^2	g^3	g^4	g^5			
	0	0.028	0.396	0.576	0			
Prior Probability	0.363							

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Table A3.3: Specific Training (Based on Figures A2.3 and A2.5)

Fuzzy Input	l^1	l^2	l^3	l^4	l^5			
	0.2	0.8	0	0	0			
Belief degrees in First mapping	$\beta_1^{1,1}$	$\beta_2^{2,1}$	$\beta_2^{3,1}$	$\beta_3^{3,1}$	$\beta_3^{4,1}$	$\beta_4^{4,1}$	$\beta_4^{5,1}$	$\beta_5^{5,1}$
	1	0.8	0.2	0.9	0.1	0.8	0.2	0.1
Belief degrees in Second mapping	$\beta_1^{1,2}$	$\beta_2^{1,2}$	$\beta_2^{2,2}$	$\beta_3^{2,2}$	$\beta_3^{3,2}$	$\beta_4^{3,2}$	$\beta_4^{4,2}$	$\beta_5^{5,2}$
	1	0.2	0.8	0.1	0.9	0.2	0.8	1
Result	g^1	g^2	g^3	g^4	g^5			
	0.328	0.528	0.144	0	0			
Prior Probability	0.796							

Table A3.4: Rest Hours (Based on Figures A2.6 and A2.10)

Fuzzy Input	l^1	l^2	l^3	l^4	l^5			
	1	0	0	0	0			
Belief degrees in First mapping	$\beta_1^{1,1}$	$\beta_2^{1,1}$	$\beta_2^{2,1}$	$\beta_3^{3,1}$	$\beta_3^{4,1}$	$\beta_4^{4,1}$	$\beta_4^{5,1}$	$\beta_5^{5,1}$
	1	0.2	0.8	0.8	0.2	0.9	0.1	1
Belief degrees in Second mapping	$\beta_1^{1,2}$	$\beta_2^{1,2}$	$\beta_2^{2,2}$	$\beta_3^{2,2}$	$\beta_3^{3,2}$	$\beta_4^{4,2}$	$\beta_4^{5,2}$	$\beta_5^{5,2}$
	1	0.2	0.8	0	1	0.8	0.2	1
Result	g^1	g^2	g^3	g^4	g^5			
	1	0	0	0	0			
Prior Probability	1							

Table A3.5: Environment (Based on Figures A2.7 and A2.10)

Fuzzy Input	l^1	l^2	l^3	l^4	l^5			
	0	0.5	0.5	0	0			
Belief degrees in First mapping	$\beta_1^{1,1}$	$\beta_2^{1,1}$	$\beta_2^{2,1}$	$\beta_3^{3,1}$	$\beta_3^{4,1}$	$\beta_4^{4,1}$	$\beta_4^{5,1}$	$\beta_5^{5,1}$
	1	0.2	0.8	0.8	0.2	0.9	0.1	1
Belief degrees in Second mapping	$\beta_1^{1,2}$	$\beta_2^{1,2}$	$\beta_2^{2,2}$	$\beta_3^{3,2}$	$\beta_3^{4,2}$	$\beta_4^{4,2}$	$\beta_4^{5,2}$	$\beta_5^{5,2}$
	1	0.2	0.8	1	0	0.8	0.2	1
Result	g^1	g^2	g^3	g^4	g^5			
	0.18	0.32	0.4	0.08	0.02			
Prior Probability	0.64							

Table A3.6: Design & Habitability (Based on Figures A2.8 and A2.10)

Fuzzy Input	l^1	l^2	l^3	l^4	l^5			
	0	1	0	0	0			
Belief degrees in First mapping	$\beta_1^{1,1}$	$\beta_2^{1,1}$	$\beta_2^{2,1}$	$\beta_3^{3,1}$	$\beta_3^{4,1}$	$\beta_4^{4,1}$	$\beta_4^{5,1}$	$\beta_5^{5,1}$
	1	0.2	0.8	0.8	0.2	0.9	0.1	1
Belief degrees in Second mapping	$\beta_1^{1,2}$	$\beta_2^{1,2}$	$\beta_2^{2,2}$	$\beta_3^{2,2}$	$\beta_3^{3,2}$	$\beta_4^{4,2}$	$\beta_4^{5,2}$	$\beta_5^{5,2}$
	1	0.2	0.8	0	1	0.8	0.2	1
Result	g^1	g^2	g^3	g^4	g^5			
	0.36	0.64	0	0	0			
Prior Probability	0.84							

Table A3.7: Situation awareness (Based on Figures A2.11 and A2.16)

