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The Development of Safety and Security Assessment Techniques and their Application to Port Operations

By

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Abstract

This research has first reviewed the current status of offshore and marine safety, and security assessment. The major problems identified in the research are associated with risk modelling under circumstances where the lack of data or a high level of uncertainty exists. Following the identification of the research needs, this PhD thesis has developed several analytical models for maritime risk assessment based on the safety principles identified from safety regulations. Such frameworks are subsequently demonstrated by their corresponding test cases with regard to safety and security of port operations.

First, in this PhD study, a risk assessment framework is proposed to evaluate port security using fuzzy set theory and the rule base technique due to the lack of data resulting from the confidentiality of the intelligence with regard to terrorism and the difficulty of the information accession. Secondly, a shortcoming occurs when the fuzzy rule base technique is applied to circumstances where there are multiple parameters to be evaluated which are described by multiple linguistic terms. Such a problem can be overcome by a proposed risk prediction model incorporating fuzzy set theory with an Artificial Neural Network (ANN). The framework is demonstrated by a test case focusing on port safety. Thirdly, human error accounts for a significant contribution in marine accidents. In this study, a new method of human error assessment using fuzzy set theory and Analytical Hierarchy Process (AHP) is proposed. It is demonstrated using a test case of a port oil cargo handling process and is capable of avoiding the criticism raised when using traditional Human Reliability Assessment (HRA) techniques. Fourthly, many real world decision analysis problems involve multiple attributes with both a quantitative and qualitative nature. A decision making model using the evidential reasoning algorithm is proposed to demonstrate the selection of the best security, safety and human error reduction measures under such circumstances. Finally, more safety regulations and security measures may often imply an increased probability of inefficiency influencing port operations. Thus, the quality of the port processes regulated by such measures is essential. A quality control model is proposed based on the Six Sigma technique and is demonstrated by a test case of a port security process. The five models are original in nature being developed from existing theoretical techniques and applied to realistic port scenarios. The development of the frameworks and the test case applications are major contributions to knowledge in this thesis.

It is concluded that the frameworks proposed possess significant potential for use in improving safety and security of port operations based on the verifications of their corresponding test cases. Accordingly, the developed models can be integrated to formulate a platform to facilitate risk assessment and safety management of port operations without jeopardising the efficiency of port operations in various situations where traditional techniques cannot be applied with confidence.

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Abbreviations

Abbreviations	Description
ABP	Associated British Ports PLC
ABS	American Bureau of Shipping
AHP	Analytical Hierarchy Process
AIS	Automated Identification System
ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
ANN	Artificial Neural Network
CAF	Cost of Averting a Fatality
CBA	Cost Benefit Analysis
CEOs	Chief Executive Officers
CN	Criticality Number
CSR	Continuous Synopsis Record
CTQ	Critical to Quality
CURR	Cost of Unit Risk Reduction
DAMA	Data Management Association
DCR: 1996	Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996
DMAIC	Define, Measure, Analyse, Improve and Control
DPMO	Defects Per Million Opportunities
D-S Theory	Dempster-Shafer Theory
EPCs	Error Producing Conditions
ER	Evidential Reasoning
ETA	Event Tree Analysis
FI	Frequency Index
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode, Effects and Criticality Analysis
FSA	Formal Safety Assessment
FTA	Fault Tree Analysis
GE	General Electric
HAZID	Hazard Identification
HAZOP	Hazard and Operability Studies
HEA	Human Error Assessment
HEART	Human Error Assessment and Reduction Technique
HEP	Human Error Probability
HOEs	Human and Organisational Errors

HRA	Human Reliability Assessment
HSC	Health and Safety Commission
HSE	Health and Safety Executive
ID	Influence Diagram
IDS	Intelligent Decision System
ILO	International Labour Organisation
IMB	International Maritime Bureau
IMO	International Maritime Organization
ISM Code	International Safety Management Code
ISPS Code	International Ship and Port Facility Security Code
JHEDI	Justification of Human Error Data Information
LMIS Database	Lloyd's Maritime Information Services Database
LSL	Lower Specification Limit
MADA	Multiple Attribute Decision Analysis
MAIB Database	Marine Accident Investigation Branch Database
MAR 1995	Management and Administration Regulations 1995
MARS Database	Marine Accident Reporting Scheme Database
MCA	Maritime and Coastguard Agency
MEPC	Marine Environment Protection Committee
MHIDS	Major Hazard Incident Data Service
MIIU	Marine Incident Investigation Unit
MSA	Maritime Safety Agency
MSC	Maritime Safety Committee
NPV	Net Present Value
OPRC	Oil Pollution Preparedness, Response and Co-operation
PFEER 1995	Prevention of Fire and Explosion and Emergency Response Regulations 1995
PHA	Preliminary Hazard Analysis
PLL	Potential Loss of Life
PMS Code	Port Marine Safety Code
PRA	Probabilistic Risk Analysis
PRC	Piracy Reporting Centre
PSFs	Performance Shaping Factors
PSR 1996	Pipeline Safety Regulations 1996
QRA	Quantitative Risk Assessment
RCOs	Risk Control Options
RI	Risk Index
RIMER	Rule-base Inference Methodology using ER
RPN	Risk Priority Number
SCR 1992	Safety Case Regulations 1992

SI	Severity Index
SLIM-MAUD	Success Likelihood Index Method using Multi-Attribute Utility Decomposition
SMS	Safety Management System
SPC	Statistical Process Control
SSO	Ship Security Officer
STCW 95	Standards for Training, Certificates and Watchkeeping 1995
SWIFT	Structured What-If Checklist Technique
THERP	Technique for Human Error Rate Prediction
TQM	Total Quality Management
UKOOA	U.K. Offshore Operators Association
USL	Upper Specification Limit
VTC	Vessel Traffic Control
WCO	World Customs Organisation
WMoM	Weighted Mean of Maximums

Chapter 1. Introduction

This chapter first presents the background of this PhD study. The research problem and research questions are then given. This is followed by a brief discussion of the research methodology and the scope of this study. Finally, the structure for this thesis is given.

1.1 Background

Historically, maritime safety regulations were introduced following an accident or a series of major accidents, intending to address the most obvious causes. Over years, after a number of defining accidents and incidents including the capsize of the semi-submersible rig 'Alexander Keilland' in 1980, the explosion aboard the 'Piper Alpha' platform in 1988 and the capsize of the 'Herald of Free Enterprise' in 1987, the way in which safety is reviewed has been altered. The characteristic of maritime safety has evolved from a reactive manner towards a proactive attitude where a goal-setting and risk-based regime is required since the introduction of the safety regulations including Safety Case Regulations (SCR) and Formal Safety Assessment (FSA) in the 1990s. The main objective of these safety regulations is to ensure that risk has been reduced to the level of As Low As Reasonably Practicable (ALARP) and Risk Control Options (RCOs) proposed are cost effective.

In general, the tendency of the maritime risk assessment is that it is not only used for verification purposes in design and operational process of marine and offshore systems, but also for making decisions from the early stages [Wang, 2006]. Accordingly, interest in the improvement of the safety of large engineering systems based on safety management from the initial stages has been growing considerably within both the regulatory bodies and industry. However, since such a safety analysis is conducted at the initial stages, circumstances of the lack or incompleteness of data, or the low or none relevance of generic data to specific areas in question are inevitably encountered. This would cause a high level of uncertainty that may undermine significantly the conclusion acquired based on the traditional quantitative risk assessment and safety management techniques. Consideration of these uncertainties may drive estimated risk levels appreciably upwards or downwards from the initial calculated results. Regardless of whether these estimated results are initially assessed as optimistic or pessimistic estimates, for instance, an upward revision could result from the consideration of the effect of a limited incident reporting in relation to its failure mode definition. Thus, the risk results evaluated under such circumstances may not be acquired with confidence.

Seaports are important for the economy of every country. Given the position in coastal areas and the great variety of substances handled there, a port can be regarded as a complex system from the environmental point of view. Due to the fact that detailed and historical safety and security related data within port areas is scarce, the issue as to the lack or incompleteness of data is also imposed on port security and safety studies. This inevitably increases the difficulty of risk assessment and safety management in ports.

1.2 Research problem and research questions

1.2.1 Research problem

As aforementioned due to the lack or incompleteness of data, the uncertainty incurred may undermine significantly the conclusion acquired based on the traditional quantitative risk assessment and safety management techniques. Accordingly, the research problem for this PhD study is shown as follows:

> **How risk assessment and safety management are conducted with confidence under circumstances where the lack or incompleteness of data or a high level of uncertainty exists?**

A number of risk and security assessment techniques need to be developed and applied to port operations under such circumstances where there is a high level of uncertainty due to the fact that the detailed safety related data is scarce. Thus, the first objective of this PhD study is to propose the frameworks capable of performing risk assessment and safety management in circumstances where the lack or the incompleteness of data exists. Secondly, the models to be developed can be integrated on which to formulate a platform to facilitate risk assessment and safety management of port operations without jeopardising the efficiency of port operations in a variety of situations where traditional techniques cannot be applied with confidence. Accordingly, the research questions raised in this study as to the objectives of this PhD project are discussed as follows.

1.2.2 Research Question 1

Due to the confidentiality of the intelligence with regard to terrorism and the difficulty of accessing information, the data available for conducting security risk assessment is scarce for most researchers. Thus, the issue as to the lack or incompleteness of data is imposed on port security risk assessment as aforementioned. Therefore, the first research question for this study is:

> **How port security is modelled in circumstances of the lack of data resulting from the confidentiality of the intelligence with regard to terrorism and the difficulty of information accession.**

1.2.3 Research Question 2

In risk assessment under circumstances where a high level of uncertainty exists, approximate reasoning methods using the fuzzy rule base technique have proven to be useful. However, such applications may become impractical as there are multiple parameters to be evaluated which are described by multiple linguistic terms. If there were five parameters described by five different linguistic variables, for example, the number of fuzzy rules needed to be developed would be 3,125. Thus, the research question with regard to this is shown below.

> **How the risks are modelled using the fuzzy rule base technique in circumstances where there are multiple parameters to be evaluated, which are described by multiple linguistic terms.**

1.2.4 Research Question 3

Human error, according to literature, accounts for a significant contribution to marine and port accidents. Human Error Assessment (HEA) has been conducted in a variety of industries. However, the nature of the sources from which the data is collected may be different from the context under consideration. Thus, the reliability of such data and quality of the HRA conducted may be questioned. A detailed review with regard to traditional HRA approaches is discussed in section 2.6.4. In addition, HRA is often absent from maritime risk assessment. This may be due to the fact that there is little or no human error related data collected by the industry [Wang *et al.*, 2004]. Accordingly, the research question with respect to human error analysis is raised as follows:

How human error assessment is conducted without the difficulty imposed on traditional human error methods.

1.2.5 Research Question 4

When evaluating RCOs for enhancing security and safety for a port, there are many parameters that need to be considered other than risk reduction and the ratio of costs and benefits such as time of deployment, current resources available, etc.. Thus, difficulties may be encountered due to the nature of the attribute of the defined criteria. The research question for this multi-attribute decision-making issue is shown as follows:

How the selection of the best RCOs by multi-experts is achieved in circumstances where the defined criteria are of a multi-attribute nature.

1.2.6 Research Question 5

More and more security and safety regulations and policies have been adopted and implemented in both the port and shipping industry. The objective of this is certainly to ensure that the international trade could be safely expedited without undue safety practices or threat from intentional crime activities. However, it may undermine the efficiency of port and shipping operations. Thus, the quality assurance of the efficiency with regard to safety and security measures should be a main concern. Accordingly, the research question for such an issue is raised as follows:

How the quality assurance concept is introduced to the port industry.

1.3 Research methodology

According to the safety regulations including SCR 1992, FSA, Port Marine Safety (PMS) Code and the International Ship and Port Facility (ISPS) Code as discussed in sections 2.2-2.5, the establishment of an effective port safety analysis should consist of the steps of hazard identification, risk estimation, preparation of RCOs, cost-benefit assessment and decision making without which the benefits discussed in section 2.3.7 cannot be foreseen [MSA, 1993] [Wang, 2002]. Therefore, the research methodology of this PhD study starts with the hazard identification of port operations, followed by risk assessment and safety management in order to meet the objective of establishing an effective safety analysis.

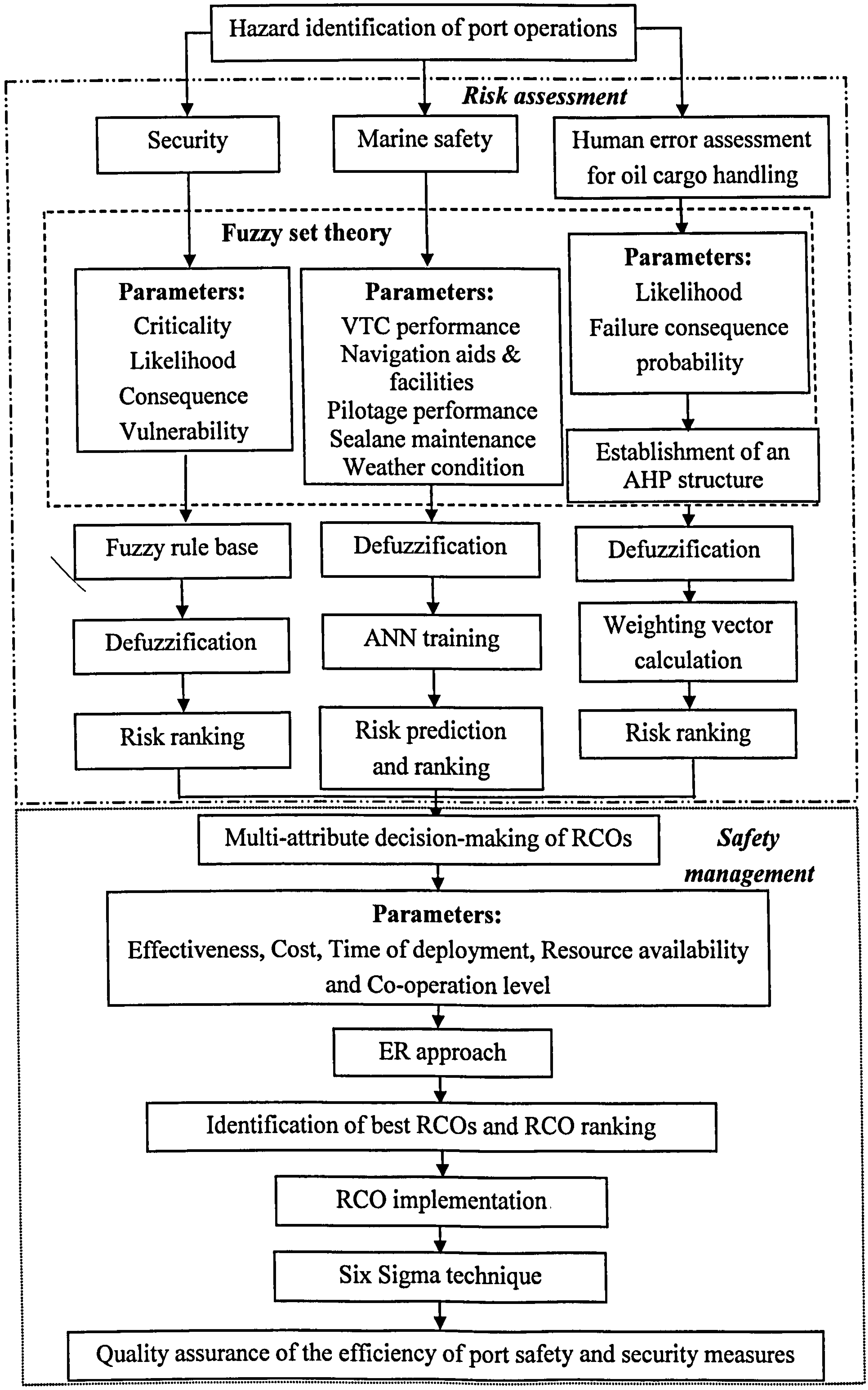

Figure 1.1. Research methodology of this PhD study

The hazard identification of port operations is concerned with the critical review of port accidents and the current safety analysis practices. The risk assessment component includes risk analysis of port security and safety as well as human error assessment in port operations whereas the safety management component consists of a multi-attribute decision-making framework and a quality assurance model. Figure 1.1 illustrates the research methodology of this study. The techniques to be applied in the risk assessment and safety management components will be justified in section 2.7 allowing for the circumstance of the lack of safety and security related data encountered by ports. The framework consisting of five different methods will be verified by five corresponding test cases in order to answer the research problems and questions stated in section 1.2. The limitations of the framework will also be identified by investigating the results acquired from the test cases. Such discussions will be conducted in a separate chapter following the development of the methods. In addition, it is noted that since the difficulty of acquiring real industrial data, the expert judgement in the test cases will be hypothetically prepared by the author based on the experience from the supervisors and expert specialising in the port industry.

1.3.1 Hazard identification of port operations

The first step of the methodology in this research is the hazard identification of port operations. The purpose of this stage is to identify the areas with high risks that have the potential to cause harm and damage to human being and the environment in port operations. The mission of this step is accomplished by conducting a critical review of port accidents as well as the current risk assessment and safety management practices in the maritime industry.

1.3.2 Risk assessment using approximate reasoning approach

After the critical review conducted, the higher risk areas identified in port operations include port security, port marine safety and oil cargo handling, respectively. In this stage, the objective is to conduct risk analysis to evaluate these higher risk areas. Allowing for the lack of data, it is necessary to incorporate subjective judgement from experts into the risk assessment component. Accordingly, the approximate reasoning approach using fuzzy set theory is applied. Three different methods based on fuzzy set theory are proposed, depending upon the number of the parameters and linguistic terms considered as well as the level of the information obtained.

1.3.2.1 Risk assessment of port security using fuzzy modelling

In circumstances where the lack or incompleteness of data exists, there is a need to incorporate expert judgement into the risk study. A framework is established based on fuzzy set theory alone with the fuzzy rule base method since it is capable of quantifying the judgement from experts who express opinions qualitatively. Four parameters are considered to evaluate the overall risk associated with each asset, namely, the criticality of each asset (C), the likelihood or probability of occurrence of each threat against a specific asset or target (P), the severity of each adverse attack against that specific asset (S), and the vulnerability of each asset or facility (V). According to literature security risk could be regarded as a function of the threat of an attack associated with the vulnerability of the object under consideration and the consequences caused by such an attack [Burn-Howell *et al.*, 2003]. However, such a combination may not genuinely reflect the risk results because of the absence of the consideration as to the relative importance of each asset. Therefore, in this study the criticality element has been incorporated into the security risk model. Criticality is defined as the relative importance of each facility, taking into account its function, location, costs and allowable time for returning operational. Five linguistic priority terms describing these four elements are employed, namely, Remote, Low, Moderate, High and Very High. A scenario associated with these four elements will then be established, representing the primary risk characteristics. Each scenario cannot be compared until the following steps have been taken. The first step is to establish the membership functions for the linguistic priority terms using a triangular distribution based on expert judgement. The values of the membership function associated with the linguistic priority terms of each of these four elements involved in a specific scenario will then be determined. This is followed by the development of a rule base which is also based on expert judgements. An element called Priority Level comprising the value of the weight associated with a defined linguistic priority term will be introduced with respect to the combinations of C, P, S and V. The first three steps are regarded as a fuzzification process expressing how well the input belongs to the linguistic priority terms used in the rules. A defuzzification process will then be adopted by employing appropriate algorithms. A value of the overall risk to a scenario will be obtained and therefore, a risk ranking of all scenarios can consequently be produced.

1.3.2.2 Risk prediction of port marine safety using fuzzy set theory and Artificial Neural Network (ANN)

In risk assessment under circumstances of the lack or incompleteness of data, the application of fuzzy set theory and the rule base technique has proven to be useful.

However, such an application may become impractical as there are multiple parameters to be evaluated which are described by multiple linguistic terms. In this study, a risk prediction model incorporating fuzzy set theory and an ANN is developed. This is due to the fact that fuzzy set theory enables safety analysts to incorporate expert judgement in a safety study and ANNs have the strength of pattern recognition. The model proposed will be demonstrated by a test case of port marine safety due to the fact that the data available for such an area is scarce. Five parameters are considered, namely, vessel traffic control (VTC) performance, navigational aids and facilities, pliotage performance, sealane maintenance and the weather conditions. These factors are regarded as the specific port marine safety functions determined based on the experience from the experts specialising in ports [Sydney Ports, 2005]. The methodology of this framework commences with the establishment of the membership functions for the linguistic terms describing the five parameters to be taken into consideration. A fuzzy combination algorithm will subsequently be developed and applied to obtain an overall risk with the crisp-value property. This is due to the fact that the data fed into neural networks must have numerical characteristics. A batch of training and testing data will then be prepared, followed by the construction of a feedforward ANN model and a training process by introducing the training data into the network. The trained network will be verified as to whether it is capable of predicting reliable results using the testing data prepared. Once the trained ANN has satisfied the acceptable accuracy established based on expert judgement, the ANN will be capable of predicting risk with high reliability. Such a framework will be able to establish a risk ranking based on the results predicted if applied.

1.3.2.3 Human error assessment in port operations using fuzzy Analytical Hierarchy Process (AHP)

In general, fuzzy set manipulation rules are applied to process the information at the same level and to conduct synthesis. However, when the information available is sufficient to a certain level and can be presented in a hierarchical structure, such an application cannot avoid the loss of useful information in the hierarchical synthesis process. A human error assessment model is developed based on fuzzy set theory and the AHP technique since it is capable of avoiding the difficulty encountered when the fuzzy rule base technique is applied. The parameters considered are the likelihood of human error, failure consequence probability and severity caused. Failure consequence probability is defined as the probability that effects will emerge provided that the failure has occurred. Traditionally, a risk study is the evaluation of the combination of likelihood and severity. However, the events with high likelihood may not always cause severe consequences. Accordingly, the parameter of failure consequence probability is considered. The test case used to demonstrate the model proposed is an oil cargo handling process in port. The framework of human error assessment in this study starts with the operational description and mission identification, so enabling a full understanding of the test case in question. Therefore, an AHP structure can be established. In this structure, there will be four hierarchies required, namely, the operation hierarchy, risk factor (criteria), mission and step hierarchies. Since the study incorporates the fuzzy set theory into the AHP method to evaluate human error related risks, a set of linguistic priority terms along with the membership functions describing the relationship between the elements in each hierarchy of the AHP structure will be adopted. Therefore, the pairwise comparisons between the elements in each hierarchy using fuzzy set theory will be able to be established. The fuzzy expressions are subsequently converted to the single crisp values using the appropriate defuzzification method. This is followed by the weighting vector calculation so as to obtain the relative importance of the elements. By repeating the steps aforementioned, the risk of the elements in the step hierarchy in terms of each criteria defined will be acquired based on the normalised weighting vectors calculated. The results obtained from these three criteria will then be synthesised and an overall risk priority will finally be established based on the combined risks.

1.3.3 Safety management

In the safety management component, a decision-making method is proposed that considers the factors of effectiveness, cost, time of deployment, resource availability and co-operation level. This is consistent with the other two elements essential for the establishment of an effective safety analysis, namely, cost-benefit assessment and decision making. After acquiring the RCO priority and the implementation of the best RCOs, next step is to ensure that the quality of the safety and security measures will not be jeopardised. A quality assurance model is accordingly proposed to enhance and maintain the quality of safety and security RCOs in port. Therefore, the purpose of this stage is to develop a decision-making model capable of considering multi-attribute factors to demonstrate the selection of best measures and to introduce the quality concept to the port industry.

1.3.3.1 Multi-attribute decision-making using Evidential Reasoning (ER)

Many real world decision analysis problems involve multiple attributes in both a qualitative and quantitative nature. A multi-attribute decision-making model is proposed to select the appropriate RCOs provided that all the RCOs have been identified. The decision-making method is developed based on the ER approach due to the fact that such an approach is capable of solving the Multiple Attribute Decision Analysis (MADA) problems characterised by both qualitative and quantitative attributes with various types of uncertainties. The parameters considered are effectiveness, cost, time of deployment, resource availability and co-operation level, respectively. This is because such factors are commonly regarded as crucial elements in risk-based decision-making projects. The framework for this topic commences with the identification of the criteria that will be used to assess the RCOs. The AHP technique is subsequently employed to determine the relative weight of the criteria identified. The effects of each RCO in terms of the criteria identified will then be evaluated by each expert. This result is then synthesised using the ER approach to acquire the overall aggregating result. This, in turn, is followed by the development of a utility category-evaluation grade matrix for each expert to estimate the utility level of each evaluation grade using the belief degree method. The utility preference of each evaluation grade estimated by each expert is then combined using the ER algorithm which will subsequently be normalised. The synthesised utility level of each evaluation grade based on all experts is subsequently applied to the aggregating result of the effects of each RCO. An RCO priority will then be acquired based on the results calculated. Finally, a sensitivity analysis will be conducted to identify the best measures and so provide another way of considering the importance of the various risk and cost aspects.

1.3.3.2 Quality assurance of the efficiency of port security and safety measures

The introduction of more and more safety and security measures may imply an increase probability of inefficiency influencing port operations. A quality assurance framework based on the Six Sigma technique is developed since such a technique is proven to be useful in quality control and improvement particularly in the manufacturing industry. When implementing a Six Sigma project to improve the quality of a process, there are five steps which should be taken, namely, Define, Measure, Analyse, Improve and Control (DMAIC). In the definition step, the unit of the measurement that will be used to judge the performance of the quality of a process should first be decided. Secondly, the goal of the quality and the value of the Critical to Quality (CTQ) must be identified. Thirdly, the term "defect" will be defined. The mission of the measurement step is to evaluate the current performance of the efficiency of a port process. At the analysis stage, the root causes of poor quality that may occur due to excessive variations contributing to the defects are identified and analysed. A sensitivity analysis will also be conducted to identify appropriate solutions. In the improvement step, the solutions aimed at reducing the root causes identified in the analysis step can be generated. Accordingly, the quality of port security and safety measures can be improved. After the implementation of the solutions, the actual improvement of the quality of the process will be realised in the final step.

1.4 Delimitations of the scope

Since the objective of this PhD research is to provide a platform for risk assessment and safety management addressing port safety and security with confidence in circumstances of the lack or incompleteness of data, the data for the test cases demonstrated in this study will be hypothetically prepared by the author based on the experience from the supervisors and expert specialising in the port industry. This is because of the difficulty of acquiring real industrial data. Furthermore, the subject matter of this study is the port industry.

1.5 Structure of thesis

A diagrammatic guide to this thesis is shown in Figure 1.2. There are 8 chapters in this study, which are outlined as follows.

Chapter 1 – Introduction

This chapter first presents the background of this PhD study. The research problem and research questions are then given, followed by a discussion of the research methodology and scope of this study. Finally, the structure of this thesis is given.

Chapter 2 – Literature review

In this chapter, the current status of offshore safety, marine safety, maritime security and port safety is reviewed. The frameworks of the safety regulations including SCR 1992, Formal Safety Assessment, the International Ship and Port Facility Security Code (ISPS) and the Port Marine Safety (PMS) Code are also discussed. The strengths and shortcomings of maritime risk assessment techniques currently and commonly applied are examined, providing a critical review for current practices. The current status of the quality assurance in port operations is also presented. Finally, this PhD research is justified based on the problems and difficulties encountered.

Chapter 3 – Risk assessment of port security using fuzzy modelling

In this chapter, a security risk assessment framework using fuzzy set theory is proposed. The security risk can be modelled and a risk ranking can be obtained based on the concept of "Failure Mode, Effects and Criticality Analysis" (FMECA) using fuzzy set theory and the fuzzy rule base technique. . The outcome of the study will be a security risk ranking based on the risk level of each scenario obtained.

Chapter 4 – Risk prediction of port marine safety using fuzzy set theory and ANN

In the risk assessment research, a drawback occurs when the fuzzy rule base technique is applied in circumstances where there are multiple parameters to be evaluated which are described by multiple linguistic terms. In this chapter, a risk prediction model incorporating fuzzy set theory and ANN capable of resolving the problem encountered is proposed. Its application is demonstrated by a test case evaluating the navigational safety within port areas.

Chapter 5 – Human error assessment in port operations using fuzzy AHP

In this chapter, following a review of Human Reliability Assessment (HRA), a new method of human error assessment using fuzzy set theory and the AHP method is proposed. In assessing the human error risk using the proposed method, the steps in each mission of port operations are compared to each other in terms of the likelihood, failure consequence probability and severity criteria to acquire the relative importance and overall risk priority. The method is demonstrated using a test case of an oil cargo handling process when in port, and is capable of avoiding the criticism raised when using traditional HRA techniques.

Chapter 6 – Multi-attribute decision-making using ER

When evaluating RCOs, difficulties may be encountered due to the attribute nature of the defined criteria. In this chapter a decision-making model using the ER approach is proposed provided that RCOs have been identified. The framework is demonstrated by a test case which considers the effects of the security, safety and human error reduction measures in ports.

Chapter 7 – Quality assurance of the efficiency of port safety and security measures

More and more security and safety regulations and policies have been adopted and implemented in the port industry. However, this could sometimes imply an increased probability of inefficiency influencing port operations. In this chapter, following the introduction of the Six Sigma method, a methodology for improving the quality of port security and safety measures is proposed. A test case is then used to demonstrate the proposed methodology.

Chapter 8 – Discussion

In this chapter, the integration of the research is discussed based on the safety principles arising from safety regulations, addressing how the findings of the previous chapters can be linked each other. This is followed by the validation of the research, explaining the degree to which the framework proposed can be tested and verified. Finally, the limitations of the research are addressed due to the nature of the design or the assumption made in the reasoning process.

Chapter 9 – Conclusion and implications

Following the introduction, the conclusions of the research questions and research problem are drawn. The conclusions and recommendations for the port industry as well as the implications for further research are also given.

References – References related to the research are presented in this section

Appendices – This section provides relevant information and data of the research.

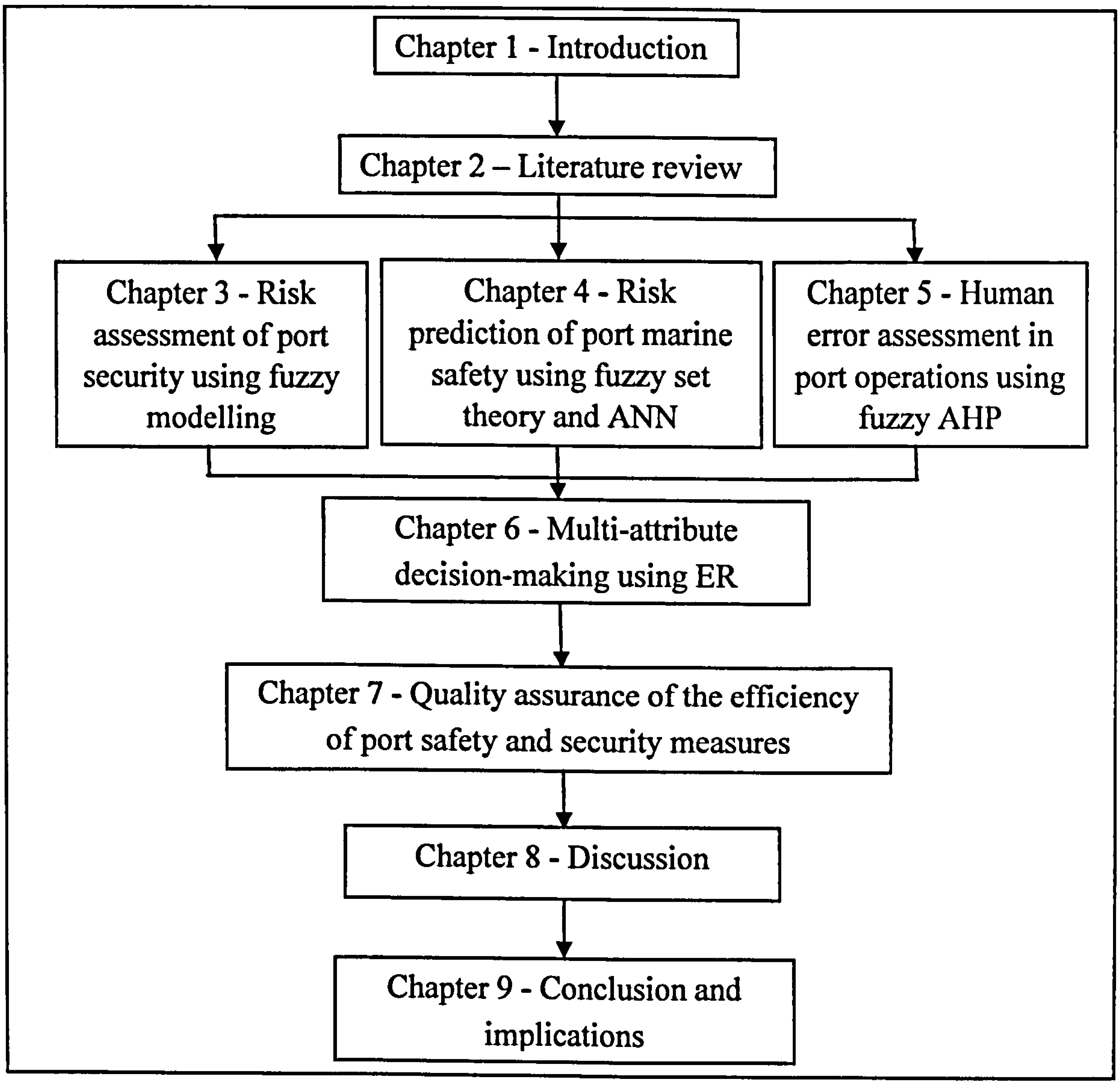

Figure 1.2. Structure of the PhD thesis

Chapter 2. Literature Review

In this chapter, the current status of offshore safety, marine safety, maritime security and port safety is reviewed. The frameworks of the safety regulations including Safety Case Regulations (SCR) 1992, Formal Safety Assessment (FSA), the International Ship and Port Facility Security (ISPS) Code and the Port Marine Safety (PMS) Code are also discussed. The strengths and shortcomings of maritime risk assessment techniques currently and commonly applied are examined, providing a critical review for current practice. The current status of the quality assurance in port operations is also presented. Finally, this PhD research is justified and discussed based on the problems and difficulties encountered.

2.1 Introduction

Maritime safety has evolved from a reactive manner towards a risk-based and goal-setting regime since the 1990s. It has become an important issue in the maritime industry due to public concern following several catastrophic accidents and the introduction of safety regulations. The main objective of these safety regulations is to ensure that risks have been reduced to As Low As Reasonably Practical (ALARP) and Risk Control Options (RCOs) to be implemented are cost effective. In addition, due to the competitive nature, there is a need for the maritime industry to constantly conduct risk assessment and safety management with regard to assets from the initial stage, develop new approaches, propose new operational procedures and invent innovative technology. This inevitably brings about new hazards and uncertainties in one form or another. Thus, risk assessment and safety management should cover all possible areas including those where traditional techniques are difficult to be applied. Accordingly, the development of a variety of novel risk modelling and decision-making techniques capable of resolving such difficulties encountered is required. In this chapter, following the discussion of the current status of maritime safety and security, the frameworks of the safety regulations including SCR 1992, FSA, the ISPS Code and the PMS Code are presented. The current status of the quality of port operations is also reviewed. The strengths and difficulties of current maritime risk assessment practices encountered are subsequently discussed. Finally, the PhD research is justified based on the research questions established.

2.2 Offshore safety and SCR 1992

The public attention to offshore safety was triggered by a series of major disasters such as the capsize of the semi-submersible rig 'Alexander Keilland' in 1980 and the explosion of the 'Piper Alpha' platform in 1988. The public inquiry into the 'Piper Alpha' accident published in 1990 covered the complete range of safety and reliability issues. The inquiry formed a cornerstone of the safety regime change in the U.K. offshore industry [Department of Energy, 1990]. The responsibilities for offshore safety regulations were transferred from the Department of Energy to the Health and Safety Commission (HSC) through the Health and Safety Executive (HSE) as the single regulatory body for offshore safety. Subsequently, the HSE Offshore Safety Division launched a review of all offshore safety legislations and implemented changes. The objective of this was to seek a more 'goal setting' regime to replace legislation which was regarded as prescriptive [Wang, 2002]. The mainstay of the regulations is the Health and Safety at Work Act, under which a draft of the offshore installation (safety case) regulations was produced [Health and Safety Executive (HSE), 1992]. It was then modified to incorporate the comments arising from public consultation. The regulations came into force at the end of May 1993 for new installations and in November 1993 for existing installations. The regulations require operational safety cases to be prepared for all offshore installations, including both mobile and fixed ones. In addition, all new fixed installations are required to have a design safety case in place. For mobiles, this duty holder is the owner. The SCR establishes a clear guidance as to what a safety case should include with respect to the design and operations of a particular type of offshore installations. Particular requirements to be included in a safety case for the design, operation, abandonment and well operations of different installations are also given.

Risk criteria are standards that represent a view of a regulator of how much risk is acceptable or tolerable [HSE, 1995a]. A framework for decisions on the tolerability of risk proposed by HSE is shown in Figure 2.1, where there are three regions, namely, intolerable, ALARP and broadly acceptable [HSE, 1995a]. The risks in the intolerable region cannot be justified on any grounds. In the region of ALARP, the risks must be reduced by introducing control measures towards the broadly acceptable region. The residual risks remaining in this region will be tolerable only if further risk reduction is impracticable or its cost required is grossly disproportionate to the improvement gained. There is no need to demonstrate ALARP in the broadly acceptable region. However, it is necessary to take any measure to assure that the risks remain at this level.

Goals have to be established when preparing a safety case. Subsequent demonstration has to prove that the goals so proposed have been achieved. Therefore, an installation cannot legally operate without such a safety case demonstration that has been approved by HSE Offshore Safety Division. An accepted operational safety case must be capable of demonstrating that hazards with the potential to cause major accidents have been identified, associated risks have been evaluated and reduced to ALARP using appropriate measures. For example, the occurrence likelihood of events causing a loss of integrity of the safety refuge should be less than 10^{-3} per platform year [Spouse, 1997], and associated risks should be reduced to ALARP. It is noted that since uncertainties in inputs may be high the application of numerical risk criteria may not always be appropriate [Wang, 2002]. Therefore, the acceptance of a safety case is unlikely to rely solely on a numerical risk assessment.

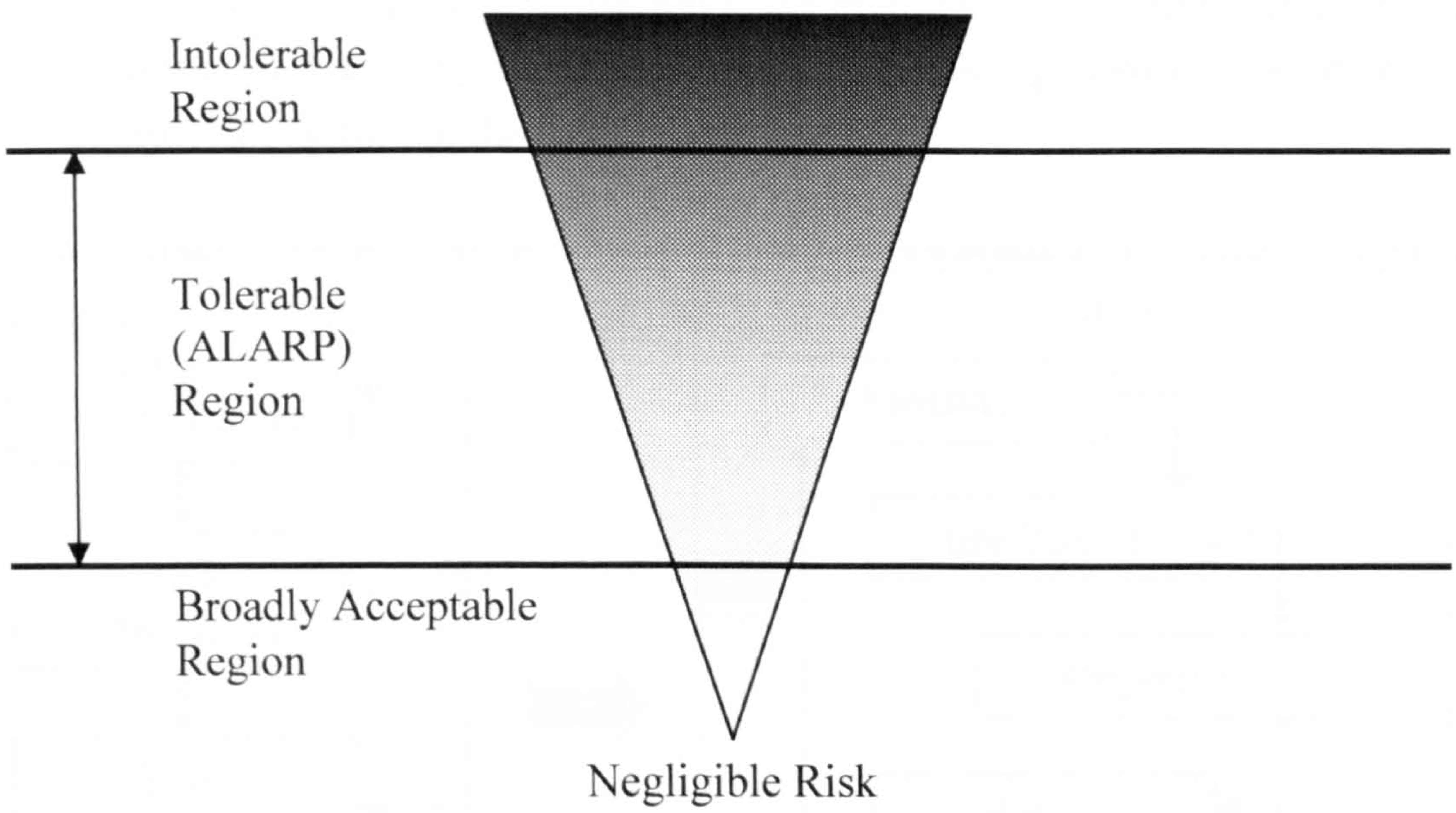

Figure 2.1. The HSE framework for decisions on the tolerability of risk [HSE, 1995a]

2.2.1 The safety case approach

The concept of the safety case came from the principles of safety assessment of system engineering or installations for which little or no previous operational experience exists [Kuo, 1998]. There are five key elements in the safety case approach, namely, hazard identification, risk assessment, risk reduction, emergency preparedness and a Safety Management System (SMS) [Wang, 2002a]. The relationships between these elements are illustrated in Figure 2.2.

1. Hazard identification. The mission of this step is to identify all hazards that have the potential to cause a major accident.

2. Risk assessment. Once the hazards have been identified, the associated risks will be evaluated using risk assessment techniques. The techniques employed may include either qualitative, quantitative, combined qualitative and quantitative or some other risk assessment techniques such as approximate reasoning methods. It depends upon circumstances encountered.

3. Risk reduction. The risk reduction measures will be identified based on the results of the risk assessment obtained from step 2.

4. Emergency preparedness. The objective of this step is to ensure that the appropriate actions have been taken in the event that a hazard has become a reality so as to minimise the negative consequences caused.

5. Safety management system. The aim of a safety management system is to demonstrate that the organisation is achieving the goals safely and efficiently without jeopardising the environment. This is regarded as one of the most important factors of the safety case approach.

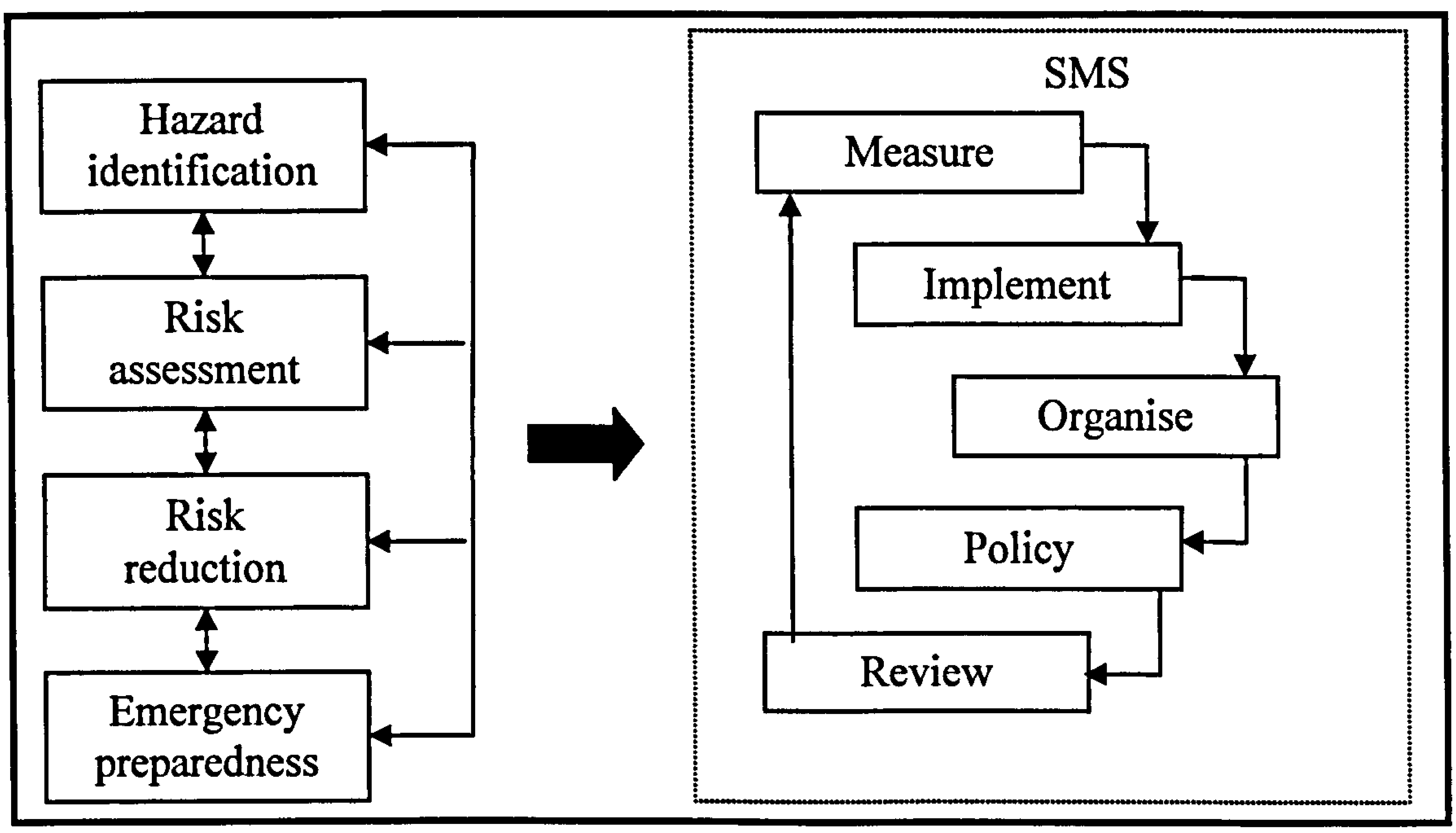

Figure 2.2. The key elements of the safety case approach [Wang, 2002a]

A safety case is a written submission prepared by the operator of an offshore installation. In general, the information contained in a safety case includes:

1. A comprehensive description of the installation.

2. Details of hazards identified.

3. Demonstrations that associated risks have been appropriately evaluated and reduced to ALARP.

4. Details of the SMS, including plans and procedures in place for both normal and emergency operations.

5. Appropriate supporting references.

It can be seen that risk assessment and safety management play crucial roles in a safety case. Accordingly, the following missions should be accomplished:

1. Establishment of acceptance criteria for safety related decision making, including environment and asset, if possible. These could be both risk-based and deterministic.

2. Consideration of both internal and external hazards using formal and rigorous hazard-identification techniques.

3. Estimation of the probability of occurrence of each hazard and its associated consequences caused if occurred.

4. Analysis of associated risks and comparison with criteria established.

5. Demonstration of ALARP.

6. Identification of remedial measures to avoid the hazard in question or mitigate its associated risks.

7. Preparation of the detailed description of the installation and the information with regard to protective systems and measures in place to manage the risk.

8. Description of the SMS, including the information demonstrating that hazards are identified and that the associated risks have been properly evaluated and managed.