Fuzzy Input	l^1	l^2	l^3	l^4	l^5			
	0	1	0	0	0			
Belief degrees in First mapping	$\beta_1^{1,1}$	$\beta_2^{1,1}$	$\beta_2^{2,1}$	$\beta_3^{3,1}$	$\beta_3^{4,1}$	$\beta_4^{4,1}$	$\beta_4^{5,1}$	$\beta_5^{5,1}$
	1	0.2	0.8	0.8	0.2	0.9	0.1	1
Belief degrees in Second mapping	$\beta_1^{1,2}$	$\beta_2^{1,2}$	$\beta_2^{2,2}$	$\beta_3^{2,2}$	$\beta_3^{3,2}$	$\beta_4^{4,2}$	$\beta_4^{5,2}$	$\beta_5^{5,2}$
	1	0.2	0.8	0	1	0.8	0.2	1
Result	g^1	g^2	g^3	g^4	g^5			
	0.36	0.64	0	0	0			
Prior Probability	0.84							

Table A3.8: Communication and Language Skill (Based on Figures A2.12 and A2.16)

Fuzzy Input	l^1	l^2	l^3	l^4	l^5			
	0	0	1	0	0			
Belief degrees in First mapping	$\beta_1^{1,1}$	$\beta_2^{1,1}$	$\beta_2^{2,1}$	$\beta_3^{3,1}$	$\beta_3^{4,1}$	$\beta_4^{4,1}$	$\beta_4^{5,1}$	$\beta_5^{5,1}$
	1	0.2	0.8	0.8	0.2	0.9	0.1	1
Belief degrees in Second mapping	$\beta_1^{1,2}$	$\beta_2^{1,2}$	$\beta_2^{2,2}$	$\beta_3^{2,2}$	$\beta_3^{3,2}$	$\beta_4^{4,2}$	$\beta_4^{5,2}$	$\beta_5^{5,2}$
	1	0.2	0.8	0	1	0.8	0.2	1
Result	g^1	g^2	g^3	g^4	g^5			
	0	0	0.8	0.16	0.04			
Prior Probability	0.44							

Table A3.9: Teamwork (Based on Figures A2.13 and A2.16)

Fuzzy Input	I^1	I^2	I^3	I^4	I^5			
	0	1	0	0	0			
Belief degrees in First mapping	$\beta_1^{1,1}$	$\beta_2^{1,1}$	$\beta_2^{2,1}$	$\beta_3^{3,1}$	$\beta_3^{4,1}$	$\beta_4^{4,1}$	$\beta_4^{5,1}$	$\beta_5^{5,1}$
	1	0.2	0.8	0.8	0.2	0.9	0.1	1
Belief degrees in Second mapping	$\beta_1^{1,2}$	$\beta_2^{1,2}$	$\beta_2^{2,2}$	$\beta_3^{2,2}$	$\beta_3^{3,2}$	$\beta_4^{4,2}$	$\beta_4^{5,2}$	$\beta_5^{5,2}$
	1	0.2	0.8	0	1	0.8	0.2	1
Result	g^1	g^2	g^3	g^4	g^5			
	0.36	0.64	0	0	0			
Prior Probability	0.84							

Table A3.10: Decision Making (Based on Figures A2.14 and A2.16)

Fuzzy Input	I^1	I^2	I^3	I^4	I^5			
	0	0	1	0	0			
Belief degrees in First mapping	$\beta_1^{1,1}$	$\beta_2^{1,1}$	$\beta_2^{2,1}$	$\beta_3^{3,1}$	$\beta_3^{4,1}$	$\beta_4^{4,1}$	$\beta_4^{5,1}$	$\beta_5^{5,1}$
	1	0.2	0.8	0.8	0.2	0.9	0.1	1
Belief degrees in Second mapping	$\beta_1^{1,2}$	$\beta_2^{1,2}$	$\beta_2^{2,2}$	$\beta_3^{2,2}$	$\beta_3^{3,2}$	$\beta_4^{4,2}$	$\beta_4^{5,2}$	$\beta_5^{5,2}$
	1	0.2	0.8	0	1	0.8	0.2	1
Result	g^1	g^2	g^3	g^4	g^5			
	0	0	0.8	0.16	0.04			
Prior Probability	0.44							

Table A3.11: Age (Based on Figures A2.17 and A2.22)

<table>
<tr><td rowspan="2">Fuzzy Input</td><td colspan="2">l^1</td><td colspan="2">l^2</td><td colspan="2">l^3</td><td>l^4</td><td>l^5</td></tr>
<tr><td colspan="2">0</td><td colspan="2">1</td><td colspan="2">0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="2">Belief degrees in First mapping</td><td>$\beta_1^{1,1}$</td><td>$\beta_2^{1,1}$</td><td>$\beta_2^{2,1}$</td><td>$\beta_3^{3,1}$</td><td>$\beta_3^{4,1}$</td><td>$\beta_4^{4,1}$</td><td>$\beta_4^{5,1}$</td><td>$\beta_5^{5,1}$</td></tr>
<tr><td>1</td><td>0.2</td><td>0.8</td><td>0.8</td><td>0.2</td><td>0.9</td><td>0.1</td><td>1</td></tr>
<tr><td rowspan="2">Belief degrees in Second mapping</td><td>$\beta_1^{1,2}$</td><td>$\beta_2^{1,2}$</td><td>$\beta_2^{2,2}$</td><td>$\beta_3^{2,2}$</td><td>$\beta_3^{3,2}$</td><td>$\beta_4^{4,2}$</td><td>$\beta_4^{5,2}$</td><td>$\beta_5^{5,2}$</td></tr>
<tr><td>1</td><td>0.4</td><td>0.6</td><td>0</td><td>1</td><td>0.6</td><td>0.4</td><td>1</td></tr>
<tr><td rowspan="2">Result</td><td colspan="2">g^1</td><td colspan="2">g^2</td><td colspan="2">g^3</td><td>g^4</td><td>g^5</td></tr>
<tr><td colspan="2">0.52</td><td colspan="2">0.48</td><td colspan="2">0</td><td>0</td><td>0</td></tr>
<tr><td>Prior Probability</td><td colspan="8">0.88</td></tr>
</table>

Table A3.12: Health (Based on Figures A2.18 and A2.22)

<table>
<tr><td rowspan="2">Fuzzy Input</td><td colspan="2">l^1</td><td colspan="2">l^2</td><td colspan="2">l^3</td><td>l^4</td><td>l^5</td></tr>
<tr><td colspan="2">0.5</td><td colspan="2">0.5</td><td colspan="2">0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="2">Belief degrees in First mapping</td><td>$\beta_1^{1,1}$</td><td>$\beta_2^{1,1}$</td><td>$\beta_2^{2,1}$</td><td>$\beta_3^{3,1}$</td><td>$\beta_3^{4,1}$</td><td>$\beta_4^{3,1}$</td><td>$\beta_4^{5,1}$</td><td>$\beta_5^{5,1}$</td></tr>
<tr><td>1</td><td>0.2</td><td>0.8</td><td>0.8</td><td>0.2</td><td>0</td><td>1</td><td>0</td></tr>
<tr><td rowspan="2">Belief degrees in Second mapping</td><td>$\beta_1^{1,2}$</td><td>$\beta_2^{1,2}$</td><td>$\beta_2^{2,2}$</td><td>$\beta_3^{2,2}$</td><td>$\beta_3^{3,2}$</td><td>$\beta_4^{4,2}$</td><td>$\beta_4^{5,2}$</td><td>$\beta_5^{5,2}$</td></tr>
<tr><td>1</td><td>0.4</td><td>0.6</td><td>0</td><td>1</td><td>0.6</td><td>0.4</td><td>1</td></tr>
<tr><td rowspan="2">Result</td><td colspan="2">g^1</td><td colspan="2">g^2</td><td colspan="2">g^3</td><td>g^4</td><td>g^5</td></tr>
<tr><td colspan="2">0.76</td><td colspan="2">0.24</td><td colspan="2">0</td><td>0</td><td>0</td></tr>
<tr><td>Prior Probability</td><td colspan="8">0.94</td></tr>
</table>

Table A3.13: Stress (Based on Figures A2.19 and A2.22)

Fuzzy Input	l^1		l^2		l^3	l^4		l^5
	0		1		0	0		0
Belief degrees in First mapping	$\beta_1^{1,1}$	$\beta_2^{1,1}$	$\beta_2^{2,1}$	$\beta_3^{3,1}$	$\beta_3^{4,1}$	$\beta_4^{3,1}$	$\beta_4^{5,1}$	$\beta_5^{5,1}$
	1	0.2	0.8	0.8	0.2	0	1	0
Belief degrees in Second mapping	$\beta_1^{1,2}$	$\beta_2^{1,2}$	$\beta_2^{2,2}$	$\beta_3^{2,2}$	$\beta_3^{3,2}$	$\beta_4^{4,2}$	$\beta_4^{5,2}$	$\beta_5^{5,2}$
	1	0.4	0.6	0	1	0.6	0.4	1
Result	g^1		g^2		g^3	g^4		g^5
	0.52		0.48		0	0		0
Prior Probability	0.88							

Table A3.14: Nutrition (Based on Figures A2.20 and A2.22)