Conventional risk assessment methods and Cost Benefit Analysis (CBA) approaches can be employed to prepare a safety case. The objective of incorporating CBA into a safety case is to ensure that the measures or RCOs proposed are cost-effective. This is achieved by comparing the cost of the proposed measure in question with its potential benefit resulting from the reduced risk. An RCO can be regarded as cost-effective only if its benefit incurred is larger than the cost. It should be noted that significant uncertainties in the data, information and factors may be encountered in the decision-making process. These may include the estimates of costs, benefits, risks, the assessment of stakeholder views and perceptions etc [Wang, 2006]. Therefore, there is a need to apply common sense and to ensure that any uncertainties are identified and addressed [U.K. Offshore Operators Association (UKOOA, 1999)].

2.2.2 Other U.K. offshore safety regulations

Fires and explosions may be regarded as the most significant hazards with potential to cause catastrophic consequences in offshore installations. Prevention of Fire and Explosion and Emergency Response Regulations 1995 (PFEER 1995) were introduced to tackle these types of hazards [HSE, 1995a]. A risk-based approach is recommended to deal with problems involving fire and explosion and emergency responses. The regulations specify goals for preventive and protective measures to manage fire and explosive hazards, to secure effective emergency response and to ensure compliance with regulations by the duty holder.

Management and Administration Regulations 1995 (MAR 1995) were developed to deal with areas such as notification to the HSE of owner or operator changes or functions and powers of offshore installation managers etc [HSE, 1995b]. The regulations are applied to fixed and mobile offshore installations, excluding subsea offshore installations. The importance of offshore pipeline safety has also been recognised. Pipeline Safety Regulations 1996 (PSR 1996) were introduced to embody a single integrated, goal setting and risk-based approach to regulations prescribing the safety issues to both onshore and offshore pipelines [HSE, 1996a].

The SCR was amended in 1996 to incorporate verification of safety-critical elements [HSE, 1996b]. Safety-critical elements are the components of an installation or its plants, including computer programmes. The failure of these components may cause or contribute substantially to a major accident. Thus, the objective of the amendment is to prevent or mitigate the consequences. Offshore Installations and Wells (Design and Construction, etc.) regulations 1996 (DCR 1996) were launched to deal with various stages of the life cycle of the installation [HSE, 1996c]. The DCR 1996 allows offshore operators to have more flexibility to deal with their own safety problems. This encourages safety analysts to develop and employ novel safety assessment and decision-making approaches to tackle offshore safety problems.

These offshore safety regulations, including SCR, in the U.K. are aimed at establishing a more goal-setting regime. This is accomplished by defining specific duties of the operator and setting forth high-level safety objectives while leaving the selection of particular hazard arrangements in the hands of the operator. This is because hazards encountered by each installation may be specific subject to its function and operating condition. In addition, the demonstration of design for safety using state-of-the-art risk assessment methods based on the principles of hazard identification, risk estimation, preparation of RCOs, cost-benefit assessment and decision making is the main concern arising from these regulations. Therefore, in order to comply with these offshore safety regulations, an integrated risk-based approach, starting from feasibility analysis and extending through the life cycle of the installation, should be applied.

2.3 Marine safety and FSA

Similar to the offshore safety regulations, the international marine safety regulations are driven by serious marine accidents. The capsize of the 'Herald of Free Enterprise' in 1987, for example, attracted the public attention on operational requirements and the role of management. It resulted in the implementation of the International Safety Management (ISM) Code for the Safe Operation of Ships and for Pollution Prevention. The 'Exxon Valdez' accident in 1989 jeopardised the environment with a relatively large oil spill (37,000 tons), facilitating the adoption of the international convention on Oil Pollution Preparedness, Response and Co-operation (OPRC) in 1990. This is followed by the requirement of double hull or mid-deck structure for existing and new oil takers. The 'Scandinavian Star' disaster with the loss of 157 lives in 1990, and the catastrophic sinking of the 'Estonia' in 1994 highlighted the role of human error in marine casualties. Consequently, the new Standards for Training, Certificates and Watchkeeping 95 (STCW 95) for seafarers were introduced [Wang, 2006].

Subsequent to a report by the House of Lords on the investigation into the capsize of the 'Herald of Free Enterprise' in 1992, the U.K. Maritime and Coastguard Agency (MCA, previously named Maritime Safety Agency (MSA)) in 1993 introduced 'Formal Ship Safety Assessment' as a proposal to the International Maritime Organization (IMO). The agency recommended that the FSA framework so proposed should be applied to ship design and operations, of which the objective was to provide a strategic oversight of safety and pollution prevention for the shipping industry. The FSA framework proposed by U.K. MCA consists of five steps [MSA, 1993] and the relationship between each step is illustrated in Figure 2.3:

1. The identification of hazards.
2. The assessment of risks associated with those hazards.
3. The identification of RCOs.
4. Cost-benefit assessment of RCOs.

5. Decision-making process.

FSA was initially studied by the IMO Maritime Safety Committee (MSC) FSA at its 62nd meeting. MSC 65 in 1995 agreed that the framework should be a high priority on its agenda. In 1997, MSC 68 and the 40th meeting of the Marine Environment Protection Committee (MEPC) 40, the interim guidelines for the application of FSA was approved [IMO, 1997a]. The interim guidelines were superseded by the Guidelines [IMO, 2002a] that were finalised based on the experience gained from the trial applications to the safety of high-speed catamaran ferries and bulk carriers [IMO, 1997b, 1998]. The objective and techniques commonly applied in each step of FSA are discussed in the following subsections.

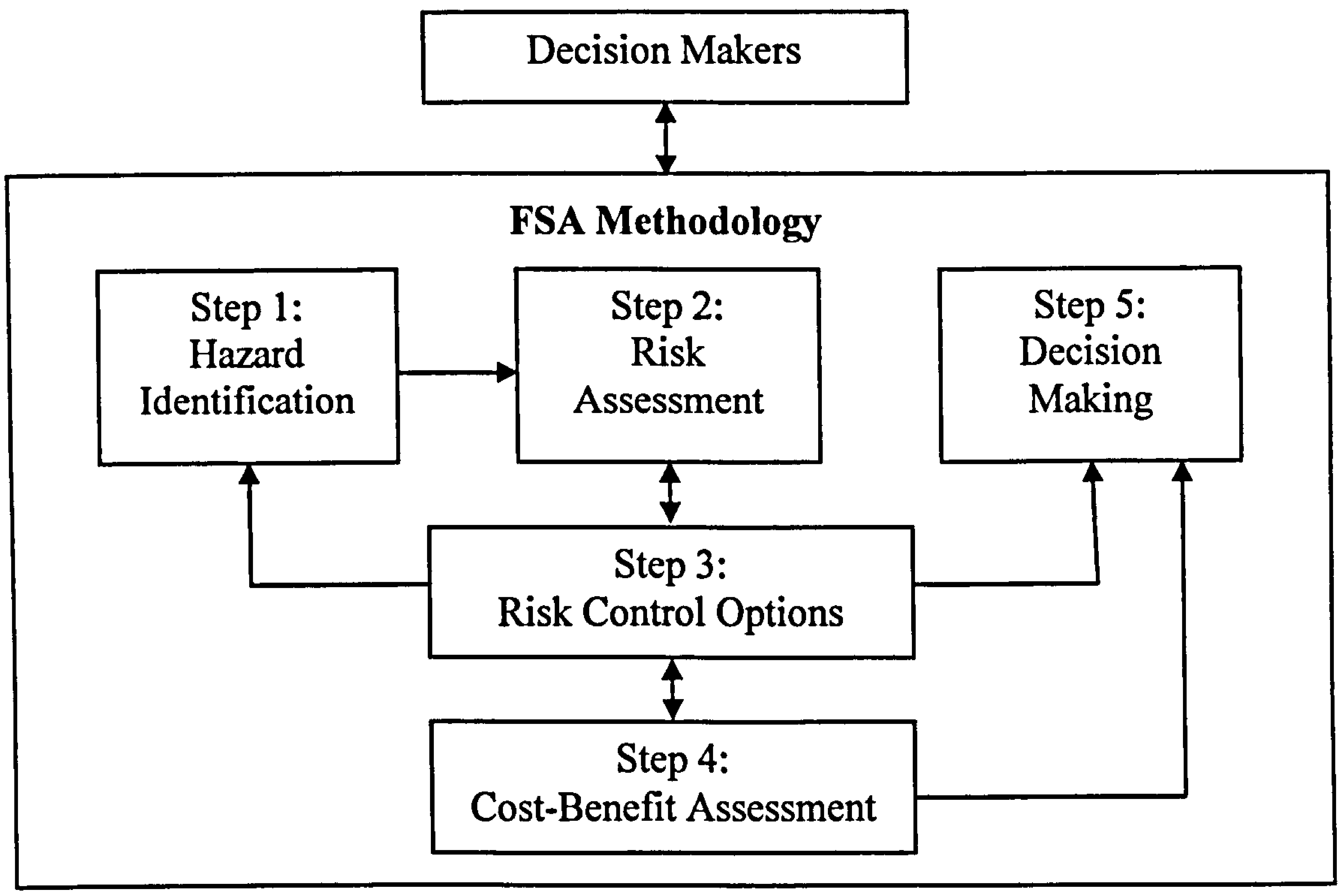

Figure 2.3. FSA Framework [MSA, 1993]

2.3.1 Hazard identification (HAZID)

The objective of this step is to identify all hazards which could potentially lead to significant consequences and also provide a rank for the hazards in terms of their risk levels. In formal ship safety assessment, hazard is defined as a physical situation with the potential to cause human injury and/or death, and/or damage to property and/or environment [MSA, 1993]. In addition, accident is defined as a status of the vessel, at the stage where it becomes a reportable incident that has the potential to progress to loss of life, major environmental damage, and/or loss of vessel [MSA, 1993]. The accident can be divided into several categories such as contact or collision, explosion, fire, flooding, grounding or stranding etc. It is noted that human error issues should also be systemically analysed in the FSA framework.

HAZID is the process of systematically identifying hazards and associated events that could have the potential to result in considerable negative consequences. The process is concerned with the application of brain-storming techniques conducted by trained and experienced personnel to determine the hazards. Therefore, it is often a qualitative exercise strongly based on expert judgement. The techniques which could be employed in this step include Hazard and Operability Studies (HAZOP), Preliminary Hazard Analysis (PHA), Failure Mode, Effects and Critical Analysis (FMECA), What-If Analysis, Checklist Analysis, Structured What-If Checklist Technique (SWIFT), Cause-Consequence Analysis, Boolean Representation Method, Simulation Analysis etc. [Henley and Kumamoto, 1992] [Villemeur, 1992] [Smith, 1993] [Wang *et al.*, 1995]. The use of the database can facilitate the HAZID process. The databases available for FSA may include Lloyd's Maritime Information Services (LMIS) Database, IMO Marine Accident Reporting Scheme (MARS) Database, U.K. Marine Accident Investigation Branch (MAIB) database, Australia Marine Incident Investigation Unit (MIIU), and Scandinavia Data Management Association (DAMA).

The risk matrix technique is often applied to prioritise the hazards identified [Wang and Foinikis, 2001] [Loughran *et al.*, 2002] [Lois *et al.*, 2004]. This is because it is capable of providing a traceable framework for explicit consideration of the frequency or probability of occurrence and consequences of hazards. In this preliminary risk assessment process, each hazard is evaluated in terms of its frequency/probability of occurrence and potential consequence. Thus, the combined result, i.e. the risk of each hazard can be obtained and a risk priority of each hazard can be determined. The hazards associated with higher risks need to be focused and evaluated in detail in the next step. It is noted that the experience and knowledge of the personnel involved play a crucial role in this step.

2.3.2 Risk assessment

The objective of this step is to evaluate risks and factors influencing the level of safety. The mission of this step is to study how hazardous events can progress and interact to cause an accident [Wang, 2006]. Shipping consists of a sequence of distinct phases starting from design, construction and commissioning, through operation, to decommissioning and disposal. The status of ship functions varies in each phase. A ship is made of several systems such as machinery, control system, electrical system, navigation system etc. A serious failure may cause a catastrophic accident. Risk assessment can be applied with respect to each phase of shipping and each system.

The probability of occurrence of each failure event and its estimated consequences can be assessed using appropriate techniques. Generic data or expert judgement may be used in this step. The construction of an Influence Diagram (ID) combining fault trees and event trees may be applied in this step. This is because it is capable of studying how the regulatory, commercial technical and political/social environments influence each accident category and of quantifying these influences with regard to human and hardware failures as well as external events [Wang *et al.*, 1999]. In other words, the ID model allows a holistic understanding of the problem area to be displayed in a hierarchical way by identifying the potential influencing factors that could contribute to a major marine accident. In addition, this approach can be applied strongly based on expert judgement. Accordingly, it is particularly useful in situations where little or no empirical data is available. The techniques which can be employed in this step include IDs, Fault Tree Analysis (FTA), Event Tree Analysis (ETA), the Frequency and Severity Index technique, the Potential Loss of Life (PLL) technique etc..

2.3.3 Risk control options (RCOs)

The purpose of this step is to deliver effective and practical risk control options to manage the risks analysed in Step 2. Accordingly, a list of countermeasures aimed at preventing or mitigating the risks in question will be identified. The hazards that have a high probability of occurrence and catastrophic consequences will be the first priorities to be dealt with. The 'Casual Chain' approach can be employed to meet the mission in this step [Passenger Vessel Association, 1997]. Figure 2.4 illustrates the basic idea of the 'Casual Chain' approach and the function of each step is discussed as follows.

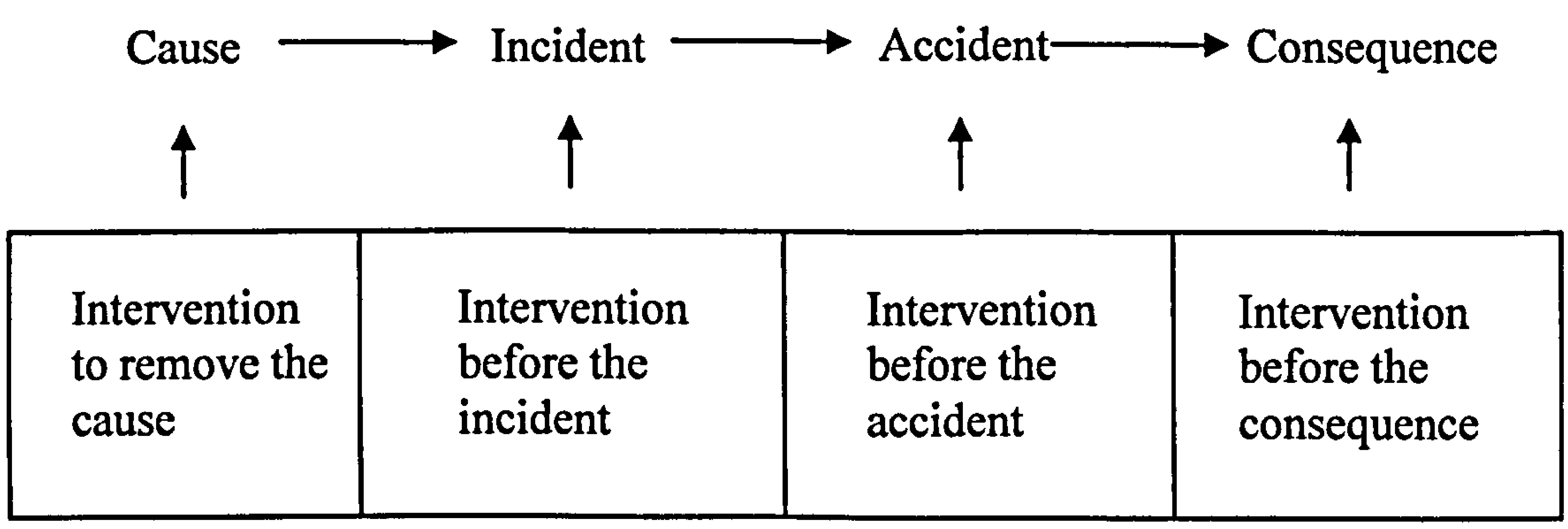

Figure 2.4. Casual chain [Passenger Vessel Association, 1997]

1. Intervention to remove cause. The measures to be proposed are capable of preventing the conditions that can lead to lapses.

2. Intervention before the incident. The RCOs to be identified can prevent or avoid the lapses that can lead to an incident.

3. Intervention before the accident. The measures to be proposed are capable of preventing or avoiding the incidents that can lead to a major accident.

4. Intervention before the consequence. The RCOs to be identified can reduce or mitigate the harm caused by the accident.

In general, RCOs have the attributes summarised below [Wang and Foinikis, 2001]:

1. Those relating to the fundamental type of risk reduction (i.e. preventative or mitigating).

2. Those relating to the type of action required (i.e. engineering or procedural).

3. Those relating to the confidence that can be placed in the measure (i.e. active, passive, redundant, auditable).

Three types of solutions are used for risk reductions, namely, the managerial, engineering and operational solutions [Loughran *et al.,* 2002]. Managerial solutions involve the activities with regard to the management of an organisation. The purpose of this is to develop a safety culture. Effective communications between each department within the organisation are the key factors to their success. A new design and/or construction of a ship can be regarded as an engineering solution. One of the features of this type of resolution is that they can clearly be identifiable. A good example for this is the introduction of double hulled oil carriers. Addressing hazards in the early stages of a vessel's life is the main strength of the engineering solutions. Operational solutions involve the development and introduction of appropriate procedures for carrying out safety-critical tasks and improving the effectiveness of personnel in these tasks. Such procedures involve safety working practices, contingency plans and safety exercises. These procedures are capable of addressing human error factors and ensuring the existence of uniformity of the adopted safety standards.

RCOs that will be analysed in the next step are those that will either reduce the risk to the acceptable level or provide a high reduction rate. The acquirement of risk reductions will be strongly based on expert judgement due to the lack of the operational data. FTA and ETA may be employed to predict the risk reductions in circumstances where the historical data with regard to the RCOs that are similar to the ones under consideration is available.

2.3.4 Cost-benefit assessment (CBA)

A distinctive feature of FSA-based RCOs is that the measures so proposed are cost-effective. The objective of this step is therefore to estimate the benefits resulting from the reduced risks and the associated costs for each RCO. The CBA conducted should take into account the overall situation (the costs and benefits of a specific RCO during its life cycle) and the various parties concerned and influenced by the problem under consideration. Such parties are referred to as stakeholders [IMO, 1997a].

A 'base case' is established as a reference for the subsequent comparisons. Such a 'base case' presents the existing situation, covering all levels of associated risks arising from a particular activity prior to the implementation of any RCO. The costs, benefits and Cost of Unit Risk Reduction (CURR value) of each RCO can be estimated by comparing the base case with the one since the implementation of the RCO under consideration. The CURR value is determined by dividing the 'Net Present Value' (NPV) of the costs and benefits of an RCO by the combined reduction in mortality and injury risks [Wang *et al.*, 1999]. Alternatively, a cost-benefit index technique [Lois *et al.*, 2004], the one similar to the Frequency and Severity Index approach, as well as the Cost of Averting a Fatality (CAF) method [Kontovas, 2005], can be employed. The cost effectiveness of each measure is then compared with each other. Subsequently, a rank of RCOs will be established based on the values of CURR, cost-benefit ratio or CAF. However, there are limitations in conducting a CBA. These limitations mainly come from imperfect data and uncertainties in estimating costs and benefits [Wang and Foinikis, 2001]. Therefore, it should be noted that CBA, as suggested for the use in FSA, is not a precise method. Thus, it can only be used as a consulting instrument in decision making.

2.3.5 Decision making

The purpose of the final step is to make decisions with regard to the selection of the appropriate RCOs and present recommendations with respect to safety improvement. The information obtained from the steps of HAZID, risk assessment, RCOs and CBA is used in this step. In the decision-making process, the decision maker should ensure that the RCOs selected are fair to all stakeholders [Spouse, 1997].

In the decision-making process, risk criteria may be used to judge whether risks are tolerable, intolerable or need to be mitigated to an ALARP level. When Quantitative Risk Assessment (QRA) is performed, numerical risk criteria are required. However, the application of absolute numerical risk criteria may not always be appropriate because of the uncertainties involved in the risk assessment and safety management process. The establishment of such criteria may cause inflexibility for the decision-making process [Wang *et al.*, 1999]. In addition, risk criteria may vary between classification societies and alter with time, accident experience and various expectations of life. Accordingly, there are no quantitative criteria in formal safety assessment for a particular type of ship, although the MCA trial applications have applied QRA to a certain context [Wang, 2002]. Thus, risk criteria can only be used as guidelines to assist judgement in the decision-making process.

It is noted that risk criteria are different in the differing industries. In the aviation industry, for example, failure with catastrophic effects must have a frequency less than 10^{-9} per aircraft year flying hour [Wang, 2006]. In the nuclear industry, the basic principle of the safety policy is that all exposures shall be kept As Low As Reasonably Achievable (ALARA), taking into account the economic and social factors [International Commission on Radiological Protection, 1977]. In the shipping industry, the general risk criteria may include [Spouse, 1997]:

1. The activity should not impose any risks that can reasonably be avoided.
2. The risks should not be disproportionate to the benefits.
3. The risks should not be unduly concentrated on particular individuals.
4. The risks of catastrophic accidents should be a small proportion of the total.

More specifically, individual risk criteria and social risk criteria need to be defined [Wang, 2001]. Maximum tolerable risk for workers, for instance, may be 10^{-3} per year according to the HSE industrial risk criteria. It is noted that the IMO has adopted HSE individual risk criteria that follow the modern risk assessment practice to define the intolerable and negligible risk. Table 2.1 shows HSE individual risk criteria adopted by the IMO [Kontovas, 2005]. In the regions between the maximum tolerable and negligible levels, risks should be reduced to an ALARP level, taking into account the economic and social factors. Again, it should be noted that these criteria should only be used as guidelines since they may vary between countries.

Table 2.1. HSE & IMO individual risk criteria

	Maximum tolerable risk criteria (per year)	Negligible risk criteria (per year)
Crew members	10^{-3}	10^{-6}
Passengers	10^{-4}	10^{-6}
Public ashore	10^{-4}	10^{-6}

Source: [Kontovas, 2005]

The RCOs to be adopted in the decision-making process would be the measures that are based on the balance of risk reductions, cost-effectiveness and the impact on the particular stakeholders.

2.3.6 Human elements

Human element is one of the most significant factors contributing to maritime accidents. It is realised that such an element is a crucial component in most marine and offshore safety practices and engineering products and it is also, historically, regarded as the most unreliable factor [Wang, 1995]. It is estimated that up to 50% of tanker accidents and 80% of all shipping accidents are caused by human errors in all phases of the process [IMO, 2000]. This has motivated risk analysts to develop methodologies capable of capturing the nature of human errors in marine accidents and storing such information in databases for further statistical study [Kristiansen *et al.*, 1999]. Accordingly, the issue of human element has been systematically addressed within the FSA framework, associating it directly with the occurrence and causes of the accidents. This may also encourage the Flag States to collect the operational data with regard to human element. The most appropriate technique for incorporating the human factor as recommended in FSA Guidelines is human reliability analysis [IMO, 2002a], consisting of the following steps:

1. Identification of key tasks.
2. Analysis of key tasks.
3. Identification of human errors.
4. Analysis of human errors.
5. Quantification of human reliability.

Human Reliability Assessment (HRA) was originally developed and implemented for the nuclear industry. It can be conducted on either a qualitative or quantitative basis. If a quantitative analysis is in order, Human Error Probability (HEP) can be derived to fit into HRA models.

2.3.7 Research activities with regard to FSA

FSA represents a fundamental change from reactive regulatory approach to one that is regarded as a proactive and integrated framework based on risk assessment and safety management in a transparent and justifiable manner. Its philosophy has been approved by the IMO for reviewing current safety and environmental protection regulations. In recent years, many research activities in maritime risk modelling and decision making have been taking place to improve both design and operations. The research findings based on the FSA framework include:

1. Trial study on high-speed craft [IMO, 1997b].
2. Trial study on bulk carriers [IMO, 1998a] [IMO, 2002b] [IMO, 2002c].
3. Trial study on passenger ro-ro vessels with dangerous goods [IMO, 1998b].
4. The FSA application to fishing vessels [Loughran *et al.*, 2002] [Pillay, 2001].
5. Application to offshore support vessels [Sii, 2001].
6. Application to containerships [Wang and Foinikis, 2001].
7. Trial application to the hatchway watertight integrity of bulk carriers [Leea *et al.*, 2001].
8. Application to ports [Trbojevic, 2002].
9. Introduction of the concept of FSA qualification to support the consolidation of confidence in FSA results [Rosqvist and Tuominen, 2004]
10. Application to cruising ships [Lois, 2004] [Lois *et al.*, 2004].
11. Application to liner shipping [Yang, 2005].