Fuzzy Input	l^1		l^2		l^3	l^4		l^5
	0		0		0.4	0.6		0
Belief degrees in First mapping	$\beta_1^{1,1}$	$\beta_2^{1,1}$	$\beta_2^{2,1}$	$\beta_3^{3,1}$	$\beta_3^{4,1}$	$\beta_4^{3,1}$	$\beta_4^{4,1}$	$\beta_5^{5,1}$
	1	0.4	0.6	0.6	0.4	0.2	0.8	1
Belief degrees in Second mapping	$\beta_1^{1,2}$	$\beta_2^{1,2}$	$\beta_2^{2,2}$	$\beta_3^{2,2}$	$\beta_3^{3,2}$	$\beta_4^{4,2}$	$\beta_4^{5,2}$	$\beta_5^{5,2}$
	1	0.4	0.6	0	1	0.6	0.4	1
Result	g^1		g^2		g^3	g^4		g^5
	0		0		0.36	0.384		0.256
Prior Probability	0.276							

Table A3.15: Motivation (Based on Figure A2.23)

Fuzzy Input	l^1	l^2	l^3	l^4	l^5			
	0	0.3	0.7	0	0			
Belief degrees	β_1^1	β_2^1	β_2^2	β_3^3	β_3^4	β_4^4	β_4^5	β_5^5
	1	0.3	0.7	1	0	0.7	0.3	1
Result	g^1	g^2	g^3	g^4	g^5			
	0.09	0.21	0.7	0	0			
Prior Probability	0.5975							

Table A3.16: Design & Layout (Based on Figure A2.24)

Fuzzy Input	l^1	l^2	l^3	l^4	l^5			
	1	0	0	0	0			
Belief degrees	β_1^1	β_2^1	β_2^2	β_3^3	β_3^4	β_4^4	β_4^5	β_5^5
	1	0.3	0.7	1	0	0.7	0.3	1
Result	g^1	g^2	g^3	g^4	g^5			
	1	0	0	0	0			
Prior Probability	1							

Appendix 4

Security Assessments

A4.1. Security Assessment of a Warehouse, Port, Manufacturing Site, Container Consolidation and de-Consolidation Facility.

The following are designed to assess the basic physical security and procedural security standards for the factories, and plants as well as container yards and warehouses (McNicholas, 2008):

1. *Perimeter barrier*: At least 8 feet in height, chain link fence or concrete wall, and topped with blade concertina wire.
    a. The basic physical security is assessed as very high.
    b. The basic physical security is assessed as high.
    c. The basic physical security is assessed as average.
    d. The basic physical security is assessed as low (i.e. the basic requirement is not met).
2. *Gates:* At least 8 feet in height, chain link fence or metal door, and topped with blade concertina wire.
    a. The basic physical security is assessed as very high.
    b. The basic physical security is assessed as high.
    c. The basic physical security is assessed as average.
    d. The basic physical security is assessed as low (i.e. the basic requirement is not met).
3. *Security gatehouse:* Vehicle and personnel control logs, visitor badges, telephone, radio, post order, emergency notification poster, fire extinguisher, flash lights.
    a. The basic physical security is assessed as very high.
    b. The basic physical security is assessed as high.
    c. The basic physical security is assessed as average.
    d. The basic physical security is assessed as low (i.e. the basic requirement is not met).

4. *Lighting:* Perimeter, exterior of buildings and loading docks, parking area, container staging areas, and all cargo storage and packing areas.

   a. The basic physical security is assessed as very high.
   b. The basic physical security is assessed as high.
   c. The basic physical security is assessed as average.
   d. The basic physical security is assessed as low (i.e. the basic requirement is not met).

5. *Segregated parking area:* Privately owned vehicles (POVs) to be separated from company vehicles, no POVs parked near loading docks or cargo or container staging area.

   a. The basic physical security is assessed as very high.
   b. The basic physical security is assessed as high.
   c. The basic physical security is assessed as average.
   d. The basic physical security is assessed as low (i.e. the basic requirement is not met).

6. *Building door and window locks/ protection:* Deadbolt locks on all exterior doors, wire mesh or bars on all windows below and second floor.

   a. The basic physical security is assessed as very high.
   b. The basic physical security is assessed as high.
   c. The basic physical security is assessed as average.
   d. The basic physical security is assessed as low (i.e. the basic requirement is not met).

7. *Access control:* Challenging, screening, inspection, and documentation of all vehicles, cargos, and persons at perimeter, gates, and building entrances and exits.

   a. The procedural security standards, monitoring and detecting systems are assessed as very high.
   b. The procedural security standards, monitoring and detecting systems are assessed as high.
   c. The procedural security standards, monitoring and detecting systems are assessed as average.
   d. The procedural security standards, monitoring and detecting systems are assessed as low (i.e. the basic requirement is not met).