FSA involves many more scientific aspects than previous conventions. The availability of suitable data necessary for each step of the FSA process is very important. When such data are not available, expert judgement, physical models, simulations and analytical models may be applied to achieve valuable results. The benefits of adopting FSA as a regulator tool include [MSA, 1993]:

1. A consistent regulator regime that addresses all aspects of safety in an integrated way.
2. Its cost-effective characteristic enabling safety investment to be targeted to areas where it will achieve the greatest benefit.
3. A proactive approach enabling hazards that have not contributed to accidents to be properly identified and considered, thus, ensuring that new ships are of good design.

4. Confidence that regulator requirements are in proportion to the severity of the risks.

5. A rational basis capable of addressing new risks posed by ever-changing marine technology.

Although FSA has been applied by many research activities, it is noted that there are areas that still need to be improved. The areas for improvement include risk criteria acceptance, cost-benefit estimates, uncertainty and expert judgement, human reliability and information availability etc. [Wang, 2006].

2.3.8 The difference between SCR and FSA

FSA is an approach to marine safety using risk assessment and CBA to assist the decision-making process. There is a significant difference between these two approaches. A safety case approach is applied to a specific ship (specific application) whereas the FSA approach is employed to address safety issues common to a ship type such as bulk carriers, or to a particular hazard such as fire or grounding (generic application) [Wang, 2002]. However, the philosophy of these two approaches is identical. The feature of the FSA approach is that it is capable of identifying commonalities and common factors that influence risk and its reduction. Such information can subsequently be reflected in the regulator's approach for all ships of a particular type. The safety case approach, on the other hand, is able to identify the features specific to a particular ship, depending upon its operating environment. Accordingly, many shipowners have begun to develop their own ship safety cases.

2.4 Maritime security and the International Ship and Port Facility Security Code (ISPS Code)

Maritime security is not a new concern within the shipping industry. For many years the industry has recognised numerous threats, including terrorism, piracy, stowaways, the smuggling of people and drugs, cargo theft and pilferage, fraud, bribery and extortion. Piracy, for example, is a threat which has never disappeared, but which has become an ever increasing problem. Both the IMO and the International Maritime Bureau (IMB) have been active with investigations into piracy since the early 1980s. On another, but related, issue the U.S. Department of Transportation published "*Port Security: A National Planning Guide*" [U.S. Department of Transportation, 1997]. That article overviewed the essential aspects of port security and it identified many challenges faced by ports. Its aim was to provide government authorities and the commercial maritime industry with a common basis upon which port security standards could be established. Subsequent to the terrorist attack in the U.S. on 11st September, 2001, even greater heed has been paid to matters relating to maritime security. In December 2002, the IMO adopted the ISPS Code, which came into force on 1st July, 2004 [IMO, 2003a]. The Code is based on the concept of risk analysis, with the prime purpose of ensuring that the international trade, as conducted by the shipping industry, could be safely expedited without undue threat or fear from terrorist or any other intentional criminal activity.

2.4.1 Piracy

Data based on annual reports of the IMO and IMB, and from books, journals and newspaper articles from 1981 to 2002, clearly demonstrate that the number of piracy incidents has been generally increasing since 1995. Table 2.2, which is based upon annual reports from 1998 to 2002 published by the IMO and IMB, indicates, notwithstanding some slight difference between the reports resulting from various sources, that the problem of piracy has been deteriorating [Bruyneel, 2003]. The worst year was 2000, when 471 and 469 actual and attempted incidents were reported by the IMO and IMB respectively. Furthermore, it is relevant to note that during 2003, 445 incidents were recorded by the IMB and the attacks have become more violent with 71 crew and passengers reported missing and 21 confirmed killed [International Maritime Bureau (IMB), 2004]. This figure is in excess of that reported in 2002. According to various sources [Abhyankar, 2001] [International Chamber of Commerce (ICC), 2002] [Gunawan, 2003], the most dangerous waters with regard to incidents of piracy are the South China Sea, the Indian Ocean and the Malacca Straits.

Table 2.2. The nomber of actual and attempted piracy incidents from 1998 to 2002 reported by the IMO and IMB

	1998	1999	2000	2001	2002
IMO	210	309	471	370	383
IMB	192	285	469	335	370

Source: [Bruyneel, 2003]

Through its "Awareness Policy" the IMB aims to help reduce the number of incidents of piracy. To this end, by the establishment in 1992 of the Piracy Reporting Centre (PRC), the IMB collects and disseminates information on piracy in a systematic and beneficial manner. The IMO, too, has been implementing anti-piracy measures. These include a project commenced in 1998, which in Phase 1 involves regional seminars and workshops attended by governmental representatives of countries in whose waters piracy is prevalent. In Phase 2, a number of evaluations and assessments are assigned to various locations of particular concern [IMO, 2003b]. Furthermore, the IMO now promulgates an annual summary of incidents and attempted incidents of piracy and armed robbery at sea (international and territorial waters) as well as in port areas. In addition, it is worthwhile noting that the figure for piracy incidents has reduced slightly since 2004 based on the IMB Annual Report in which there are 329 actual and attempted incidents reported in 2004, 276 in 2005 and 61 in the first quarter of 2006 [ICC IMB, 2006].

2.4.2 Terrorism

The terrorist act on 11st September, 2001 in New York resulted in the estimated death of 3,029 people, injuries to some 8,700 persons, and a certain level of damage to the world economy. Until that tragedy, not much attention had been paid over years to such activities occurring within the shipping industry, in spite of notable maritime attacks such as the hijacking aboard the passenger ships 'Santa Maria' in 1961 [Miller, 1997], and 'Achille Lauro' in 1985 and the terrorist attack of the Greek cruise ship, 'City of Poros' in 1989 [Williamson, 2001]. In addition, a recent maritime terrorist act was committed in October 2002 where a French tanker, the 'Limburg', was ripped apart by an explosive device [ICC, 2002]. Table 2.3 shows the number of significant terrorist attacks from 1993 to 2002 based on the statistics collated by Dudley Knox Library [Ung *et al.*, 2004]. The increasing number of incidents implies that the world is continuously under the shadow of terrorist attacks. Thus, there is an urgent need for appropriate solutions capable of preventing human beings from such attacks.

Table 2.3. The number of significant terrorist attacks from 1993 to 2002

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
62	57	81	84	94	119	167	149	123	136

Source: [Ung *et al.*, 2004]

At the 2002 Conference on Maritime Security, the IMO adopted comprehensive measures designed to strengthen maritime security and to constrain and prevent the acts of terrorism. To this end, the core document was the ISPS Code incorporating a review of issues relating to the long range identification and tracking of ships at sea. A Maritime Security Trust Fund was also established. The purpose of this Trust Fund is to provide financial support to developing countries in order that they can strengthen their maritime security infrastructure. To further enhance security there is a requirement for co-operation between the International Labour Organisation (ILO) and the World Customs Organisation (WCO).

2.4.3 The principles of maritime security

The fundamental goal of maritime security is the establishment of an environment wherein trade can be conducted with high probability that it will neither be hampered by criminal activity, nor will it be a conduit for such an activity. Therefore, when developing a proactive security programme, the emphasis must be directed at determining, preventing, detecting and reducing the losses which could be attributed to intentional and criminal activities. Such a programme requires both intelligence input and the co-ordinated co-operation of the national and international security authorities as well as that from the law enforcement agencies connected with the shipping industry and port facilities. When dealing with port security, an effective port security related programme must be consistent with port policies, and it must be integrated into the port planning and operational functions. In summary, the principles of a maritime security programme should be [Ung *et al.*, 2004]:

1. Proactive and capable of preventing physical access and of protecting infrastructure from attacks.

2. Nationally and internationally co-ordinated.

3. Capable of identifying threats, vulnerabilities and consequences.

4. Consistent with port policies and compatible with port planning and operations.

5. Cost-effective.

6. A continuing process.

7. A dynamic and cybernetic process subject to refinement and adjustment as changing circumstances necessitate.

It should be apparent that the successful implementation of a maritime security programme is dependent upon the commitment of all personnel and the full support of senior management. It follows that there must be induction and training courses for all those involved in the various aspects of the programme. All must affirm to the programme and the standards established.

2.4.4 The ISPS Code

In 2002 the IMO addressed security threats to maritime transportation systems essentially by first, the partition of the 1974 SOLAS Chapter XI into two parts, namely, Chapter XI-1 for Special Measures to Enhance Maritime Safety and a new Chapter XI-2 for Special Measures to Enhance Maritime Security; and secondly, the establishment of the ISPS Code to support the security regulations incorporated in the SOLAS XI-2 regulations. In addition, SOLAS XI-1 introduces the new regulation XI-1/5 requiring ships to be issued with a Continuous Synopsis Record (CSR) and modifies regulation XI-1/3 for ships identification numbers to be permanently visibly marked. There has also been a further modification to SOLAS chapter V/19 with a new timetable for the fitting of Automated Identification Systems (AIS).

The ISPS Code adopted by the IMO contains detailed security requirements for governments, port authorities and shipping companies in a mandatory section (Part A), together with a series of guidelines about how to meet these requirements in a non-mandatory section (Part B). The Code raises the issue that ensuring the security of ships and port facilities is basically a risk analysis activity and that to determine what security measures are appropriate, a risk assessment must be conducted in each particular case [IMO, 2002d].

According to the Code, each government has to conduct a Port Facility Security Assessment consisting of the following three important components:

1. The identification and evaluation of important assets, infrastructures, areas and structures that may cause significant loss of life or damage to the economy of a port facility or environment if damaged.

2. The identification of the actual threats to those critical assets and infrastructure in order to prioritise security measures.

3. A statement of vulnerability of the port facility by the assessment of its weaknesses in physical security, structural integrity, protection systems, procedural policies, communication systems, transportation infrastructure, utilities and other areas within a port facility that may be a likely target.

In addition, there are minimum functional security requirements for ships and port facilities. For ships, the requirements include:

1. Ship security plans.

2. Ship security officers.

3. Company security officers.

4. A system of survey, verification, certification and control.

5. Certain onboard equipment and specific documents (e.g. International Ship Security Certificate).

For port facilities, the requirements are:

1. Port facility security plans.
2. Port facility security officers.
3. Certain security equipment.
4. Report of certain security-related information to the Government.

Apart from that, the requirements for both ships and port facilities include:

1. Monitoring and controlling access.
2. Monitoring the activities of people and cargo.
3. Ensuring that security communications are readily available.

The matter of security levels is also dealt with in the Code. The setting of the security level applying at any particular time is the responsibility of each contracting government and such a setting will apply to its ships and port facilities. Security levels 1, 2, and 3 correspond to "Normal", "Heightened risk", and "Exceptional risk" situations. The definition of the security levels is presented in Table 2.4. The security level is determined from ashore and is imposed on vessels in waters and ports relevant to that nation. Consequently, the common link of an identical security level is legally applicable to both ship and port facilities. This of necessity triggers the implementation of appropriate identical security measures both for the ship and for the port facility.

Table 2.4. The definition of security levels in the ISPS Code

Security level	Definition
1 (Normal)	Minimum protective security measures to be maintained at all times.
2 (Heightened risk)	Additional protective security measures shall be maintained for a period of time as a result of medium risk of security incidents.
3 (Exceptional risk)	Further specific protective security measures need to be maintained for a limited period of time when a security-related incident is probable or imminent although it may not be possible to identify the specific target.

Source: [IMO, 2002d]

2.5 Port safety and Port Marine Safety Code (PMSC)

Seaports are important for the economy of each country. Given the position in coastal areas and the great variety of substances handled there, ports can be regarded as complex systems from the environmental point of view. They tend to be associated with water and air pollution; soil contamination; dust and noise problems; the generation of waste; dredging operations; movements of ships, lorries and trains; warehouse storage of hazardous substances; etc. According to a study carried out to investigate accidents in seaports from the beginning of the twentieth century to October 2002 collected by Major Hazard Incident Data Service (MHIDS), 43.6 % of a total of 471 accidents occurring in 95 countries are caused by an impact or collision between ships or between a ship and dry land, vehicle collisions etc. [Darbra and Casal, 2004]. Therefore, navigational safety is an important factor to be considered as far as port safety is concerned. In the U.K., the guidelines indicating a general framework on port safety were originated form 'Safety in Docks-Docks Regulations 1988 and Guidance' [HSC, 1988]. The current status of port safety reveals that there is a close relation between the MCA and the port authorities in order to ensure adequate levels of safety and pollution prevention in U.K. ports [Wang, 2006]. Furthermore, following the 'Sea Empress' disaster in 1996, a review of the Pilotage Act 1987 was published in 1998. The outcome of the review was the recommendation of a development of a 'Marine Operations Code for Ports'. The Code to be developed shall cover all port safety functions including pilotage. Consequently, the process of enhancing management control systems for the safety of navigation in ports was initiated. The PMS Code (previously called 'Marine Operation Code for Ports' was finalised and came out in March 2000). The Code requires all ports in the U.K. to demonstrate that a SMS for marine operations is established and that it is underpinned by a formal safety assessment process [DETR, 2000]. The important issues addressed in the Code are as follows [Wang, 2006].

1. It established the term 'duty holder' i.e. harbour authority. 'Board members' are collectively and individually responsible for the proper exercise of their legally authorised duties. It is clear that 'it' and 'they' are severally and collectively the 'duty holder'.

2. Harbour authorities have powers to appoint harbour masters and authorise pilots, and properly entrust the operation of the harbour to such professional personnel. However, the authority cannot assign its accountability.

3. Harbour authorities should publish policies, plans and periodic reports setting out how they comply with the standards regulated by the Code.

4. Powers, policies, plans and periodic reports should be introduced based on a formal assessment of hazards and risks. In addition, harbour authorities shall have formal safety management systems.

5. The objective of a SMS is to ensure that all risks are tolerable and ALARP. Risk assessment methods shall be applied and control measures shall be proposed and implemented to minimise risks. Although each port will implement a SMS differently depending upon its size and functions, each SMS will have the same basic format.

The demonstration of ALARP principle, which is already applied to the offshore safety and all other hazardous activities in the U.K., is also required. The extent of the ALARP demonstration is illustrated by the quotation shown below from the Guide to the Health and Safety at Work Act [HSE, 1991].

> *'If someone is prosecuted for failing to comply with a duty so far as is reasonably practicable, they have to prove that it was not reasonably practicable to meet the requirement or that there was no better practicable means of meeting the requirement '.*

A SMS has to be structured, cohesive, transparent and auditable. It should be based on the following five functions [DETR, 2000]:

1. Definition of the safety policy.
2. Definition of the organisation and personnel roles.
3. Establishment of standards.
4. Development of performance-measuring methods.
5. Development of an audit and review system.

The Code will also attempt to establish the best practice in marine operations which will positively influence other ports in the EU and worldwide. The most influential outcome may be the reduction in insurance for the ports equipped with risk-based SMS and ALARP demonstration [Wang, 2006].

2.6 Critical review of maritime risk assessment

The attitude of safety in the maritime industry has evolved from a reactive manner towards a risk-based and goal-setting regime since the 1990s. In the past, safety regulations were introduced as a result of an accident or a series of accidents and intended to address the most obvious causes. Over years, however, a number of defining incidents and accidents as discussed in the previous sections of this chapter have altered the way in which safety is reviewed. Risk assessment researchers and safety engineers are motivated to develop and apply a variety of risk modelling and decision-making techniques. In general, the tendency of risk assessment is that it is not only used for verification purposes in design and operational process of marine offshore systems, but also for making decisions from the early stages [Wang, 2006]. Accordingly, interest in the improvement of the safety of large engineering systems based on safety analysis from the initial stages has been growing considerably within both the regulatory bodies and industries. Some large companies and organisations have applied quantitative safety management techniques to a considerable extent while others have merely used qualitative methods mainly due to the lack of data. In addition, over the last two decades, the increasing public concerns with regard to safety together with the growing technical complexity of large engineering systems have contributed great interest to the development and application of safety assessment procedures. In this section, in order to have a holistic view of maritime risk assessment, a critical review of its current practice is conducted and the problems encountered are also addressed.

2.6.1 Traditional risk assessment

Traditional risk assessment involves the processes of probability of occurrence or frequency estimates, consequence predictions and the combination of such elements to obtain the degree of risk. Historical casualty data and information play important roles in risk studies. If historical data are available, risk profiles can be established without the need to model scenarios. This is particularly true for the FSA studies relevant to bulk carriers. However, this usage may not be proactive for new designs and systems and cannot even measure the potential effect of proposed RCOs since sufficient data is unavailable. Thus, in some cases, especially for the conduction of simple FSA work, historical data can be directly used while in general, analytical modelling incorporating expert judgement is strongly recommended.

The risk matrix technique is often applied to prioritise hazards based on the risk index method [Wang and Foinikis, 2001] [Loughran *et al.*, 2002] [Lois *et al.*, 2004]. Such a technique is also employed by security analysts. The technique, as shown in Tables 2.5 and 2.6, uses the index method to represent the frequency and consequence of hazards. It is capable of providing a traceable framework for explicit consideration of the frequency or probability of occurrence and consequences of hazards. A 7×4 risk matrix introduced by the IMO is shown in Table 2.7 based on the frequency and severity indices in Tables 2.5 and 2.6 respectively [IMO, 2002a]. The risk index of a specific hazard is obtained based on the summation of the frequency and severity indices.

Table2. 5. Frequency index (FI)

FI	Frequency	Definition	F (per ship year)
7	Frequent	Likely to occur once per month on one ship	10
5	Reasonably probable	Likely to occur once per year in a fleet of 10 ships, i.e. likely to occur a few times during the ship life	10^{-1}
3	Remote	Likely to occur once per year in a fleet of 1,000 ships, i.e. likely to occur in the total life of similar ships	10^{-3}
1	Extremely remote	Likely to occur once in the lifetime (20 years)	10^{-5}

Source: [IMO, 2002a]

Table 2.6. Severity index (SI)

SI	Severity	Effects on human safety	Effects on ship	S (Equivalent fatalities)
1	Minor	Single or minor injuries	Local equipment damage	10^{-2}
2	Significant	Multiple or severe injuries	non-severe ship damage	10^{-1}
3	Severe	Single fatality or multiple severe injuries	Severe damage	1
4	Catastrophic	Multiple fatalities	Total loss	10

Source: [IMO, 2002a]

Table 2.7. Risk index (RI)

FI	Frequency	Severity (SI)			
		1	2	3	4
		Minor	Significant	Severe	Catastrophic
7	Frequent	8	9	10	11
6		7	8	9	10
5	Reasonably probable	6	7	8	9
4		5	6	7	8
3	Remote	4	5	6	7
2		3	4	5	6
1	Extremely remote	2	3	4	5

Source: [IMO, 2002a]

However, there are weaknesses when applying such an approach:

1. It can be seen from Table 2.7 that since the risk of a specific hazard is obtained based on the summation of the frequency and severity indices, the risk implications of the hazards with identical risk indices may be different. A risk index of 8, for example, is the combination of either frequent frequency and minor severity, frequent frequency and significant severity, reasonably probable frequency and severe severity, or reasonably probable frequency and catastrophic severity. This may result in the underestimation or misunderstanding of the hazards in question.

2. In circumstances where multiple outcomes are possible, e.g. the consequence of a fall on a slippery deck could range from nothing of consequence to a broken neck, it may be difficult to select the appropriate frequency or severity for the risk categorisation. It is noted that many practitioners suggest the use of the more pessimistic outcome [Kontovas, 2005].

3. The risk matrix approach evaluates hazards one at a time rather than in accumulation. However, risk decisions should be made based on the total risk of an activity. Potentially many smaller risks can accumulate into an undesirably high risk whereas each of these smaller risks on its own may not warrant risk reduction [Kontovas, 2005]. Accordingly, the approach may underestimate the total risk if such an accumulation is ignored.

4. According to experiences from conducted FSAs, experts prefer to provide percentile values rather than point estimates [Rosqvist and Tuominen, 2004]. Thus, experts may have the difficulties of estimating the frequency and severity of hazards.

Other commonly used techniques include IDs, FTA, ETA and the PLL method. An ID model allows for a holistic understanding of the problem area to be displayed in a hierarchical way by identifying the potential influencing factors that could contribute to a major marine accident and as discussed in section 2.3.2. A fault tree is a logic diagram presenting the causal relationship between events which individually or collectively contribute to the occurrence of a higher level event. Thus, the probability of occurrence of a specific hazard can be determined. In addition, FTA is capable of considering common cause failures in systems with redundant or standby elements. It also has the capability of contemplating failure events or causes related to human errors. FTA is a top-down approach, systematically considering the causes or events at levels below the top level. Prior to the use of the quantitative FTA, the probability of occurrence of each basic event has to be obtained. If two or more lower events need to occur to cause the next higher event simultaneously, a logic gate, AND gate, is employed to express the operation. If any one of two or more lower events can cause the next higher event directly, an OR gate is applied to show such an operation. The logic gates determine the addition or multiplication of probabilities to obtain the values for the top event.

An event tree is a logic diagram applied to analyse the effects of unintended events. Such a technique first expresses the probability or frequency of the accident linked to the safeguard measures required to be implemented to mitigate or prevent escalation after the occurrence of the event. The probabilities of success or failure of these actions are subsequently evaluated. Success and failure paths lead to various consequences with differing magnitude. The likelihood of each consequence is finally obtained by multiplying the probability of occurrence of the accident by the likelihood of failure or success in each path. Another technique of estimating consequences is the use of PLL. Equation 2.1 shows its formula.

$$PLL = \frac{N_f}{S} \qquad \text{(Equation 2.1)}$$

where N_f represents the number of fatalities of a specific type of vessel, and

S denotes the shipyears of that type of vessel.

As aforementioned historical data is crucial for risk assessment. In theory, the reliability of the results obtained depends upon the data collected. Therefore, it is highly likely that the risk analysis techniques previously discussed will produce a reliable outcome if the data in hand is complete.

However, such techniques may not be practicable in circumstances where the lack of data exists or the level of uncertainty associated with failure data may be unreasonably high [Wang *et al.*, 2004]. This is particularly true for large maritime systems at the initial design stages or newly adopted processes and regulations for ports or vessels. Only nonnumerical data, which could be subjective, may be available at such a stage. To sum up, the problems encountered by risk assessment researchers due to the nature of maritime operations include [Sii *et al.*, 2001a][Sii *et al.*, 2001b][Wang *et al.*, 2004]:

1. Nonexistence or inadequacy of historical data for many newly adopted processes and regulations for ports and vessels and for many novel designs. In many cases the statistical accuracy of these inadequate and the limited data

available for safety analysts may be poor. It may also be difficult to acquire failure information considering the effects of human factors with confidence.

2. Since safety is a multiple level and multiple variable optimisation subject, it is difficult to establish a mathematical model to represent and describe the safety with regard to a specific port system or a newly designed maritime product. There are many instances where causes of an accident involved operational procedures, human errors and decisions determined by designers and management. Accordingly, the safety of a system is influenced by a variety of factors including manufacturing, installation, commissioning, operations, maintenance etc.

3. A number of effective techniques capable of dealing with human factors are mostly absent in risk assessment conducted within the safety case regime. This may be due to the fact that there is little or no human error related data with regard to maritime safety.

4. It may be difficult to quantify the probability of occurrence and consequences of hazards. This is because hazards are associated with the operational processes in a very changeable environment and therefore it may involve a high level of uncertainty.

5. A large number of assumptions, judgements and opinions are involved subjectively in a risk quantification process. As such, considerable skills are required for safety analysts to interpret the results produced.

6. It may be impracticable for a full scale experimentation to be conducted due to a high level of cost. The use of computer simulation may be potentially possible.

7. Since safety is only one of the important factors involved in the appraisal of the acceptability of an activity, it is difficult to establish an absolute safety criterion for acceptance standard.

2.6.2 Uncertainty

Uncertainty is defined as a situation in which a person does not have appropriate quantitative and qualitative information to describe, prescribe or predict deterministically and numerically a system, its behaviour or other characteristics [Zimmermann, 2000]. Some of the problems encountered by risk assessment researchers discussed in section 2.6.1 present a high level of uncertainty which may bias the results acquired. Uncertainty in principle is originated from the areas including, at least but not last, failure and accident data, assumptions, consequence methodologies, the lack or incompleteness of data and non-specificity with regard to RCOs.

2.6.2.1 Failure and accident data

The uncertainties affecting the use of failure and accident data can be considered with respect to the statistical significance of such data. Uncertainties mainly come from the following sources [Schofield, 1998]:

1. The effect of a small sample size.

2. The relevance of generic data to specific facilities or operating conditions in question.

3. The effect of a limited reporting in relation to failure mode definition.

The effect of a small sample size may bias the results acquired since such a sample may not fully reflect the characteristic of the population. If a small sample size were merely the only source of uncertainty, sample theory could provide confidence intervals relating to failure rates. Accordingly, such uncertainty could be addressed in the risk assessment process.

The relevance of generic data to specific items of equipment or specific scenarios of operating conditions is a factor that is more difficult to address. This is because the facilities and operating conditions under consideration may not be as relevant as first thought to those for which data have been collected. Under such circumstances, none of the methods is capable of addressing what data should be appropriate [Schofield, 1998].

The effect of a limited reporting in relation to failure mode definition is also a potentially insuperable problem from the quantification point of view. It may result in the underestimation of the potential significance of some failure modes which were not included within the domain of definition. The existence of such lesser failure modes is due to the fact that these failure modes have random possibility to escalate to the failure modes within the domain of definition [Schofield, 1998]. Inclusion or otherwise of these lesser failure modes depends upon the factors that may not be significant statistically. An example of this is the possible absence of near-misses in incident reporting.

The overall effects of these three factors may be the data that do not adequately represent a realistic potential rate of occurrence of defined failure modes.

2.6.2.2 Assumptions

Various types of assumptions have been used in risk analysis. Some relate to the use of data subject to the discussion of the data uncertainty as addressed in section 2.6.2.1. Some relate to the use of consequence methodologies which will be discussed in section 2.6.2.3. Another category of assumptions is concerned with the definition of the system under consideration. This includes the identification of hazards and associated accident scenarios as well as the physical conditions which exist within these scenarios. Assumptions within this category are often stated explicitly and openly based on practical knowledge about the subject matter under consideration. As such, they can be scrutinised and varied using the techniques such as sensitivity analysis to assess their effect on risk results.

2.6.2.3 Consequence methodologies

Consequence methodologies are concerned with the predictions of risks arising from accident escalation. Such modelling may at one extreme comprise very simple assumptions. At another extreme it may consist of a very complex mathematical model implemented by sophisticated computer software. Alternatively, it is the modelling which may be somewhere between these extremes. A problem with attempting to model maritime accident scenarios is the often complex nature of escalating events leading to a major accident [Schofield, 1998]. This complexity is associated with the intrinsic nature of many of the consequence phenomena under consideration. This may make the consequence become unpredictable. Some phenomena may be characterised by chaotic behaviour associated with inherent non-linearities, for which model predictions may be very sensitive to small changes in factors such as initial conditions or assumptions about parameter values. Examples of these include smoke migration, explosion overpressure, fire development and personnel movement during escape and evacuation.

2.6.2.4 Lack or incompleteness of data

The lack of incompleteness of data can lead to uncertainty, in particular for novel maritime products or safety processes at the initial stage. The gaps in such data are usually bridged based on a combination of scientific data or analysis if applicable, expert judgement and through the use of some analogous data that may be the only option available. The information obtained sometimes tends to be non-numerical and subjective as previously addressed. Very often such information gathered is vague. This would cause the inconsistency of information interpretation between safety analysts. Thus, this lack of consensus can increase uncertainty.

2.6.2.5 Non-specificity with regard to RCOs and others

Non-specificity with regard to RCOs is a lack of information resulting from not explicitly stating or distinguishing alternatives. It is characterised by sizes of relevant sets of alternatives. The more possible alternatives a situation has, the less specific the situation is. In addition, other sources leading to uncertainties may include the estimates of the costs, time-scales, risks, safety benefits, the assessment of stakeholder views and perceptions etc.

2.6.2.6 Overall effect and uncertainty treatment

When the uncertainties originating from these sources are combined, the overall effect caused may undermine significantly the conclusion arising from a quantitative risk analysis. Consideration of these uncertainties may drive estimated risk levels appreciably upwards or downwards from the initially calculated results. Regardless of whether these estimated results are initially assessed as best or pessimistic estimates, an upward revision could result from the consideration of, for example, the effect of a limited incident reporting in relation to its failure mode definition.

Methods for analysing and describing uncertainty can range from simple to complex depending upon circumstances encountered. Common approaches applied to handle uncertainty can be divided into two different categories: those developed based on probabilistic analysis, including classical set theory, probability theory and Bayes theory; and those modelled based on possibilistic analysis, including possibility theory and fuzzy set theory [Eleye-Datubo, 2006]. Each approach has various strengths and characteristics regarding its representational and propagation capabilities. The uncertainty modelled by the methods under the first category is represented by a collection of estimates of the quantity and the degree of certainty or uncertainty measured by means of the distribution of values in the collection of such estimates. The methods falling into the second category are reasoned with regard to an epistemic state using max/min or max/product calculus that is not found in probability theory. Among the approaches under the category of possibilistic analysis, the significance of fuzzy set theory is the use of linguistic variables capable of providing a flexible modelling of imprecise data and information.

It should be noted that in risk analysis if uncertainties could be expressed quantitatively, the conduction of sensitivity analysis would be recommended so that such negative effects might be reduced to a certain level.

2.6.3 CBA and decision making

The objective of CBA is to estimate cost and benefit and so compute their ratios for all ROCs, followed by the identification of the RCOs with lower and minimum costs related to a unit of risk reduction. Evaluation of the cost component is usually not the problem in CBA. In general, the cost component consists of one-time (initial) and running costs cumulating over the predicted lifetime of the system. The benefit component, however, is much more intricate as it may not only be valued in terms of risk reduction but also in terms of safety margin or robustness to risk [Rosqvist and Tuominen, 2004]. Thus, it may be difficult to compare cost and benefit on a common basis. Furthermore, when more parameters such as reliability are contemplated, simple comparison of cost and benefit cannot reasonably be conducted.

In addition, the CAF method is the technique that is often applied in CBA due to its characteristic of simple calculations. However, it is often corrupted by the manipulation of cost and benefit in order to satisfy or unsatisfy the given criteria. This would bias the results obtained in CBA.

A cost-benefit index technique applied by a company providing ferry services, the North Ferry Company, offers another way of analysing costs and benefits of each alternative [PVA, 1997] [Lois *et al.*, 2004]. It consists of three stages:

1. Estimate of benefit using the references shown in Table 2.8.
2. Cost estimate based on the scale developed in Table 2.9.
3. Combination of the estimated cost and benefit by dividing the estimated benefit by the predicted cost as shown in Table 2.10.

Table 2.8. Estimate of benefit

Level of linguistic terms	Description	Estimated index
Very low	No benefit from reduced risks	1
Low	Small benefit from reduced risks	2
Medium	Medium benefit from reduced risks	3
High	High benefit from reduced risks	4
Very high	Very high benefit from reduced risks	5

Source: [PVA, 1997] [Lois *et al.*, 2004]

Table 2.9. Estimate of cost

Level of linguistic terms	Description	Estimated index
Very low	No cost for the implementation of the countermeasure	1
Low	Small cost for the implementation of the countermeasure	2
Medium	Medium cost for the implementation of the countermeasure	3
High	High cost for the implementation of the countermeasure	4
Very high	Very high cost for the implementation of the countermeasure	5

Source: [PVA, 1997] [Lois *et al.*, 2004]

Table 2.10. Cost-benefit assessment

Cost-benefit assessment	
Countermeasures	Estimate of benefit ÷ Cost estimate = Overall score

Source: [PVA, 1997] [Lois *et al.*, 2004]

Tables 2.8 and 2.9 provide another way of modelling benefit and cost based on the index method. This technique can be particularly useful in circumstances where safety analysts have the difficulty of explicitly expressing cost and benefit on a common basis. The overall score obtained from Table 2.10 is capable of assisting decision makers to select the best option. However, such a technique, in some circumstances where the values of the overall score of some RCOs are equal, may not be applicable. This is because the cost-effective implications of these RCOs may be different. An RCO with the estimated benefit score of 4 and cost score of 2, for example, would have an overall score identical to the one with the score of 2 for its estimated benefit and score of 1 for the estimated cost. The implications of these RCOs are different and may not be discriminated if decision makers fully rely on the values of their overall scores.

When considering the cost-effectiveness of RCOs, the decision should ensure that such effects are impartial to all stakeholders. The Stakeholder Analysis technique is capable of providing information about the distribution of benefit and cost of RCOs. Such information is useful for refining the options. In particular, RCOs may be augmented with monetary compensation for the unfairness that may be perceived by some stakeholders. A spreadsheet model describing the cost-benefit distribution among stakeholders has been developed [Gilfillan, 2002]. However, models addressing such compensation between stakeholders have not been proposed.

It is noted that in the decision-making process risk criteria are also important. They are used to judge whether risks are tolerable, intolerable or need to be mitigated to an ALARP level. ALARP may be demonstrated by historical data of low or acceptable levels of risk and by the adoption of the best practice. When QRA is performed, numerical risk criteria are required. However, the application of absolute numerical risk criteria may not always be appropriate because of the uncertainties involved in the risk assessment and safety management process as aforementioned. The establishment of such criteria may therefore cause inflexibility for the decision-making process [Wang *et al.*, 1999]. As such, in the offshore safety case regime, the ALARP demonstration seems to be lost in numerical estimates of risk and is considered as an add-on to the risk assessment process [Trbojevic, 2001]. Such a demonstration may also become complicated with new technologies or procedures for which there is no historical data and the good practice has not yet been established. Furthermore, decision making would become more complex if there were many parameters to be considered apart from the factors of risk criteria and cost effectiveness with regard to each RCO.

2.6.4 Human error assessment

Human error assessment deals with the risk contributed by human error. Most HRA material is concerned with the quantification of the potential of human error. In general, HRA has three fundamental functions, namely, the identification of human errors, the prediction of their likelihood and reduction of the likelihood if required [Kirwan, 1992a]. The HRA approaches can be divided into two categories, those using a database, and those using expert judgement [Kirwan, 1996]. The approaches falling into the first category apply a database containing generic HEP to the specific circumstance being assessed. The manipulation is often based on the assessment of circumstance related Performance Shaping Factors (PSF) that modify the probabilities based on environmental and contextual circumstances. The HEPs obtained based on the approaches in the second category are acquired by asking experts directly with regard to the scenario under consideration. Alternatively, some approaches in this category generate HEPs by manipulating and interrogating a quasi database which has some basis in real data from industrial incidents and which is incorporated with expert judgement. Some most widely used HRA techniques in the UK include Technique for Human Error Rate Prediction (THERP) [Swain and Guttmann, 1983], Human Error Assessment and Reduction Technique (HEART) [Kirwan, 1994], Justification of Human Error Data Information (JHEDI) [Kirwan, 1992b], Success Likelihood Index Method using Multi-Attribute Utility Decomposition (SLIM-MAUD) [Gertman and Blackman, 1993], Paired Comparisons [Hunns, 1982], and Absolute Probability Judgement [Seaver and Stillwell, 1983].

Although HRA has been adopted in various industries, it is not without some problems. The issues addressed below are the drawbacks criticised when applying the HRA approaches [Hollnagel, 1993] [Fields, 2001] [Kirwan, 1994].

1. For the methods such as THERP, the information contained in the database is from a variety of sources. The reliability of such data has always been questioned.

2. The approaches often involve steps of breaking the task into small components, assigning probabilistic estimates to the components and producing the results to provide an overall risk index. The validity of these steps is often criticised.

3. The nature of the sources from which the data is collected may be different from the context to be assigned to the HEPs. This may influence the quality of the HRA.

4. The precision of the opinions with regard to the relative importance of the PSFs or the HEP predictions is often questioned.

5. Interdependencies existing between the factors under consideration are rarely addressed. The Error Producing Conditions (EPCs) in the HEART method, for instance, interact with each other in complex ways and such interdependencies are usually ignored.

2.6.5 Quality assurance in the port industry

High performance quality of safety and security measures can ensure the effectiveness and efficiency of port operations so as to achieve safety and security objectives without jeopardising customer satisfactions simultaneously. However, according to literature, very few port authorities employ a quality assurance system to maintain and improve the quality with regard to the services provided. Associated British Ports PLC (ABP) formed in 1983, for instance, is the single largest U.K. operator controlling 22 of the privatised ports. Neither ABP itself nor its individual ports have a system-wide quality control mechanism. Nevertheless, there are some ports incorporating quality assurance system into some of the operations provided. Port of Singapore, for instance, requesting bunker tankers to carry onboard a Certificate of Quality (COQ) showing that the quality of bunker fuels carried are in compliance with the ISO 8217 Standard [Maritime and Port Authority of Singapore, 2003].

2.7 Justification of research

In the risk assessment and safety management research, management of the effects caused by uncertainty is an important issue. However, causes of uncertainty as discussed in section 2.6.2, are diverse. Thus, regardless of what approach is to be applied, it is always dependent upon human judgement to manage such negative effects. In other words, the deficiencies of risk modelling resulting from the lack of information or a high level of uncertainty must be made up by means of the general evaluation capacity of humans who are able to grasp the essence of an object, even if it is vague and unclear. One feasible way to model such a situation under a high level of uncertainty is the use of approximate reasoning approaches using a fuzzy inference system where the conditional part and/or the conclusions contain linguistic variables [Wang *et al.*, 1995] [Wang, 1997]. It is capable of handling imprecise, ambiguous and qualitative information and quantitative data in a consistent manner. This greatly reduces the need for safety analysts to know the precise point at which a risk factor exists. It also permits experts to evaluate the risk associated with failure modes directly using linguistic terms that are commonly employed in carrying out risk assessment. In this context, a safety model using the approximate reasoning approach may be more appropriate to model the risks of the systems associated with incomplete safety information.

Fuzzy set theory, formalised in 1965, has been widely applied in different fields. Its use in system safety and reliability analysis could prove to be useful since such analysis often requires the use of subjective judgement and uncertain data. The use of linguistic variables provides flexible modelling of imprecise data and information. A linguistic variable differs from a numerical variable in that its values are not numerals but words or sentences in a natural or artificial language. The significance of fuzzy variables is that they facilitate gradual transition between states and therefore are able to deal with the observation and measurement of uncertainties. On the other hand, traditional variables, which may be referred to as crisp variables, do not have such a capability. Although the definition of states by crisp sets is mathematically correct, in many cases it may be regarded as unrealistic in the face of unavoidable measurement errors. When dealing with the safety of a system using fuzzy set theory, the parameters including occurrence likelihood, consequence and probability of failure consequence can be judged and described using linguistic terms and the membership values associated. These fuzzy variables can then be synthesised with confidence using a fuzzy rule base or some other techniques such as Artificial Neural Network (ANN) or Analytical Hierarchy Process (AHP).

Traditionally, risk assessment is usually carried out using either a top-down approach or a bottom-up approach, depending upon the availability of failure data, the level of the analysis required, the degree of complexity of the interrelationships between the components in a design and the level of innovation in the design [Wang *et al.*, 1995]. The success of a top-down safety assessment is highly dependent upon the reliability of failure data in previous incident and accident reports where proper investigations and appropriate data collections of incidents and accidents are crucial. In the bottom-up safety assessment process, a system can be divided into subsystems that can be further broken down to the component level in order to identify all possible hazards. Possible failure events at both the component and the subsystem levels can then be combined. Consequently, possible serious failure events can be identified. Compared to the top-down safety assessment, the bottom-up analysis provides safety analysts with a higher level of confidence that possible failure events are identified with less or no omissions. Therefore, the risk assessments of port security, marine safety and human error to be conducted in this PhD study are based on the bottom up approach, breaking down port operating systems into subsystems and even system components. Such an analysis in this research can be regarded as a hierarchical process where risks associated with the elements at higher levels are determined by the risks of the parameters at lower levels.

2.7.1 Risk assessment of port security using fuzzy modelling

As aforementioned in section 2.4.4, under the ISPS Code each government has to perform a Port Facility Security Assessment for each port facility within its territory which serves ships engaged on international voyages. Such an assessment is basically a risk analysis of all operational aspects of a port system in order to determine which parts of it are more susceptible and more likely to be the target of an attack. Hence, it could be reasonable to deduce that the purpose of security is to protect all assets including people, information and the physical assets.

According to literature, security risk could be regarded as a function of the threat of an attack associated with the vulnerability of the object under consideration and the consequences caused by such attack [Burns-Howell *et al.*, 2003]. Threat could be defined as an action or potential action likely to cause damage, harm or loss [Burns-Howell *et al.*, 2003]. If explained quantitatively, it would be a measure of the likelihood that a specific type of attack will be initiated against a specific target (i.e. a scenario). The threats related to the shipping industry may include terrorism, robbery, cargo theft, stowaways and the smuggling of people, and drug and currency laundering. Vulnerability is a weakness in any system or equipment, or in procedures designed to protect assets [Burns-Howell *et al.*, 2003]. Its quantitative description could be the likelihood that various types of safeguard measures against a scenario would fail. Consequence (impact) is either the amount of expected loss or damage, or it is the negative effects in the shipping industry should the attack be successful. However, the risk results obtained from such a combination may not genuinely reflect the risk levels with the absence of the consideration as to the relative importance of each asset. Thus, in this PhD study, another parameter has been incorporated into this security risk function, namely, criticality. Thus, criticality is defined as the relative importance of each facility, taking into account its function, location, costs and allowable time for returning operational.

However, due to the confidentiality of the intelligence with regard to terrorism and difficulty of the information accession, the data available for conducting security risk assessment is rare for most researchers. Accordingly, fuzzy set theory is employed in this study. Under the concept of FMECA, the parameters of criticality, likelihood, vulnerability, and consequence of each scenario are modelled using linguistic terms and the membership values associated. Such elements are then synthesised to obtain the fuzzy conclusions based on a fuzzy rule base developed. A defuzzification process is subsequently employed to acquire the numerical values. Consequently, a security rank of the scenarios under consideration can be established.

2.7.2 Risk prediction of port safety using fuzzy Artificial Neural Network (ANN)

As aforementioned that 43.6 % of a total of 471 accidents occurring in 95 countries are caused by an impact of heavy objects or collision between ships or between a ship and dry land, and vehicles [Darbra and Casal, 2004]. Table 2.11 summarises the specific causes of the accidents in seaports. It can be seen from the impact category, the causes of 71 % of the accidents are related to a ship/land, or ship/ship collision.

In addition, using the same statistics, 56.5 % of accidents took place during the transport process [Darbra and Casal, 2004] as shown in Table 2.12. The transport category includes, all accidents that occurred in moving ships (entering or leaving the port), and in lorries or trains entering or leaving port facilities. Therefore, as far as port safety is concerned, navigational safety is an important factor to be considered. The salient parameters playing important roles in navigational safety in this research include the Vessel Traffic Control (VTC) performance, navigation aids and facilities, pilotage performance, sealane maintenance and the weather condition. The first four elements mentioned above are regarded as the specific port safety functions relating to navigation by the experts specialising in ports [Sydney Ports, 2005] whereas the weather condition is the parameter that cannot be managed or controlled by a port. In addition, due to the scarcity of navigational safety data, fuzzy set theory is employed.

From the risk assessment point of view, the applications of fuzzy set theory with the adoption of a fuzzy rule base become impractical as there are multiple parameters to be evaluated which are described by multiple linguistic terms. If there were five parameters described by five different linguistic variables, for example, the number of fuzzy rules needed to be developed would be 3,125. In this study, a risk prediction model incorporating fuzzy set theory and ANN capable of resolving the problem encountered is proposed. An algorithm capable of converting the risk-related parameters and the overall risk level from the fuzzy property to the crisp-valued attribute is also developed.

Table 2.11. Specific causes of accidents in seaports

Specific cause	Number of accidents	Percentage of category
Impact		
Ship/land impact	79	45
Ship/ship impact	45	26
General operation	8	5
Heavy object	8	5
Rail accident	7	4
High winds	7	4
Others	20	11
Subtotal	193	100
Human		
General operation	21	23
Overfilling	10	11
Maintenance	9	10
Procedures	7	8
Ship/land impact	6	6
Others	39	42
Subtotal	92	100
Mechanical		
Valve	13	14
Flange coupling failure	8	9
Metallurgy failure	7	8
Hose	6	7
High winds	6	7
Over pressure	5	5
Others	45	50
Subtotal	90	100
External		
High winds	21	25
Sabotage	10	14
External fire	9	13
Ship/land impact	7	7
Ship/ship impact	6	6
others	30	35
Subtotal	83	100
Unknown	13	100

Source: [Darbra and Casal, 2004]

Table 2.12. Specific origins of accidents in seaports

Specific origin	Number of accidents	Percentage of category
Transport		
Ocean going vessel	173	65
Pipeline	31	12
Portable transport container	26	10
Barge	14	6
Road tanker	12	4
Rail tanker	7	3
Tank container	3	1
Subtotal	266	100
Loading/unloading		
Ocean going vessel	24	34
Pipework	10	14
Hose	10	14
Not defined	6	8
Barge	5	7
Portable transport container	4	6
Road tanker	4	6
Solid conveyance	2	3
Pipeline	2	3
Tank container	2	3
Pumps/compressor	1	1
Rail tanker	1	1
Subtotal	71	100
Storage		
Atmospheric pressure storage vessel	31	56
Portable container	9	16
Solid storage	5	9
Not defined	5	9
Small commercial tank	1	2
Pipework	1	2
Pressurised storage vessel	1	2
Solid conveyance	1	2
Barge	1	2
Subtotal	55	100
Process		
Not defined	19	37
Pipework	7	13
Process vessel	6	12
Reactor	5	10
Pump/compressor	6	12
Fired process equipment	4	8
Heat exchangers	3	6
Process machinery drives	1	2
Subtotal	51	100
Unknown	28	100

Source: [Darbra and Casal, 2004]

2.7.3 Human error assessment in port operations using fuzzy Analytical Hierarchy Process (AHP)

The human element is one of the most important factors contributing to maritime accidents. This can be verified by the statistics shown in Table 2.11 where human errors make a significant contribution in port operations, consisting of 19.5 %. In addition, it can be seen from Table 2.12 that 15.1 % of seaport accidents are caused by cargo loading and unloading. With the available information from MHIDS, the accidents have been divided into the categories of oils, chemicals, acids, natural gas and others. The greatest proportion of the accidents, 59 % occurred with oils [Darbra and Casal, 2004]. Therefore, the test case selected for illustrating the proposed framework of human error assessment is an oil cargo handling process.

The human error assessment in this PhD research is conducted based on the bottom-up safety approach since such an approach provides safety analysts with a higher level of confidence that possible failure events are identified with less or no omissions. This is achieved by combining the fuzzy set theory and the AHP technique, allowing for the difficulties aforementioned in section 2.6.4 when using traditional HRA techniques as well as the lack of human error related data. The human error assessment framework is demonstrated by a test case with regard to an oil cargo handling operation as aforementioned. Cargo handling operations involve several missions in different phases and each mission is accomplished by a number of steps in order. By virtue of breaking down the oil cargo handling operation to the missions (subsystem) and the steps (component) levels, the probability of occurrence, the failure consequence probability and the severity of the hazards associated in each step can be determined based on pairwise comparisons. Consequently, the step with the highest risk can be identified. Likewise the mission that has the highest risk can then be obtained by combining the risks of each associated step.