8. *Security officers:* Deployed at all entrances/exits and on patrol.

   a. The procedural security standards, monitoring and detecting systems are assessed as very high.
   b. The procedural security standards, monitoring and detecting systems are assessed as high.
   c. The procedural security standards, monitoring and detecting systems are assessed as average.
   d. The procedural security standards, monitoring and detecting systems are assessed as low (i.e. the basic requirement is not met).

9. *Intrusion detection:* Alarms, passive infrared (PIR) systems, taut wires, buried cables etc., at the perimeter and at the access points to all restricted areas.

   a. The procedural security standards, monitoring and detecting systems are assessed as very high.
   b. The procedural security standards, monitoring and detecting systems are assessed as high.
   c. The procedural security standards, monitoring and detecting systems are assessed as average.
   d. The procedural security standards, monitoring and detecting systems are assessed as low (i.e. the basic requirement is not met).

10. *Closed circuit television (CCTV) system:* Cameras mounted at perimeter, entrance/exits, container and cargo staging areas, loading dock and restricted areas, monitored and recorded 24/7 in central monitoring office.

    a. The procedural security standards, monitoring and detecting systems are assessed as very high.
    b. The procedural security standards, monitoring and detecting systems are assessed as high.
    c. The procedural security standards, monitoring and detecting systems are assessed as average.
    d. The procedural security standards, monitoring and detecting systems are assessed as low (i.e. the basic requirement is not met).

11. *Identification cards:* For employees, vendors and visitors.

    a. The procedural security standards, monitoring and detecting systems are assessed as very high.
    b. The procedural security standards, monitoring and detecting systems are assessed as high.

c. The procedural security standards, monitoring and detecting systems are assessed as average.

d. The procedural security standards, monitoring and detecting systems are assessed as low (i.e. the basic requirement is not met).

12. *Security key:* Issue and control programme in place.

a. The procedural security standards, monitoring and detecting systems are assessed as very high.

b. The procedural security standards, monitoring and detecting systems are assessed as high.

c. The procedural security standards, monitoring and detecting systems are assessed as average.

d. The procedural security standards, monitoring and detecting systems are assessed as low (i.e. the basic requirement is not met).

13. *Container seals:* Inventory controls, issue logs and reconciliation procedures.

a. The procedural security standards, monitoring and detecting systems are assessed as very high.

b. The procedural security standards, monitoring and detecting systems are assessed as high.

c. The procedural security standards, monitoring and detecting systems are assessed as average.

d. The procedural security standards, monitoring and detecting systems are assessed as low (i.e. the basic requirement is not met).

14. *Security standard operating procedure manual:* Written, comprehensive, implemented and audited.

a. The procedural security standards, monitoring and detecting systems are assessed as very high.

b. The procedural security standards, monitoring and detecting systems are assessed as high.

c. The procedural security standards, monitoring and detecting systems are assessed as average.

d. The procedural security standards, monitoring and detecting systems are assessed as low (i.e. the basic requirement is not met).

15. *Personal security:* Screening all applicants for employment, completion of detailed employment interview by the manager, criminal history and credit checks and interview of references and prior employs.

a. The procedural security standards, monitoring and detecting systems are assessed as very high.
b. The procedural security standards, monitoring and detecting systems are assessed as high.
c. The procedural security standards, monitoring and detecting systems are assessed as average.
d. The procedural security standards, monitoring and detecting systems are assessed as low (i.e. the basic requirement is not met).

16. *Contraband detection systems:* Non intrusive technology (i.e. passive gamma, passive neutron, active radiography, X-Ray machines, portal monitors, radiation detective pagers) [**Applicable for Ports**].

a. The procedural security standards, monitoring and detecting systems are assessed as very high.
b. The procedural security standards, monitoring and detecting systems are assessed as high.
c. The procedural security standards, monitoring and detecting systems are assessed as average.
d. The procedural security standards, monitoring and detecting systems are assessed as low (i.e. the basic requirement is not met).

17. *Raw material and finished product:* Controlled, inspected, inventoried, secured and monitored [**Applicable for Factories**].

a. The procedural security standards, monitoring and detecting systems are assessed as very high.
b. The procedural security standards, monitoring and detecting systems are assessed as high.
c. The procedural security standards, monitoring and detecting systems are assessed as average.
d. The procedural security standards, monitoring and detecting systems are assessed as low (i.e. the basic requirement is not met).

Table A4.1: Answer Key for A4.1

Question Number	Point Values of Answers			
	a	b	c	d
1	10	8	6	(-120)
2	10	8	6	(-120)
3	10	8	6	(-120)
4	10	8	6	(-120)
5	10	8	6	(-120)
6	10	8	6	(-120)
7	10	8	6	(-120)
8	10	8	6	(-120)
9	10	8	6	(-120)
10	10	8	6	(-50)
11	10	8	6	(-120)
12	10	8	6	(-120)
13	10	8	6	(-120)
14	10	8	6	(-120)
15	10	8	6	(-120)
16	10	8	6	(-50)
17	10	8	6	(-120)

Based on Table A4.1, the highest score for a warehouse, container consolidation and de-consolidation facility can be calculated as 150 points (i.e. very high security standard). However, if the security standards are evaluated as high and average the score can be evaluated as 120 and 90 points respectively. Furthermore, if any of the basic security requirements are not met the score is calculated as 30 points. A quantitative criterion (i.e. the scores), as shown in Figure A4.1, can be transformed to a qualitative criterion (i.e. reliability) by exploiting the membership functions. In the same manner the membership functions for a port or a manufacturing site, as shown in Figure A4.2, can be constructed.

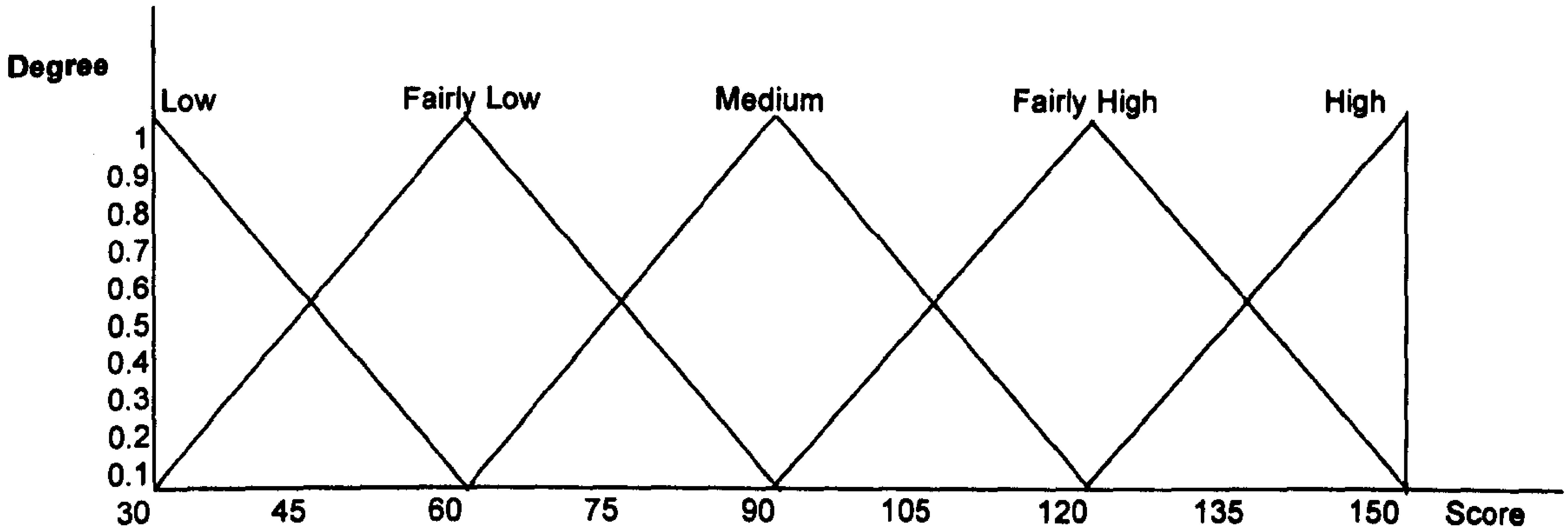

Figure A4.1: Membership Functions of Warehouse, Container Consolidation and de-Consolidation facility