2.7.4 Multi-attribute decision making using ER

In the decision making process of this PhD study, the factors considered when evaluating each RCO include, effectiveness, cost, time of deployment, resource availability and co-operation level. Effectiveness is defined as the effectiveness of the RCOs on risk reductions in terms of the security, safety and human error aspects. Cost is the capital that will be consumed once the RCOs are implemented, including initial costs, operational costs, maintaining costs and decommissioning costs. Time of deployment is the time spent in deploying the measures, including the time taken for personnel training and for facility or equipment installations. Resource availability is, regardless of monetary capitals, defined as the existing resource available for the measures such as existing facilities, equipment or skilled personnel capable of accomplishing the missions established. Co-operation level is the level of the diversity that different departments both within and outside the port need to participate in the activities proposed by the measures, depending upon the functions and complexity of the RCOs. In other words, a specific measure would be preferred if the number of different departments participating in the proposed activity was low (e.g. one or two) in terms of the co-operation level criterion. Thus, the decision making in this study is the analysis with multiple objectives that both have a quantitative and qualitative nature. The research method employed is the ER approach. It is one of the techniques that were developed to solve multi-attribute decision-making problems. By using this technique, subjective judgement with uncertainty and precise data can be consistently modelled under the unified framework based on an evaluation analysis model and the Dempster-Shafer (D-S) theory of evidence [Lopez de Mantaras, 1990]. A sensitivity analysis considering the aspects of effectiveness and cost will be conducted to obtain the best and preferred RCOs.

When applying such a technique, a drawback occurs in circumstances where a decision-making project is evaluated by multiple experts due to the fact that the utility appreciation of each evaluation grade by the experts may be different. This could result in a general attribute or RCO ranking order conflict between the experts. The phenomenon would become obvious if the evaluation grades and belief degrees evaluated for each alternative or general attribute were close. The framework proposed in this study is capable of solving such a difficulty.

2.7.5 Quality assurance of efficiency of port security and safety measure using Six Sigma

Nowadays, more and more security and safety regulations and policies have been adopted and implemented in both the port and shipping industries. The objective of this is certainly to ensure that the international trade could be safely expedited without undue safety practices or threat from intentional crime activities. However, it may undermine the efficiency of port and shipping operations. In the port context, it is therefore necessary to incorporate the opinions with regard to the quality of the implementation of safety and security measures from port customers such as vessels and traders having businesses within port areas. The purpose of this is to achieve customer satisfaction based on the opinions gathered to improve the quality of security and safety measures adopted so as to ensure that the efficiency of port operations is improved and maintained.

Many quality assurance approaches are capable of achieving the aforementioned objective. However, the method chosen for this study is Six Sigma. This is because many well-known quality assurance methods such as Total Quality Management (TQM) or International Organization for Standardization (ISO) do not emphasise data collection and analysis. Six Sigma, on the other hand, is a data-driven method that focuses on customer satisfaction and scientifically leads a company to attain the best quality level. From the statistical point of view, the term Six Sigma is defined as having less than 3.4 defects per million opportunities or a success rate of 99.9997% where sigma is a unit used to represent the variation about the process average [Antony and Coronado, 2002]. From the business point of view, however, it is defined as a business strategy used to improve business profitability, the effectiveness and efficiency of all operations to meet or exceed customer needs and expectations [Antony and Banuelas, 2001]. Motorola was the first organisation to adopt Six Sigma in the 1980s as part of its quality performance measurement and improvement programme. Such a method has since been successfully applied in other manufacturing organisations such as General Electric, Boeing, DuPont, Toshiba, Seagate, Allied Signal, Kodak, Honeywell, Texas Instrument, Sony etc.. The benefits and savings reported are composed and presented in Table 2.13 from investigating various literatures in Six Sigma [Kwak and Anbari, 2006]. On the other hand, however, there are some criticisms with regard to this quality assurance tool. One of the criticisms is that Six Sigma is a high investment and resource-intensive programmes that only big companies can afford [Caulcutt, 2001]. Therefore, it may be argued that Six Sigma seems to be an expensive tool for small enterprises. It is worthwhile noting that a number of modifications [Wessel and Burcher, 2004] have been proposed to adjust the approach in this context. In addition, a research carried out using multilevel case analysis identify that a certain degree of the Six Sigma problems is attributed to the lack of empowerment. It suggests that organisations need to evaluate their existing culture, empowering employees where appropriate, before the adoption of Six Sigma [McAdam and Lafferty, 2004]. The factors that play important roles in quality assurance using the Six Sigma programme have also been identified. These include, namely, upper management commitment, training, linking Six Sigma to business strategy and customers, culture change and organisational structure [Henderson and Evans, 2000] [Antony and Coronodo, 2002] [Dale, 2000] [Harry and Schroeder, 2000]. Such elements are crucial for the establishment of an effective Six Sigma system without which any organisation will not be able to acquire the benefits listed in Table 2.13.

As aforementioned that Six Sigma has been widely and successfully applied in the manufacturing industry to improve the performance quality. However, it has not been employed in the port industry as far as quality issues are concerned. The research framework proposed will be demonstrated using a test case of a transport process of ship stores. This will provide a positive starting point by introducing quality assurance approaches on a scientific and quantitative basis to the port industry.

Table 2.13. Benefits and savings from Six Sigma in the manufacturing sector

Company/Project	Metric/Measures	Benefits/Savings
Motorola	In-process defect levels	150 times reduction
Raytheon/Aircraft integration systems	Depot Maintenance inspection time	Reduced 88% as measured in days
GE/Railcar leasing business	Turnaround time at repair shops	62% reduction
Allied Signal/Bendix IQ brake pads	Concept-to-shipment cycle time	Reduced from 18 months to 8 months
Hughes aircraft missiles systems group/Wave soldering operations	Quality/productivity	Improved 1,000% in quality and 500% in productivity
General Electric	Financial	$2 billion
Motorola (1999)	Financial	$15 billion over 11 years
Dow Chemical/Rail delivery project	Financial	Savings of $2.45 million in capital expenditures
DuPont/Yerkes plant in New York	Financial	Savings of more than $25 million
Telefonica de Espana	Financial	Increases in revenue 30 million euro in the first 10 months
Texas Instruments	Financial	$600 million
Johnson and Johnson	Financial	$500 million
Honeywell	Financial	$1.2 billion

Source: [Kwak and Anbari, 2006]

In summary, this PhD research attempts to establish a platform of risk assessment and safety management consisting of various frameworks addressing port safety and security without jeopardising the efficiency of port operations under circumstances where the lack or incompleteness of data exists or a high level of uncertainty is presented.

2.8 Discussion

Maritime safety has been moving towards a risk-based and goal-setting regime since the 1990s. Traditional risk assessment techniques such as FTA and ETA are capable of providing results with confidence if historical data are available. However, they may not be applicable in circumstances where the lack of data exists or the information available consists of a high level of uncertainty. As such, it is very often that risk analysis under such circumstances strongly relies on human judgement. Approximate reasoning approaches may be more appropriate due to the capabilities of modelling vague, fuzzy, imprecise and qualitative information as well as quantitative data in a consistent manner. The information and data available for port security and navigational safety in ports are scarce. Human error assessment in port operations would encounter some difficulties aforementioned if traditional HRA methods were applied due to the lack of such data in ports. Accordingly, the risk assessment of port security and safety together with human factors in this PhD study is based on the approximate reasoning approach. Different techniques including ANN and AHP can also be incorporated respectively into the risk assessment framework alone with fuzzy set theory to facilitate the analysis performance and provide results with confidence. In the decision-making process, many factors need to be considered when evaluating the RCOs proposed for port security, safety and human error assessment. Under such circumstances where the factors considered have different attributes, the best RCOs will be identified using the ER approach together with the conduct of a sensitivity analysis. For the purpose of maintaining and improving the quality of the RCOs once implemented, the Six Sigma technique is employed. This provides a positive starting point for the port industry to consider the quality of its measures and policies resulting from safety regulations based on the scientific and quantitative methods. Finally, there are five technical chapters presented in this PhD study, namely, risk assessment of port security using fuzzy modelling, risk prediction of port marine safety using fuzzy ANN, human error assessment using fuzzy AHP, multi-attribute decision making using ER and quality assurance in ports using Six Sigma. Each chapter provides its research methodology, which is subsequently demonstrated by its corresponding test case. The objective of this PhD research is to establish a platform of risk assessment and safety management consisting of various frameworks addressing port safety and security without jeopardising the efficiency of port operations under circumstances where the lack or incompleteness of data exists or a high level of uncertainty is presented.

Chapter 3. Risk Assessment of Port Security using Fuzzy Modelling

A security assessment is considered as a difficult mission because of the characteristically unpredictable outcomes associated with high consequences. However, due to the confidentiality of the intelligence with regard to terrorism and the difficulty of the information accession, the data available for conducting security risk assessment is scarce for most researchers. In this chapter, a security risk assessment framework using fuzzy set theory is proposed. The security risk can be modelled and a risk ranking can be obtained based on the concept of Failure Mode, Effects and Criticality Analysis (FMECA) using a fuzzy rule base method. The model presented in this study is based on the assumption that the elements of criticality at each port facility, and of the vulnerability of the security measures associated, are more important than the elements of probability of occurrence of the threat associated and its severity. This is because the criticality determines the relative importance of each asset and vulnerability is the only factor that can be fully under control of the port authority. The outcome of the study will be a security risk ranking based on the risk level of each scenario obtained.

3.1 Introduction

Since the terrorist attack in the U.S. on 11st September 2001, even greater heed has been paid to matters relating to maritime security. In December 2002, the International Maritime Organization (IMO) adopted the International Ship and Port Facility Security (ISPS) Code, which came into force on 1 July 2004. The Code is based on the concept of risk assessment, with the prime purpose of ensuring that the international trade, as conducted by the shipping industry, could be safely expedited without undue threat or fear from terrorists or any other intentional criminal activity. Such an assessment is basically a risk analysis of all operational aspects of a port in order to determine which facilities in the port area are more susceptible and more likely to be the target of attack. It treats the security risk as identical to others caused by either natural hazards or human errors. When developing a port security assessment model, four elements are introduced, namely; the criticality of each asset (C), the probability of occurrence of each threat against a specific asset or target (P), the severity of each adverse attack against that specific asset (S) and the vulnerability of each asset or facility (V). **C** is defined as the relative importance of each facility, taking into account its function, location, costs and allowable time for returning operational. **P** would be a measure of the likelihood that a specific type of attack will be initiated against a specific target. **S** is either the amount of expected loss or damage, or it is the negative effects in the shipping industry should the attack be successful. **V** would be the likelihood that various types of safeguard measures against a scenario would fail [Ung *et al.*, 2004]. According to literature security risk could be regarded as a function of the threat of an attack associated with the vulnerability of the object under consideration and the consequences caused by such an attack [Burn-Howell *et al.*, 2003]. However, such a combination may not genuinely reflect the risk results because of the absence of the consideration as to the relative importance of each asset. Therefore, in this study the criticality element has been incorporated into the security risk model. In the model, a **scenario** is defined as a specific type of attack that would be initiated against a specific target. Therefore, when assessing a scenario the four elements aforementioned will be taken into account. However, due to the confidentiality of the intelligence with regard to terrorism and difficulty of the information accession, the data available for conducting a security risk assessment is scarce for most researchers as aforementioned. Thus, the security risk in this study is evaluated using FMECA based on fuzzy theory. The outcome for this study is a risk ranking for all scenarios based on the results obtained.

3.2 Background

3.2.1 Fuzzy set theory

Fuzzy set theory, formalised in 1965, has been widely applied in different fields. Its use in system safety and reliability analysis could prove to be useful since such an analysis often requires the use of subjective judgement and uncertain data. The use of linguistic variables provides flexible modelling of imprecise data and information. A linguistic variable differs from a numerical variable in that its values are not numerals but words or sentences in a natural or artificial language. The significance of fuzzy variables is that they facilitate gradual transition between states and therefore are able to deal with the observation and measurement of uncertainties. On the other hand, traditional variables, which may be referred to as crisp variables, do not have such a capability. Although the definition of states by crisp sets is mathematically correct, in many cases it may be regarded as unrealistic in the face of unavoidable measurement errors. When dealing with the safety of a system using fuzzy set theory, the parameters including occurrence likelihood, consequence and probability of failure consequence can be judged and described using linguistic terms and the membership degrees (values) associated. These fuzzy variables can then be synthesised using a fuzzy rule base or some other techniques.

Consider a fuzzy set, A, with points or objects in some relevant universe, X, is defined as the elements of x that satisfy the membership property defined for A. In traditional 'crisp' sets theory, each element of x either is or is not an element of A. Elements in a fuzzy set can have a continuum of degrees of membership ranging from complete membership to complete non-membership [Zadeh, 1987].

Suppose $\mu(x)$ expresses the degree of the membership for each element where $x \in X$ and $\mu(x)$ is defined on [0,1]. A membership of zero means that the value does not belong to the set under consideration. A membership of 1 would mean full representation of the set under consideration. A membership somewhere between these two limits indicates the degree of membership. The manner in which values are assigned to a membership is not fixed and may be established according to the preference of the person conducting the investigation.

Formally a fuzzy set A is represented as the ordered pair $[x, \mu(x)]$:

$$A = \{(x, \mu(x)) \mid x \in X \text{ and } 0 \leq \mu(x) \leq 1\} \quad \text{(Equation 3.1)}$$

The use of a numerical scale for the degree of a membership provides a convenient way to represent gradation in the degree of the membership. Fuzzy sets can be represented by various shapes. They are commonly represented by S-curves, π-curves, triangular curves and linear curves. The shape of a specific fuzzy set depends on the best way to represent the data. In general the membership (often indicated on the vertical axis) starts at 0 (no membership) and continues to 1 (full membership). The domain of a set is indicated along the horizontal axis. The fuzzy set shape defines the relationship between the domain and the membership values of a set.

3.2.2 Failure Mode, Effects and Criticality Analysis

Failure Mode and Effects Analysis (FMEA) was first adopted as a formal design methodology in the 1960s by the aerospace industry seeking to enhance the safety and reliability level [Sankar and Prabju, 2000]. Since then, it has been applied to assure the safety and reliability of products in many industries, mainly including aerospace, automotive, nuclear and medical technologies. In the automotive industry for example, most companies divide FMEA into two processes, design FMEA and process FMEA [Aldridge *et al.*, 1991] [Ford Motor Company, 1988]. Design FMEA is a procedure to ascertain that the right materials are being used to confirm customer specifications, and to ensure that government regulations are being met before finalising the product design. Process FMEA deals with the manufacturing and assembly processes. Several variations of FMEAs have been developed. These include the use of a knowledge based system for the automation of the FMEA process [Price *et al.*, 1992] [Price *et al.*, 1995] [Russomano *et al.*, 1992], and the introduction of a causal reasoning model for FMEA [Bell *et al.*, 1992]. An improved FMEA has also been proposed using a single matrix to model the entire system and a set of indices derived from a probabilistic combination reflecting the importance of an event relating to the indenture under consideration and to the entire system [Kara-Zaitri et *al.*, 1992] [Kara-Zaitri *et al.*, 1991]. Usually, FMEA is applied to evaluate the system behaviour in terms of identifying potential failure modes and their impact on every system component.

FMECA is an extension of FMEA capable of ranking each potential failure mode according to the combined impacts from the parameters such as severity, probability of occurrence and detectability. The criticality assessment of each failure mode is traditionally performed by either calculating its Criticality Number (CN) or developing a Risk Priority Number (RPN). The first method was proposed in U.S. MIL-STD-1629A *Procedures for Performing a Failure Mode, Effects and Criticality Analysis (FMECA)* presenting a well-known criticality assessment methodology based on the calculation of a CN for each system failure mode i. That is, $CN_i = \alpha_i \beta_i \lambda_p t$, where β_i is the failure effect probability, α_i the failure mode ratio, λ_p the failure rate and t the operating time. The procedure includes the determination of β_i, α_i, λ_p, and t and the calculation of the values determined to obtain a CN for each failure mode. However, there are some shortcomings raised when applying the CN calculation method [Bowles and Pelaez, 1995]:

- The CN may be underestimated in that a failure mode has multiple effects in different severity categories since only the severest effect is considered in the calculation.

- The determination of β_i, α_i, λ_p and t is based on qualitative assessment using expert predictions or generic apportionments, making the calculation less precise.

An alternative approach for criticality assessment capable of prioritising failures for corrective actions is based on an RPN [Pillay and Wang, 2003]. When assessing a risk level of a specific failure mode, the RPN method uses linguistic priority terms to rank the elements of probability of occurrence (S_f), severity (S) and detectability (S_d) on a numeric scale from 1 to 10. These rankings are subsequently multiplied to give the RPN, that is, $RPN = S_f \times S \times S_d$. Failure modes with higher RPN are deemed to be more risky and give a higher priority than those having a lower RPN. Tables 3.1, 3.2 and 3.3 show how traditional FMEA employs linguistic priority terms to rank (S_f), (S) and (S_d).

Table 3.1. Traditional FMECA scale for probability of occurrence (S_f)

Criteria	Score	Possible failure occurrence rate (operating days)
Remote	1	< 1/20000
Low	2	1/20000
	3	1/10000
Moderate	4	1/2000
	5	1/1000
	6	1/200
High	7	1/100
	8	1/20
Very High	9	1/10
	10	1/2

Source: [Pillay and Wang, 2003]

Table 3.2. Traditional FMECA scale for severity (S)

Criteria	Score
Remote	1
Low	2, 3
Moderate	4, 5, 6
High	7, 8
Very High	9, 10

Source: [Pillay and Wang, 2003]

Table 3.3. Traditional FMECA scale for detectability (S_d)

Criteria	Score	Possible detection rate (%)
Remote	1	86-100
Low	2	76-85
	3	66-75
Moderate	4	56-65
	5	46-55
	6	36-45
High	7	26-35
	8	16-25
Very High	9	6-15
	10	0-5

Source: [Pillay and Wang, 2003]

However, some criticisms have been raised with regard to the application of the RPN method [Gilchrist, 1993] [Ben- Daya and Raouf, 1996] [Deng, 1989]:

- There is no precise algebraic rule to assign a score to the possible failure occurrence rate and detection rate. Although the application of the traditional FMECA scales for probability of occurrence, severity and detectiability as shown in Tables 3.1, 3.2 and 3.3 simplify the calculation, there can nevertheless be problems. The reason for that is because the relationship between detection rate and its corresponding score is linear, whereas the failure rate and its score do not follow the linear law.

- Although the risk ranking based on the RPN values enables management to allocate the limited resources to the most risky events, there is no rationale in obtaining it as a product of the elements of (S_f), $(S\ )$ and (S_d).

- In situations where various sets of (S_f), $(S\ )$ and (S_d) produce an identical value of RPN, however, the risk implication may be totally different. For example, if considering two different sets of (S_f), $(S\ )$ and (S_d) with values of 1, 4, 6 and 2, 3, 4, respectively, the RPN value of these two sets is identical (24). However, the risk implication is different. When such a circumstance occurs, a misjudgement could take place, consequently, the more risky event would become unnoticed.

- The RPN value does not consider the relative importance between (S_f), $(S\ )$ and (S_d), that is, these three elements are assumed to have the same importance. However, this may not always be the case and sometimes it is regarded as impractical.

3.2.3 Fuzzy Logic FMECA

In a fuzzy logic based FMECA, linguistic variables such as the probability of occurrence and severity can be represented as members of a fuzzy set, described using linguistic priority terms associated with corresponding membership values (fuzzy inputs) and combined by matching them against rules in a rule base. The input and output membership functions as well as the rules are developed based on expert judgement. The outcome of such a combination is referred to as a set of fuzzy conclusions. By introducing the defuzzification method taking into account the consequent membership functions, the risk level of an event based on the defuzzified value acquired can be realised. If there are many events in question, a list of risk priority of these events will then be developed on the basis of their defuzzified values.

Bowles and Pelaez evaluated a stopper valve on the water tank levelling system illustrates the idea well [Bowles and Pelaez, 1995]. The method has also been employed to perform reliability assessment of electronic devices [Zafiropoulos and Dialynas, 2004]. A modified method proposed by Braglia and Bevilacqua outlines how the AHP method may assist the practitioners in establishing the numerousness fuzzy rules [Braglia and Bevilacqua, 2000]. This is because it has several advantages:

- It provides a tool for directly working with the linguistic priority terms used in assessing risks. Thus, fuzzy theory enables analysts to evaluate risks in a natural way.
- Ambiguous, qualitative or imprecise information as well as quantitative data can be used in the assessment and can be handled in a consistent manner.
- It is capable of providing a flexible structure for combining the elements of criticality, probability of occurrence, severity and vulnerability. In other words, these elements can be evaluated taking into account their individual importance.

In addition, the traditional method only allows for three elements in the fuzzy logic FMECA model whereas this study evaluates four. Furthermore, the work presented here demonstrates how a fuzzy rule base can be established as each element has its own degree of importance. Figure 3.1 clearly illustrates the idea of risk assessment using the fuzzy modelling proposed in this research [Ung *et al.*, 2005].

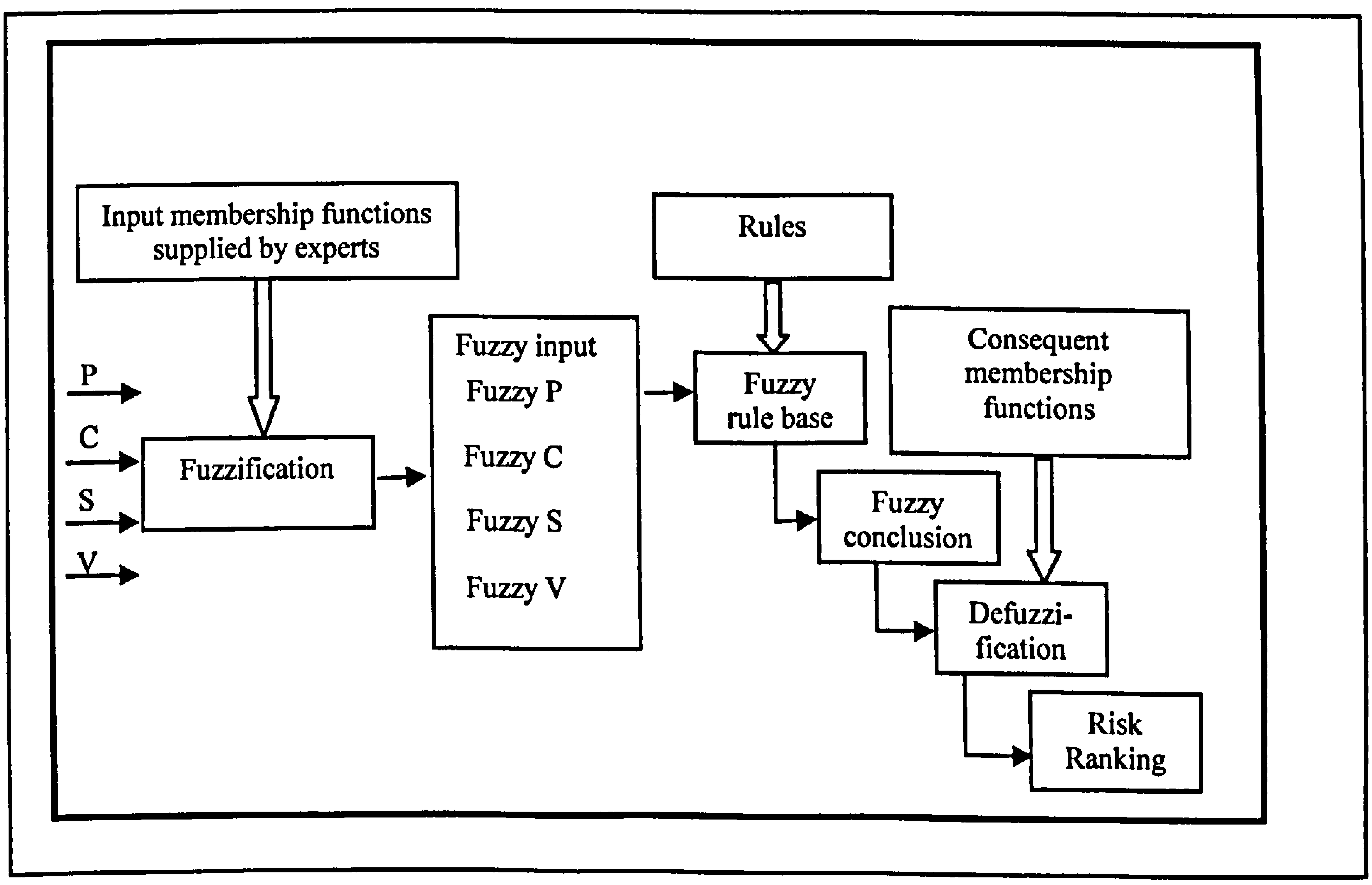

Figure 3.1. The proposed idea of risk assessment using fuzzy modeling [Ung *et al.*, 2005]

3.3 Research methodology

In circumstances where the lack or incompleteness of data exists, there is a need to incorporate expert judgement into the risk study. A framework is established based on fuzzy set theory alone with the fuzzy rule base method since it is capable of quantifying the judgement from experts who express opinions qualitatively. The parameters considered include the elements of C, P, S and V. Five linguistic priority terms describing these four elements are employed, namely, 'Remote', 'Low', 'Moderate', 'High' and 'Very High'. A scenario associated with these four elements will then be established, representing the primary risk characteristics. Each scenario cannot be compared until the following steps are taken. The first step is to establish the membership function for the linguistic priority terms using a triangular distribution based on expert judgements. The values of the membership function associated with the linguistic priority terms of each of these four elements involved in a specific scenario will then be determined. This is followed by the development of a rule base which is also based on expert judgements. An element, namely, Priority Level, comprising an arbitrary value associated with a defined linguistic priority term, will be introduced with respect to the combinations of C, P, S and V. The first three steps are regarded as a fuzzification process expressing how well the input belongs to the linguistic priority terms used in the rules. A defuzzification process will then be adopted by employing appropriate algorithms. A value of the overall risk to a scenario will be obtained. A risk ranking of all scenarios can consequently be produced. Figure 3.2 shows the research methodology [Ung *et al.*, 2005].