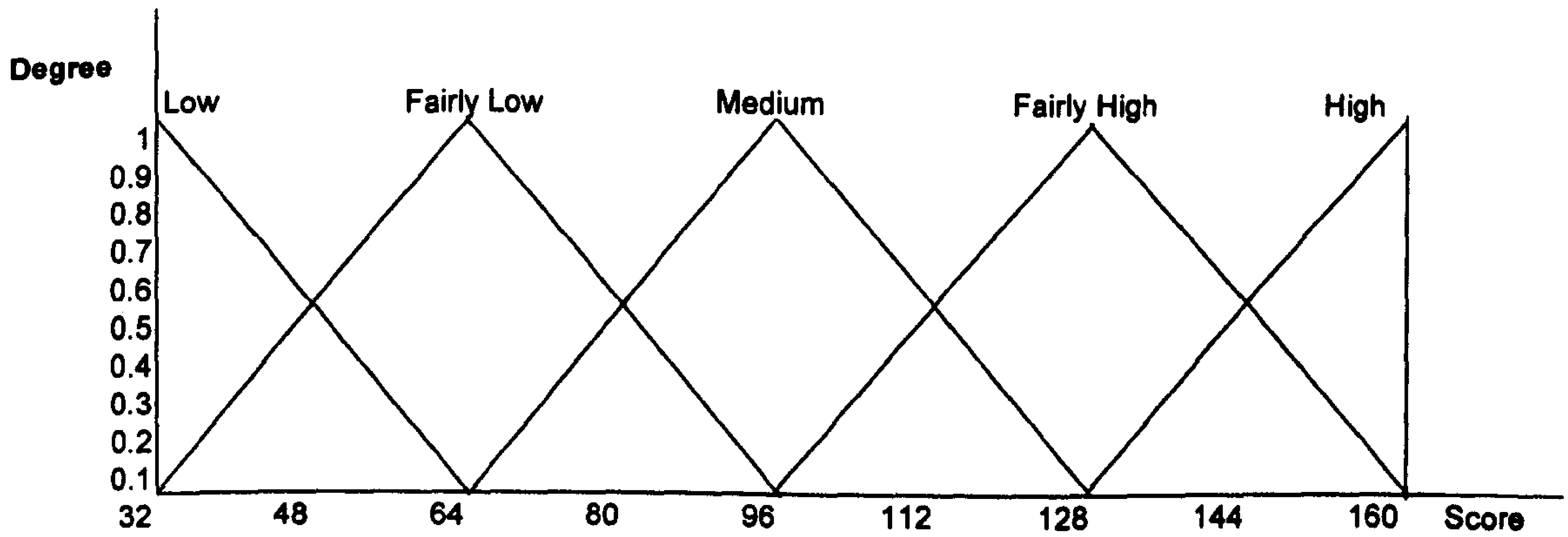

Figure A4.2: Membership Functions of Port and Manufacturing Site

A4.2. Assessment of Exporters or Manufacturers for Export Readiness.

The following are designed and modified to assess the exporter or the manufacturer's reliability (Zakner and Belisa, 2004):

1. What product (products) does (do) the exporter offer?
   a. Fast-selling consumer goods (e.g. food, drink, confectionary product).
   b. Consumer durables (e.g. furniture, hi-fi, appliances).
   c. Industrial consumables or durables (e.g. raw material, components, machinery, etc.).
2. How long is the exporter in the business?
   a. More than 15 years.
   b. Less than one year.
   c. Between one and three years.
   d. More than three years.
3. Is the trend of sales and inquiries up or down?
   a. Up.
   b. Down.
   c. About the same.
   d. Do not know.
4. How many sales offices, sales locations, or distribution points does the company have?
   a. One or more domestic office and at least one foreign office.
   b. One.
   c. Two.
   d. More than two.
5. What is the timeframe for the exporter's business plan?
   a. Six months.
   b. One year.

c. Three years.

d. No business plan.

6. Have the exporter exported before?

a. Yes.

b. No.

7. Had the exporter exported to the concerned country (i.e. discharging port) before?

a. Yes, more than three times and no violation history or noncompliance with customs laws and regulations observed.

b. Yes, less than three times and no violation history or noncompliance with customs laws and regulations observed.

c. No.

d. A violation history or noncompliance with customs laws and regulations observed.

8. How much time is the exporter dedicated to export planning?

a. Considerable planning efforts (i.e. three to six months).

b. Some (one or two months).

c. Minimal(less than a month).

d. Do not know.

9. How quickly does the management expect export operations to become self-sustaining?

a. Three years.

b. Immediately.

c. Six months or already self-sustained.

d. Do not know.

10. Has the company's management allocated resources for the export effort?

a. Assigned extra personnel only.

b. Allocated extra financial resources.

c. Allocated both personnel and financial resources.

d. No extra resources will be allocated.

11. Which of the following market entry barriers have the exporter researched?

a. Tariffs and non-tariff barriers.

b. International standards.

c. Product modification.

d. All of the above.

12. For the product what factors did the exporter take into account?

a. Cost only.

b. Market demand and cost only.

c. Competition and cost only.

d. All of the above.

13. What factors does the company include in its market analysis?

a. Structure.

b. Market share and size.

c. All of above.

d. None of above.

14. Does the exporter have a website in English language?

a. Yes.

b. No.

15. With how many countries has business been conducted?

a. None.

b. One.

c. Between two and three.

d. More than three.

16. Has the exporter participated in the international trade exhibition?

a. Never.

b. Once as an attendee.

c. Twice and more as an attendee.

d. More than once as an attendee and at least once as an exhibitor.

17. How much international business experience does the company's staff have, either /both in theory and /or practice?

a. None.

b. Moderate amount.

c. Considerable amount.

d. Do not know.