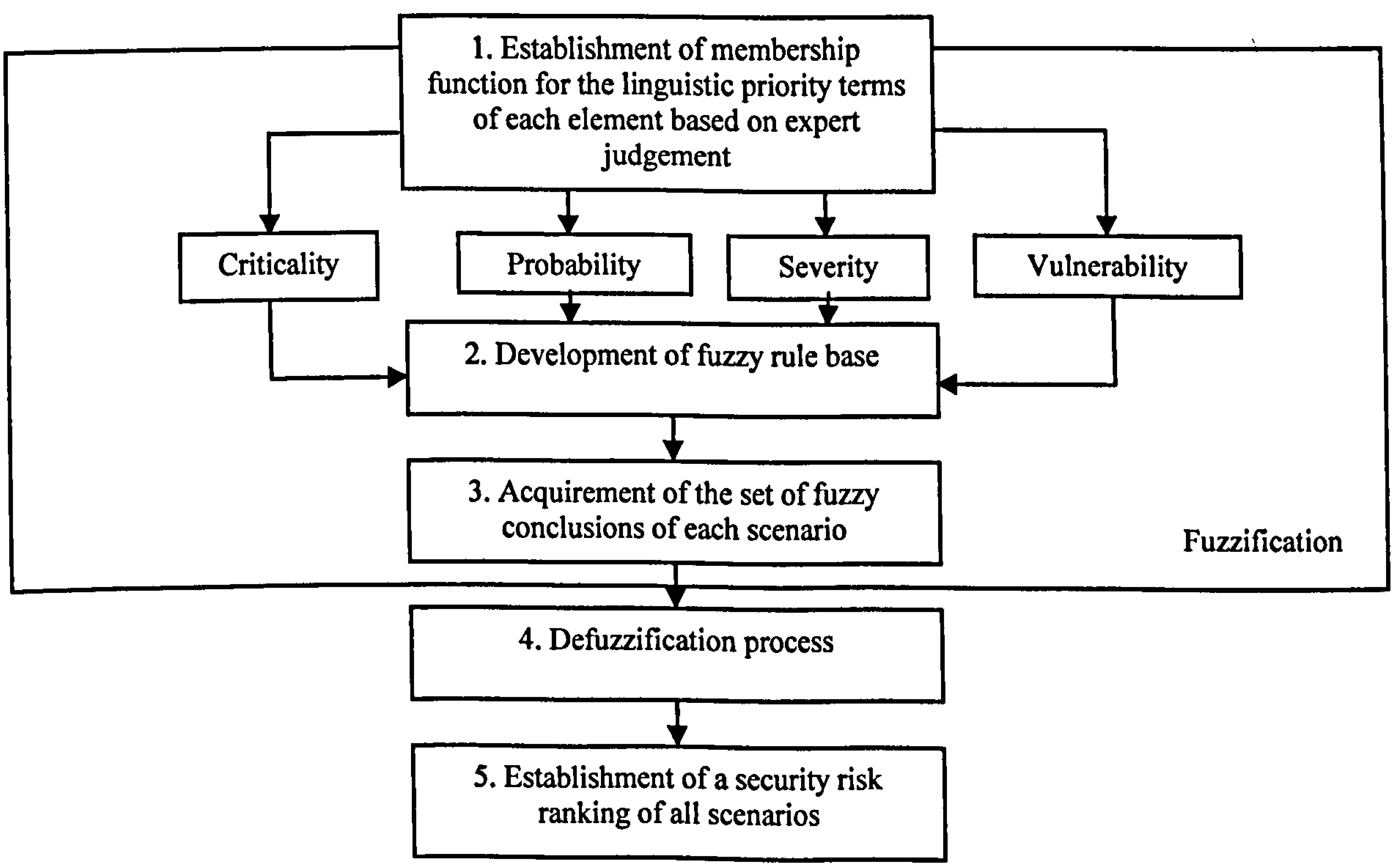

Figure 3.2. The flowchart of the research methodology

3.3.1 Establishment of membership function for linguistic priority terms of each element

The membership function is established for the linguistic priority terms describing the linguistic variables C, P, S and V using multiple experts. The experts involved in a port security project should be appropriately selected in order that an unrealistic and biased membership function will be avoided [Kuusela *et al.*, 1998]. Each expert is asked to evaluate a proposition 'x belongs to A ?'. Suppose A is a fuzzy set on X that represents a linguistic priority term associated with a given linguistic variable and $a_i(x)$ is a value of scores within a certain range in X i.e. $a_i(x) \in$ X (in this study, X follows the same pattern the traditional FMEA adopts, 1-10 categories). In the situation where there are n experts and each of them has equal competence, the following formula is applied [Klir and Yuan, 1995]:

$$\mathrm{A}(x) = \frac{\sum_{i=1}^{n} a_i(x)}{n} \qquad \text{(Equation 3.2)}$$

where $\mathrm{A}(x)$ is the final answer (value) after the judgements made by these n experts are synthesised, and

$a_i(x)$ is the answer (value) given by the i^{th} expert, $i \in n$.

In the case where the experts have different degrees of competencies, Equation 3.2 is modified as:

$$\mathrm{A}(x) = \sum_{i=1}^{n} Comp_i a_i(x) \qquad \text{(Equation 3.3)}$$

where $Comp_i$ is the degree of competency of the i^{th} expert, and

$$\sum_{i=1}^{n} Comp_i = 1 \qquad \text{(Equation 3.4)}$$

It is important to note that the degree of competency for each of the experts should be determined based on his knowledge and experience in risk assessment as well as the port security field.

The triangular membership function is adopted since it has a smooth transition from one linguistic priority term to the other. In addition, it facilitates easy defuzzification of each linguistic priority term. The membership function for each linguistic priority term is evaluated within its limits on an arbitrary scale from 0 to 1.

Prior to the determination of the membership function for C, it is important to conduct a criticality assessment since it is capable of identifying and evaluating significant assets and infrastructure in terms of various factors. The following factors should be taken into account when evaluating the criticality of facilities within port areas:

- The importance of the function of each facility in terms of overall port operations.
- The location of each facility.
- The allowable time for returning the facility to operational capability if attacked [U.S. Department of Veteran Affairs, 2002].
- The costs of permanent replacement and temporary substitute as well as the loss of income in the downtime period [ASIS International Guidelines Commission, 2003].

Traditional risk assessment techniques evaluating the element of likelihood of occurrence is often based on failure rates obtained from daily operations. When assessing the likelihood of occurrence of potential threats in port security, however, there is usually no such data available. It may only be possible to rely on complicated factors such as politics, intelligence, the capability, intention and past activities of potential criminal organisations etc. to determine the likelihood of occurrence level using linguistic priority terms. Additionally, the level of severity would depend upon the extent to which the negative effects impose on the port operations once an attack or intentional crime was initiated. The criteria of evaluating such effects may include the number of injuries and fatalities as well as the damage to the facility.

A vulnerability assessment is a process that obtains the probability of the weaknesses identified in physical structures, personnel protection systems, the security processes aimed at the surveillance of the passage of cargoes and personnel and some other measures designed to prevent attacks that may be exploited by terrorists or criminals. By conducting drills periodically, the data available for the vulnerability assessment can be collected and analysed. In general such an assessment is performed by teams of experts specialising in engineering, intelligence, security, etc..

Thus, the first step of the methodology is strongly concerned with the application of braining-storming techniques conducted by trained and experienced personnel to determine the hazards. Therefore, it is often a qualitative exercise strongly based on expert judgement. The techniques which could be employed in this step include Hazard and Operability Studies (HAZOP), Preliminary Hazard Analysis (PHA), FMECA, What-If Analysis, Checklist Analysis, Structured What-If Checklist Technique (SWIFT), Cause-Consequence Analysis, Boolean Representation Method, Simulation Analysis etc. [Henley and Kumamoto, 1992] [Villemeur, 1992] [Smith, 1993] [Wang *et al.*, 1995].

In addition, as stated earlier, five linguistic priority terms are employed to describe the linguistic variables of each scenario, whose interpretations are given in Tables 3.4, 3.5, 3.6 and 3.7.

It is worthwhile noting that the more quantified the data supporting the criteria adopted in each of these four elements is, the more precise the acquired outcome will be. The output of this step is that each element of a scenario has at least one membership degree associated with one linguistic priority term.

Table 3.4. The interpretation of the linguistic priority terms for criticality

Linguistic priority term	Interpretation
Remote	The importance of the facility is near none. Its location is much further away from the centre where important personnel are located and/or confidential information is stored. Its costs and time for returning to operational capability would be extremely low if attacked.
Low	The importance of the facility is low. Its location is far away from the centre. Its costs and time for returning to operational capability would be low if attacked.
Moderate	The importance of the facility is moderate. Its location is not far away from the centre. Its costs and time for returning to operational capability would be moderate if attacked.
High	The importance of the facility is high. The location is near the centre. The costs and time for returning to operational capability would be high if attacked.
Very High	The importance of the facility is very high. The location is very near or in the centre. The costs and time for returning to operational capability would be extremely high if attacked.

Table 3.5. The interpretation of the linguistic priority terms for probability of occurrence

Linguistic priority term	Interpretation
Remote	It would be very unlikely for the scenario in question to occur even once in the facility's lifetime.
Low	It would be unlikely for the scenario in question to occur once in the facility's lifetime.
Moderate	It would be likely for the scenario in question to occur more than once in the facility's lifetime.
High	It would be very likely for the scenario in question to occur at least once in the facility's lifetime.
Very High	It would be almost certain for the scenario in question to occur several times in the facility's lifetime.

Table 3.6. The interpretation of the linguistic priority terms for severity

Linguistic priority term	Interpretation
Remote	The scenario in question would have almost no effect on port operations.
Low	The scenario in question would have low effect on port operations, e.g. a few people slightly injured and / or little damage to the facility.
Moderate	The scenario in question would cause moderate effect on port operations, e.g. a limited amount of injuries and a limited amount of damage to the facility.
High	The scenario in question would have high effect on port operations, e.g. a certain amount of injuries and fatalities and serious damage to the facility.
Very High	The scenario in question would have extremely high effect on port operations, e.g. serious injuries and fatalities and complete damage of the facility.

Table 3.7. The interpretation of the linguistic priority terms for vulnerability

Linguistic priority term	Interpretation
Remote	It is extremely unlikely that the security measures designed to prevent the intentional crimes would fail once attacked.
Low	It is unlikely that the safety and security measures designed to prevent the intentional crimes would fail once attacked.
Moderate	It is likely that the safety and security measures designed to prevent the intentional crimes would fail once attacked.
High	It is very likely that the safety and security measures designed to prevent the intentional crimes would fail once attacked.
Very High	The safety and security measures designed to prevent the intentional crimes would definitely fail once attacked.

3.3.2 Development of a fuzzy rule base

Fuzzy rule base systems are constructed from human knowledge in the form of fuzzy IF / THEN rules [Wang, 1997]. A fuzzy IF / THEN rule is an IF / THEN statement in which some words are characterised by continuous membership functions [Pillay and Wang, 2002]. It provides a systematic procedure capable of transforming a knowledge base into non-linear mapping. The first part of an IF / THEN rule is the input variables, including the elements of C, P, S and V. The second part is the consequent describing the risk level based on a value of weight established by experts and a linguistic priority term attached. In this study, the consequence is referred to as Priority Level and five linguistic priority terms are introduced to interpret it, namely, Minor, Low, Moderate, Significant and Very Significant.

A fuzzy rule base is developed in the fashion where the selected experts are asked to group the various combinations of linguistic priority terms describing C, P, S and V of each scenario into a consequent described by one of the five linguistic priority terms reflecting the Priority Level. Since there are four elements associated with five linguistic priority terms, the total number of the rules is 625. When developing the rule base in this study, it is decided to put more weight onto the elements of criticality and vulnerability i.e. 0.3 each for C and V and 0.2 each for P and S. This is due to the fact that the criticality determines the relative importance of each asset whereas the vulnerability is the only element that the administration can fully control when encountering intentional crimes. It is noted that the purpose for assigning the weights to each parameter in this test case is to demonstrate that the rule base established is capable of taking into account different importance of parameters and the values of the weight for each parameter may vary depending upon the assumption made. The consequent (the column of Priority Level) is determined by the five linguistic priority terms (Minor, Low, Moderate, Significant and Very Significant) and an arbitrary value based on the combination of the weights assigned and the level of each linguistic priority term describing the four parameters. The membership function for the linguistic terms depicting the Priority Level of each rule developed can be determined by applying Equations 3.3 and 3.4. The procedure to determine a Priority Level is indicated below:

If Criticality is Remote, Probability of Occurrence is Remote, Severity is Remote and Vulnerability is Remote, then the Priority Level is Minor (1). The value of 1 is determined by the summation of the product of the individual weight assigned (that is, Criticality = 0.3, Probability of Occurrence = 0.2, Severity = 0.2 and Vulnerability = 0.3) and the level of each linguistic priority term describing these four elements (Remote = Level 1, Low = Level 2, Moderate = Level 3, High = Level 4 and Very High = Level 5). The value of threshold of each linguistic priority term describing Priority Levels is set up to be 1 (that is, Minor = 1, Low = 2, Moderate = 3, Significant = 4 and Very Significant = 5). If Criticality is Remote, Probability of Occurrence is Remote, Severity is Low and Vulnerability is Remote, for instance, the summation of the product based on the individual weight assigned and the level of the linguistic terms describing the security parameters is 1.2 ($0.3 \times 1 + 0.2 \times 1 + 0.2 \times 2 + 0.3 \times 1$). Therefore, the linguistic priority term and its associated value adopted to describe the Priority Level is Low (0.2).

Thus, the fuzzy rule base to be developed in this study takes the relative importance of each linguistic variable into consideration and this is a distinguishing feature from traditional rule base methods.

3.3.3 Acquirement of the set of fuzzy conclusions of each scenario

The Priority Level of a specific scenario will be decided on the basis of the fuzzy rule base developed. Using the 'min-max' approach, a set of fuzzy conclusions for each scenario will be obtained. When applying the 'min-max' approach, the following steps are taken:

i. Identify the possible combinations of C, P, S and V in which the membership values associated with the corresponding linguistic priority terms are not zero. The outputs of such combinations can be obtained from the fuzzy rule base developed.

ii. Determine the minimum value of each combination (rule) by comparing the values obtained from each element and the value of summation of the product based on the individual weights assigned and the level of the linguistic terms describing the security parameters established in the Priority Level.

iii. Determine the highest minimum values obtained from the last step with respect to each linguistic priority term.

If there is only one rule that can be applied to the scenario in question, then the minimum value of the combination and the linguistic priority term associated describing the Priority Level will be the set of fuzzy conclusions. In the above, each maximum value and its associated linguistic priority term is a fuzzy conclusion, each set of fuzzy conclusions of each scenario will be defuzzified using the method proposed in the next section.

In general fuzzy set manipulation rules are applied to process the fuzzy information at the same level and to conduct synthesis between different levels. However, the use of fuzzy set manipulation rules cannot avoid the loss of useful information in a hierarchical synthesis process. It is noted that in this study, the number of the hierarchy is only two. That is, the bottom level containing the parameters of C, P, S and V and the top level consisting of the overall security risk. Thus, the loss of useful information can be restricted to a certain level. Accordingly, the overall results to be obtained can still express the risk levels with confidence.

3.3.4 Defuzzification process

The defuzzification process is capable of createing a single crisp value based on the fuzzy conclusion set describing the Priority Level of scenarios to express the inherent security risk. Several defuzzification algorithms have been developed [Runkler and Glesner, 1993]. The one selected for use in this study is the Weighted Mean of Maximums (WMoM). The algorithm averages the points of maximum possibility of each Priority Level of scenarios, weighted by the degree of truth at which the membership functions reach their maximum values [Pillay and Wang, 2002] [Andrew and Moss, 2002]. The formula of WMoM is as follows:

$$WMoM = \frac{\sum w_i x_i}{\sum w_i} \qquad \text{(Equation 3.5)}$$

where w_i is the degree of truth of the membership function of the i^{th} linguistic priority term, and

x_i is the risk rank at maximum value of the membership function of the i^{th} linguistic priority term.

3.3.5 Establishment of a security risk ranking for all scenarios

It is in this step that the security risk ranking of all scenarios will be presented. Based on the results obtained from the defuzzification process, the scenarios with relatively higher risks will be identified. The higher the defuzzified values the scenarios have, the more the attention that should be paid.

3.4 Test case

The aim of this study is to demonstrate how the methodology can be applied to port security. A difficulty exists however in that data is difficult to acquire and thus, the data in this research is obtained based on expert judgement. In real world case studies, however, such data should be evaluated by the experts specialising in risk assessment and port security operations.

3.4.1 Establishment of the membership functions for linguistic priority terms of C, P, S and V

As described in Section 3.3, five linguistic priority terms are introduced for modelling C, P, S and V, namely, Remote, Low, Moderate, High and Very High. Using Equations 3.3 and 3.4 provided that the weight of each expert is given, the values capable of fully representing each linguistic priority term (that is, the limits where the membership function reaches 1 or becomes 0) can be determined. The value ($\mathrm{A}(x)$) that fully represents the linguistic priority term when the membership function reaches 1, e.g. Remote, can be obtained as follows (provided that there are five experts with the weights of 0.3, 0.3, 0.2, 0.1 and 0.1, associated with their individual answers as to the value that can fully describe the linguistic term, Remote, when the membership function reaches 1, which are 1.5, 1.5, 1, 2, and 2, respectively):

$$\mathrm{A}(x) = \sum_{i=1}^{n} C_i a_i(x) = 0.3 \cdot 1.5 + 0.3 \cdot 1.5 + 0.2 \cdot 1 + 0.1 \cdot 2 + 0.1 \cdot 2 = 1.5$$

The values of two limits of the linguistic priority term, "Remote", as the membership function reaches 0, can also be calculated using the pattern illustrated above. Figure 3.3 illustrates the membership functions established in this test case for the five linguistic priority terms depicting the parameters of C, P, S and V based on expert judgements. In the real world, the establishment of membership functions and determination of the linguistic priority terms and its associated membership depend upon the data collected if possible and the factors already stated in the section 3.3.1.

3.4.2 Development of a fuzzy rule base

As stated in the previous subsection, since there are four linguistic variables and each has been assigned five linguistic priority terms, the number of fuzzy rules developed is 625 $(5 \times 5 \times 5 \times 5)$. As already described in the research methodology section, due to the fact that the criticality and vulnerability assessments are the internal factors that can be fully controlled by the administration, the weight assigned to each is 0.3, which is higher than the other two, 0.2. The consequent (the column of Priority Level) is determined by five linguistic priority terms (Minor, Low, Moderate, Significant and Very Significant) and an arbitrary value based on the combination of the weights assigned and the level of each linguistic priority term describing the four elements. By applying Equations 3.3 and 3.4, the membership functions of the linguistic terms depicting the Priority Level of each rule developed can be obtained as shown in Figure 3.4. Also by applying the procedure described in section 3.3.2, a fuzzy rule base is developed. Appendix 1 shows the fuzzy rule base developed for this test case that is capable of taking the relative importance of each parameter into consideration, possessing such a distinguishing feature from traditional rule base methods.