18. Which of the company's employees speak English?

a. Top management only.

b. Middle and top managements.

c. Administrative staff as well as top and middle managements.

d. None of the above.

19. Did the company succeed in obtaining a bank loan in the last 10 years?

a. Yes.

b. No.

c. Do not know.

20. What method of payment does the exporter consider the least secure?

a. Open account.

b. Cash in advance.

c. Letter of credit.

d. Documentary collection.

21. Which method of e-mail communication is used by the company?

a. External communication only.

b. Internal communication only.

c. Both as internal and external communication method.

d. Not used at all.

Table A4.2: Answer Key for A4.2

Question Number	Point Values of Answers			
	a	b	c	d
1	3	3	3	-
2	5	0	1	3
3	5	0	1	0
4	5	0	1	3
5	(-30)	1	4	(-50)
6	5	0	-	-
7	15	5	0	(-40)
8	5	1	(-15)	(-15)
9	(-2)	1	2	0
10	2	3	5	0
11	0	0	0	5
12	0	0	0	5
13	1	1	5	0
14	5	0	-	-
15	0	1	2	3
16	0	1	2	5
17	1	2	3	0
18	2	3	4	0
19	5	0	0	-
20	5	0	0	0
21	2	2	5	0

Based on Table A4.2, the highest score (i.e. sum of the highest values for each question) for an exporter or a manufacturer can be calculated as 104 points. However, if an exporter has exported less than three times or if an exporter is exporting for the first time the score may be evaluated as 94 or 84 points respectively. Furthermore, if an exporter has a serious interest in exporting, but there are some areas of weakness in the exporter's strategy the score may be evaluated as 64-84 points. The quantitative criterion (i.e. the scores), as shown in Figure A4.3, can be transformed to a qualitative criterion (i.e. reliability) by exploiting the membership functions.

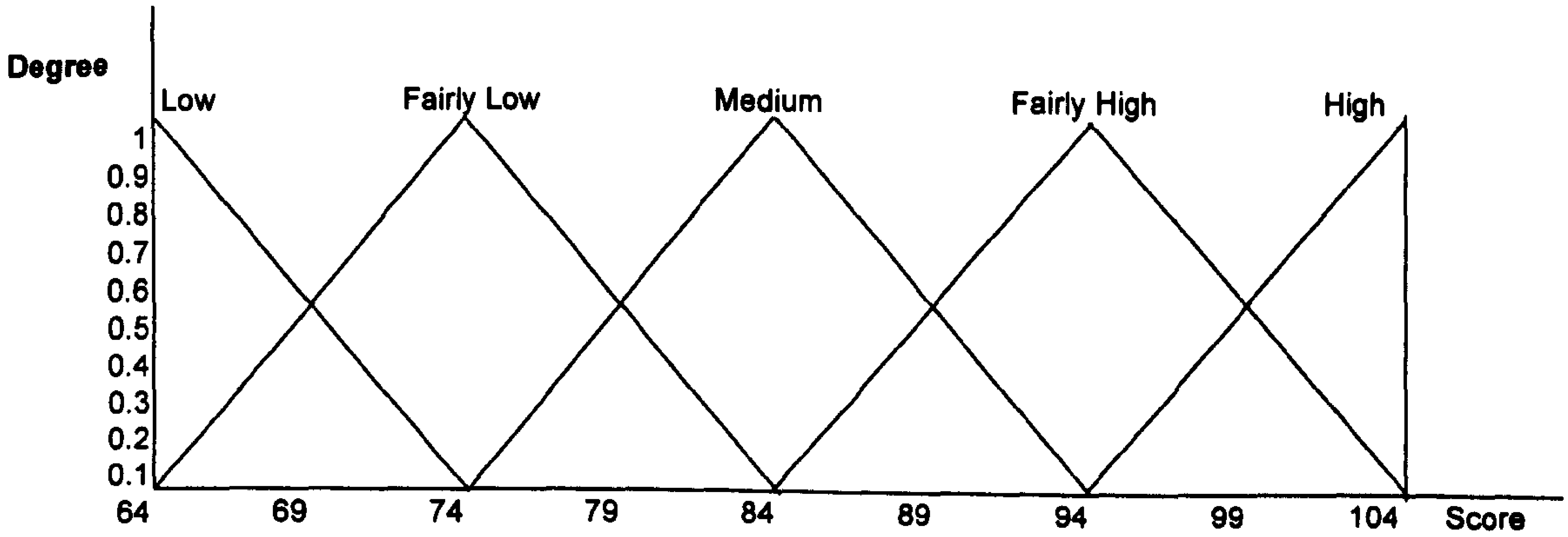

Figure A4.3: Membership Functions of Exporter and Manufacturer for Export Readiness