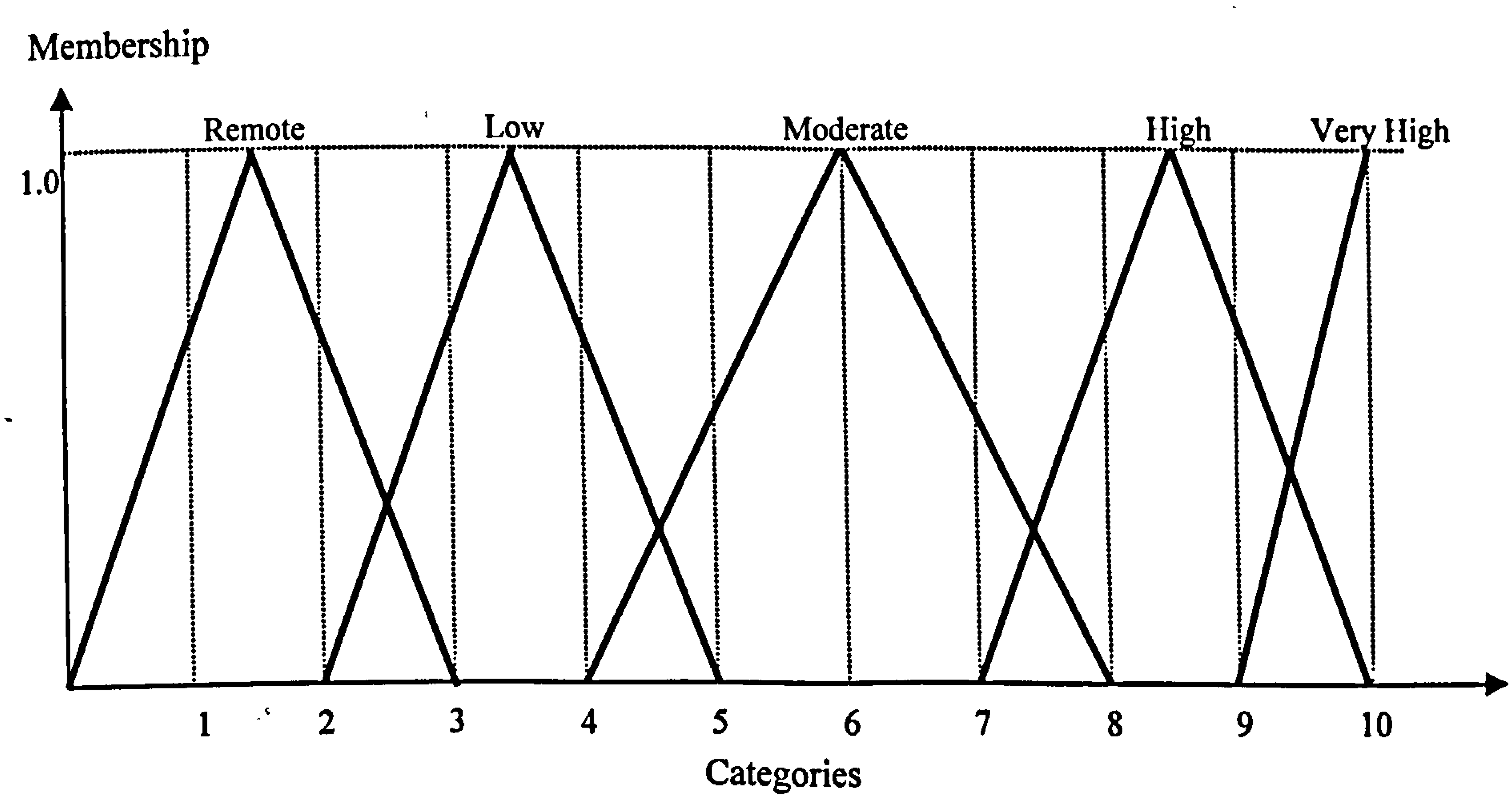

Figure 3.3. Membership function for linguistic priority terms reflecting C, P, S and V

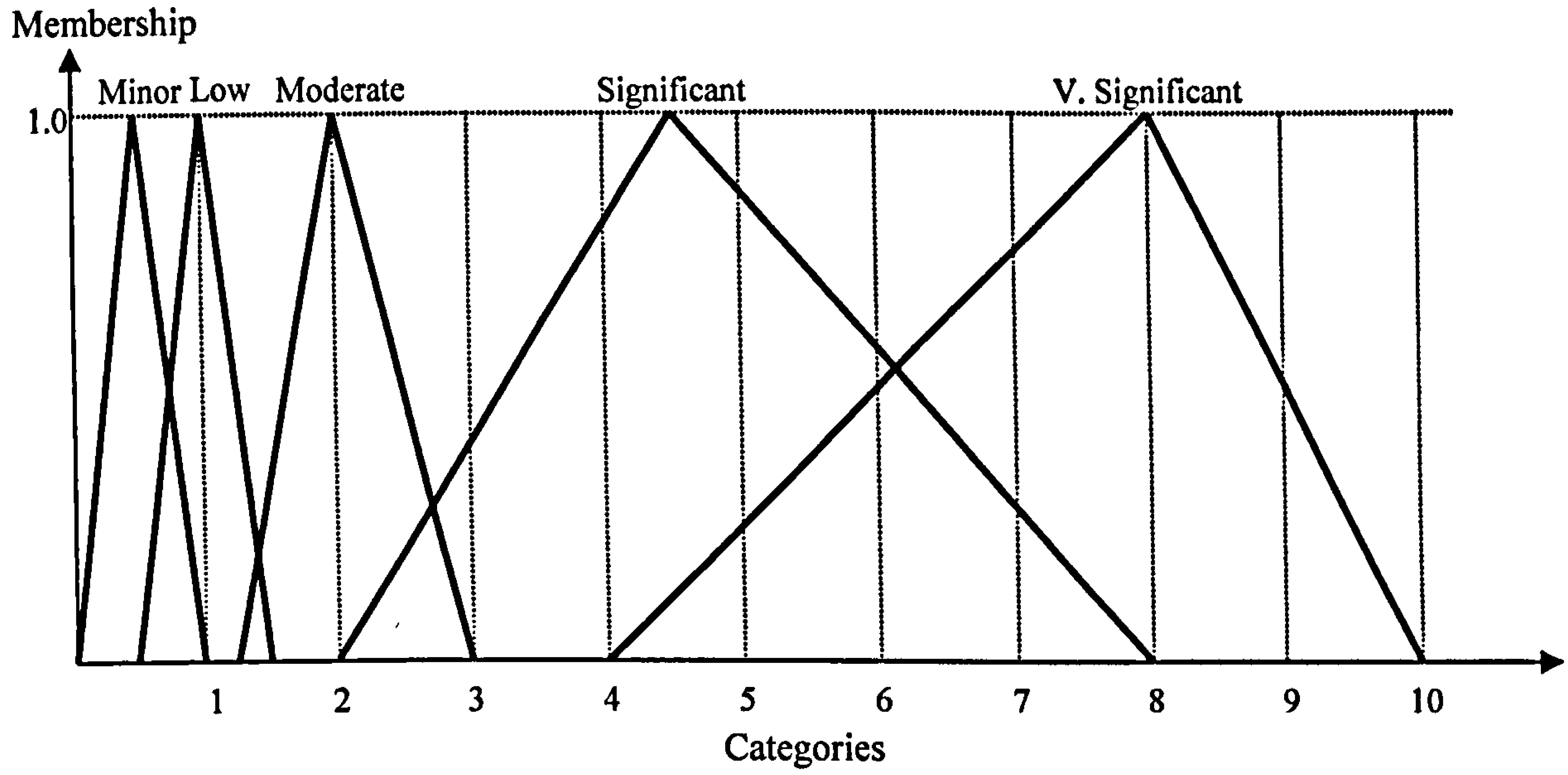

Figure 3.4. Membership function for linguistic priority terms describing the fuzzy rule base

3.4.3 Determination of risk levels for C, P, S and V of each scenario and the acquirement of its fuzzy conclusion

In order to obtain a security risk ranking, two steps are required. First, the linguistic priority terms and the membership values associated reflecting the risk levels for C, P, S and V of each scenario should be carefully decided. Secondly, the fuzzy set conclusion of each scenario will be obtained based on the fuzzy rule base using the 'min-max' approach. Since the purpose of this research is to demonstrate how the security risk can be modelled, in the first step a test case containing 10 scenarios is established. Suppose the risk category of the criticality of scenario 1 falls within categories 7 and 8, 7.3, for example, the level for C from a specific scenario is described as Moderate 0.38 and High 0.18 as shown in Figure 3.5.

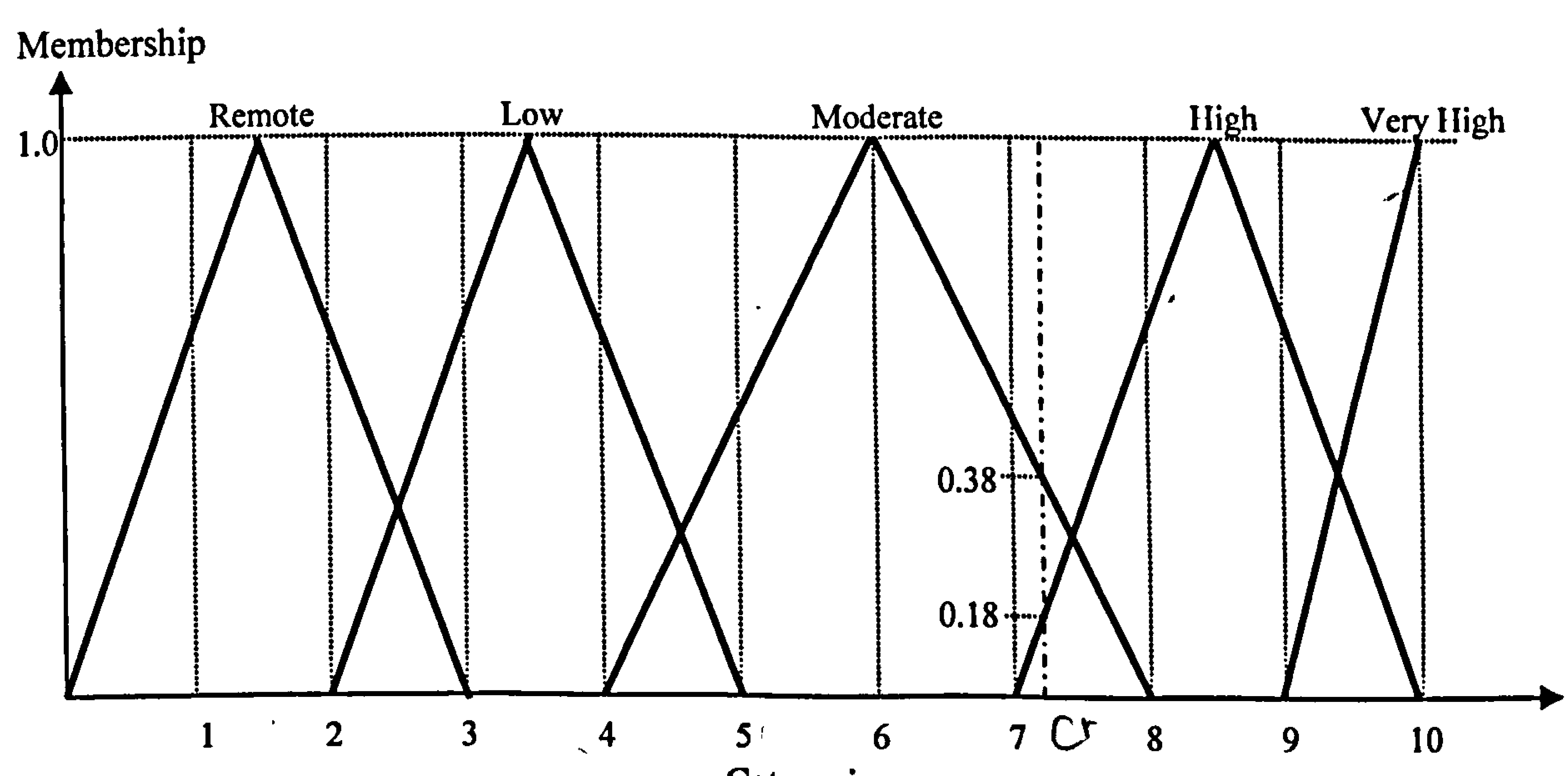

Figure 3.5. The Determination of Membership Function for the Criticality

In a similar way, the descriptions of C, P, S and V for all scenarios can be produced as described in Table 3.8.

Table 3.8. The levels of C, P, S and V of each Scenario

Scenario No.	Criticality	Probability of Occurrence	Severity	Vulnerability
1	Moderate 0.38, High 0.18	Low 0.42, Moderate 0.14	Very High 0.8, High 0.1	High 0.41, Moderate 0.17
2	Remote 0.5	High 0.6, Very High 0.1	Moderate 0.7	High 0.55, Moderate 0.09
3	Very High 0.4, High 0.4	High 0.4, Moderate 0.18	Moderate 0.5	Very High 0.52, High 0.29
4	Moderate 1	Low 0.28, Moderate 0.28	High 0.65	Very High 0.9, High 0.05
5	Very High 0.9, High 0.05	Low 0.39, Moderate 0.19	Moderate 0.39, Low 0.12	Very High 0.81, High 0.12
6	Low 0.39, Moderate 0.19	Very High 0.805, High 0.12	Very High 0.9, High 0.05	Moderate 0.39, Low 0.12
7	Low 0.5, Remote 0.17	Low 0.31, Remote 0.31	Moderate 0.44, Low 0.08	Remote 1
8	Moderate 0.38, High 0.18	High 0.65	Low 0.39, Moderate 0.19	Moderate 0.7
9	Low 0.42, Moderate 0.14	High 0.6, Very High 0.1	High 0.4, Moderate 0.18	Low 0.28, Moderate 0.28
10	Very High 0.9, High 0.05	Remote 0.5	Remote 0.5	Very High 0.81, High 0.12

By applying the 'min-max' approach, the set of fuzzy conclusions of Scenario 1 is obtained as follows:

i. List the membership function values according to the rules developed.

(1) If C = Moderate 0.38, P = Low 0.42, S = Very High 0.8 and V = High 0.41, then the Priority Level is Significant 0.5.

(2) If C = High 0.18, P = Low 0.42, S = Very High 0.8 and V = High 0.41, then the Priority Level is Significant 0.8.

(3) If C = Moderate 0.38, P = Moderate 0.14, S = Very High 0.8 and V = High 0.41, then the Priority Level is Significant 0.7.
(4) If C = High 0.18, P = Moderate 0.14, S = Very High 0.8 and V = High 0.41, then the Priority Level is Significant 1.
(5) If C = Moderate 0.38, P = Low 0.42, S = Moderate 0.1 and V = High 0.41, then the Priority Level is Significant 0.1.
(6) If C = High 0.18, P = Low 0.42, S = Moderate 0.1 and V = High 0.41, then the Priority Level is Significant 0.4.
(7) If C = Moderate 0.38, P = Moderate 0.14, S = Moderate 0.1 and V = High 0.41, then the Priority Level is Significant 0.3.
(8) If C = High 0.18, P = Moderate 0.14, S = Moderate 0.1 and V = High 0.41, then the Priority Level is Significant 0.6.
(9) If C = Moderate 0.38, P = Low 0.42, S = Very High 0.8 and V = Moderate 0.17, then the Priority Level is Significant 0.2.
(10) If C = High 0.18, P = Low 0.42, S = Very High 0.8 and V = Moderate 0.17, then the Priority Level is Significant 0.5.
(11) If C = Moderate 0.38, P = Moderate 0.14, S = Very High 0.8 and V = Moderate 0.17, then the Priority Level is Significant 0.4.
(12) If C = High 0.18, P = Moderate 0.14, S = Very High 0.8 and V = Moderate 0.17, then the Priority Level is Significant 0.7.
(13) If C = Moderate 0.38, P = Low 0.42, S = Moderate 0.1 and V = Moderate 0.17, then the Priority Level is Moderate 0.8.
(14) If C = High 0.18, P = Low 0.42, S = Moderate 0.1 and V = Moderate 0.17, then the Priority Level is Significant 0.1.
(15) If C = Moderate 0.38, P = Moderate 0.14, S = Moderate 0.1 and V = Moderate 0.17, then the Priority Level is Moderate 1.
(16) If C = High 0.18, P = Moderate 0.14, S = Moderate 0.1 and V = Moderate 0.17, then the Priority Level is Significant 0.3.

ii. Determine the minimum value of each combination in terms of comparing the values obtained from each element and the value of the product based on the individual weight assigned and the level of the linguistic terms describing the security parameters established in the Priority Level.

In the first combination, C = Moderate 0.38, P = Low 0.42, S = Very High 0.8 and V = High 0.41 and the Priority Level is Significant 0.5. Therefore, the minimum value of C, P, S and V is 0.38, which is associated with the linguistic priority term Significant according to the fuzzy rule developed. The minimum values of the other 15 combinations can be determined in a similar way as shown in Table 3.9.

Table 3. 9. The minimum value of each combination

1	Significant 0.38	2	Significant 0.18	3	Significant 0.14	4	Significant 0.14
5	Significant 0.1	6	Significant 0.1	7	Significant 0.1	8	Significant 0.1
9	Significant 0.17	10	Significant 0.17	11	Significant 0.14	12	Significant 0.14
13	Moderate 0.1	14	Significant 0.1	15	Moderate 0.1	16	Significant 0.1

iii. Determine the maximum value of the minimum values obtained from the last step that has the same category of linguistic priority term.

In the first scenario, there are 16 combinations and two different categories of linguistic priority terms, Moderate and Significant. The membership values in the Significant category are 0.38, 0.18, 0.14, 0.1 and 0.17, respectively. Therefore, the maximum membership value is 0.38 as shown in Table 3.10. Likewise, the values in the Moderate group are 0.1 in the 13th combination and the 15th combination. Thus, the maximum membership value in the Moderate category is 0.1. The sets of fuzzy conclusions of the other 9 scenarios can be obtained in a similar way, which will be defuzzified in the next section. Table 3.11 shows the set of fuzzy conclusions of the 10 scenarios.

Table 3.10. The maximum value associated with the same category of linguistic priority terms

Category of linguistic priority terms	Maximum values
Moderate	0.1
Significant	0.38

Table 3.11. The sets of fuzzy conclusions of the 10 scenarios

Scenario No.	The set of fuzzy conclusions
1	Moderate 0.1, Significant 0.38
2	Moderate 0.5, Significant 0.1
3	Significant 0.29, High 0.4
4	Significant 0.28
5	Significant 0.39, High 0.19
6	Moderate 0.12, Significant 0.39
7	Fairly Low 0.31
8	Moderate 0.38, Significant 0.19
9	Moderate 0.28, Significant 0.14
10	Moderate 0.05, Significant 0.4

3.4.4 Defuzzification process

By applying Equation 3.5 in the defuzzification process, taking into account the risk ranks at the maximum value of the membership function as shown in Figure 3.4, the defuzzified value of scenario 1 can be detailed as follows:

$$WMoM = \frac{\sum w_i x_i}{\sum w_i} = \frac{0.1 \cdot 2 + 0.38 \cdot 4.5}{0.1 + 0.38} \cong 3.98$$

In a similar way, the defuzzified values of all scenarios are obtained as shown in Table 3.12. The scenarios with higher defuzzified values are considered to be more risky.

Table 3.12. The defuzzified values of the 10 scenarios

Scenario No.	Defuzzified Values
1	3.98
2	2.42
3	6.53
4	4.5
5	5.65
6	3.91
7	1.0
8	2.83
9	2.83
10	4.22

3.4.5 Establishment of a security risk ranking for all scenarios

The security risk ranking of all scenarios can be determined based on the defuzzified values calculated. Table 3.13 shows the ranking based on the risk results acquired.

Table 3.13. The security risk ranking of the 10 scenarios

Scenario No.	Security risk ranking (associated with defuzzified vales)
1	5 (*3.98*)
2	8 (*2.42*)
3	1 (*6.53*)
4	3 (*4.5*)
5	2 (*5.65*)
6	6 (*3.91*)
7	9 (*1.0*)
8	7 (*2.83*)
9	7 (*2.83*)
10	4 (*4.22*)

It can be seen from Tables 3.8 and 3.13 that the scenarios in which the parameters described by more negative linguistic terms have higher risks than those depicted by more positive terms. This is consistent with the human-being common sense. Furthermore, the difference of the risk level between these scenarios can be appreciated. It can also be seen from Table 3.13 that the first five scenarios with higher security risks are Scenarios 3, 5, 4, 10 and 1, respectively. This is because their corresponding defuzzified values are higher than the rest, which are 6.53, 5.65, 4.5, 4.22 and 3.98, respectively. These scenarios are the ones that need to deserve more attention and appropriate RCOs should be devised and employed to reduce the risks.

3.5 Conclusion

The security assessment is usually difficult to model since its characteristic has been regarded as an unpredictable likelihood but with a high consequence. In this chapter, port security is evaluated based on the concept of risk assessment using fuzzy modelling, illustrating a different thinking of assessing security. Within the FMECA framework, the risk level of each scenario can be appreciated. Based on the results obtained from the defuzzification process, the scenarios with relatively higher risks can be identified. The higher defuzzified values the scenarios have, the more the attention that should be paid. Thus, security measures aimed at reducing security risks will be able to be identified based on the ranking acquired. In addition, although the model proposed in this study is capable of dealing with the security risk in ports when there is not much precise information in hand based on the partial validation conducted in section 3.4.5, the quantification of the data compiled and collected from daily operations associated with security by port authority is still recommended. It is noted that although the fuzzy rule base technique applied in this study is capable of modelling and synthesising the fuzzy parameters under consideration in a consistent manner, it has drawbacks. A shortcoming occurs as the technique is applied to circumstances where there are multiple parameters to be evaluated which are described by multiple linguistic terms. If there were five parameters described by five different linguistic variables, for instance, the number of fuzzy rules needed to be developed would be 3,125. Accordingly, the applications of fuzzy set theory with the adoption of a fuzzy rule base would become impractical. Such a drawback can be overcome by incorporating the fuzzy set theory with an Artificial Neural Network (ANN). The framework so proposed is discussed in the next chapter.

Chapter 4. Risk Prediction of Port Marine Safety using Fuzzy Set Theory and Artificial Neural Network

The traditional fuzzy-rule-based risk assessment technique has been applied in many industries due to the capability of combining different parameters to obtain an overall risk. However, a drawback occurs as the technique is applied in circumstances where there are multiple parameters to be evaluated which are described by multiple linguistic terms. In this chapter, a risk prediction model incorporating fuzzy set theory and Artificial Neural Network (ANN) capable of resolving the problem encountered is proposed. An algorithm capable of converting the risk-related parameters and the overall risk level from the fuzzy property to the crisp-valued attribute is also developed. Its application is demonstrated by a test case evaluating the navigational safety within port areas. It is concluded that a risk predicting ANN model is capable of generating reliable results as long as the training data takes into account any potential circumstance that may be met.

4.1 Introduction

Fuzzy set theory has been applied in many fields including that of the maritime industry for decades. One of its great advantages is that it has the ability of representing mathematically a class of decision problems with the involvement of many vague goals and constraints. It is common for risk practitioners to apply the theory in association with the development of a fuzzy rule base. Successful applications of fuzzy set theory in the maritime industry include the combinations of fuzzy set modelling and evidential reasoning assessing the safety associated with and the cost incurred in each option of safety requirements specifications [Wang and Yang, 2001]; the risk assessment of fishing vessels using fuzzy set theory [Pillay and Wang, 2002]; a decision making model using fuzzy set theory and a Dempster-Shafer algorithm based approach dealing with multiple-attribute decision making problems [Sii *et al.*, 2002]; a risk assessment approach based on modified failure mode and effects analysis using a fuzzy rule base [Pillay and Wang, 2003], etc.

However, the applications of fuzzy set theory with the adoption of a fuzzy rule base become impractical as there are multiple parameters to be evaluated which are described by multiple linguistic terms. If there were five parameters described by five different linguistic variables, for example, the number of fuzzy rules needing to be developed would be 3,125. In this study, a risk prediction model incorporating fuzzy set theory and ANN aimed at resolving the problem encountered is proposed due to the strength of such a network in data recognition.

The framework proposed is demonstrated by modelling the navigational safety within a port area by taking into account the crucial factors affecting it. According to a study carried out to investigate the accidents in seaports from the beginning of the twentieth century to October 2002 collected by Major Hazard Incident Data Service (MHIDS) as discussed in Chapter 2, 43.6 % of a total of 471 accidents are caused by an impact of heavy objects or collision between ships or between a ship and dry land, and vehicles [Darbra and Casal, 2004]. Table 2.11 in Chapter 2 summarises the specific causes of accidents in seaports. It can be seen that within the impact category, the causes of 71 % of the accidents are related to a ship and land, or ship and ship collision. In addition, using the same statistics, 56.5% of accidents took place during the transport process [Darbra and Casal, 2004] as shown in Table 2.12. The transport category includes, all accidents that occurred in moving ships (entering or leaving the port), and in lorries or trains entering or leaving port facilities. Therefore, as far as port safety is concerned, navigational safety is an important factor to be considered. The salient parameters playing important roles in navigational safety in the study include the Vessel Traffic Control (VTC) performance, navigation aids and facilities, pilotage performance, sealane maintenance and the weather condition. The first four elements aforementioned are regarded as the specific port safety functions relating to navigation by the experts specialising in ports [Sydney Ports, 2005] whereas the weather condition is the parameter that cannot be managed or controlled by a port.

Fuzzy set theory enables safety analysts to evaluate risks under circumstances where the lack of data exists whereas an ANN has the strength of predicting reliable results based on the quantitative training data prepared. Therefore, for the purpose of incorporating the advantages of these two techniques and allowing for the fact that the data entered into an ANN must be quantitative, an interface between the fuzzy set theory and ANN must be provided. Accordingly, an algorithm capable of converting the risk-related parameters and the overall risk level from the fuzzy property to the crisp-valued attribute is developed. The model will be tested and modified by inputting the testing data until it meets the accuracy criteria established appropriately. Consequently, the model can be utilised as a risk prediction tool facilitating the process of decision making.

4.2 Background

4.2.1 Fuzzy set theory

One of the objectives of fuzzy set theory is to help in making decisions characterised by imprecise information [Zadeh, 1965] [Klir and Folger, 1988] [Predrycz and Gomide, 1998]. The strengths and background of fuzzy set theory is available and can be found in section 3.2.1 of this PhD study.

Frequently fuzzy set theory is applied along with the development of a fuzzy rule base, followed by a defuzzification process to yield an overall risk index. However, as the number of the parameters or objects to be evaluated and the linguistic terms associated increases, such an application becomes, as aforementioned, impractical.

4.2.2 Artificial Neural Network

ANNs can be defined as an interconnected assembly of simple processing elements, neurons or nodes, of which the functionality is based on the human brain neurons [Gurney, 1997]. The processing ability of the network is stored in the interunit connection strengths, or weights that are obtained and adjusted by a learning process from a set of training patterns. A trained ANN is capable of recognising, recalling and comparing non-linear and multidimensional input-output patterns.

Figure 4.1 is a simple neuron illustrating the signal processing ability. It receives the signals from n inputs $(x_1, x_2, ... x_n)$, each of which has its own connection strength $(w_1, w_2, ... w_n)$. The neuron subsequently evaluates the signals by adding the product of each input and the connection strength associated and comparing the summation to its threshold value, θ. The vector calculated is then converted using the transfer function, F. Consequently, the converted value is the output of the neuron. Figure 4.2 shows two examples of transfer functions and each of them determines the value of outputs in different ways.

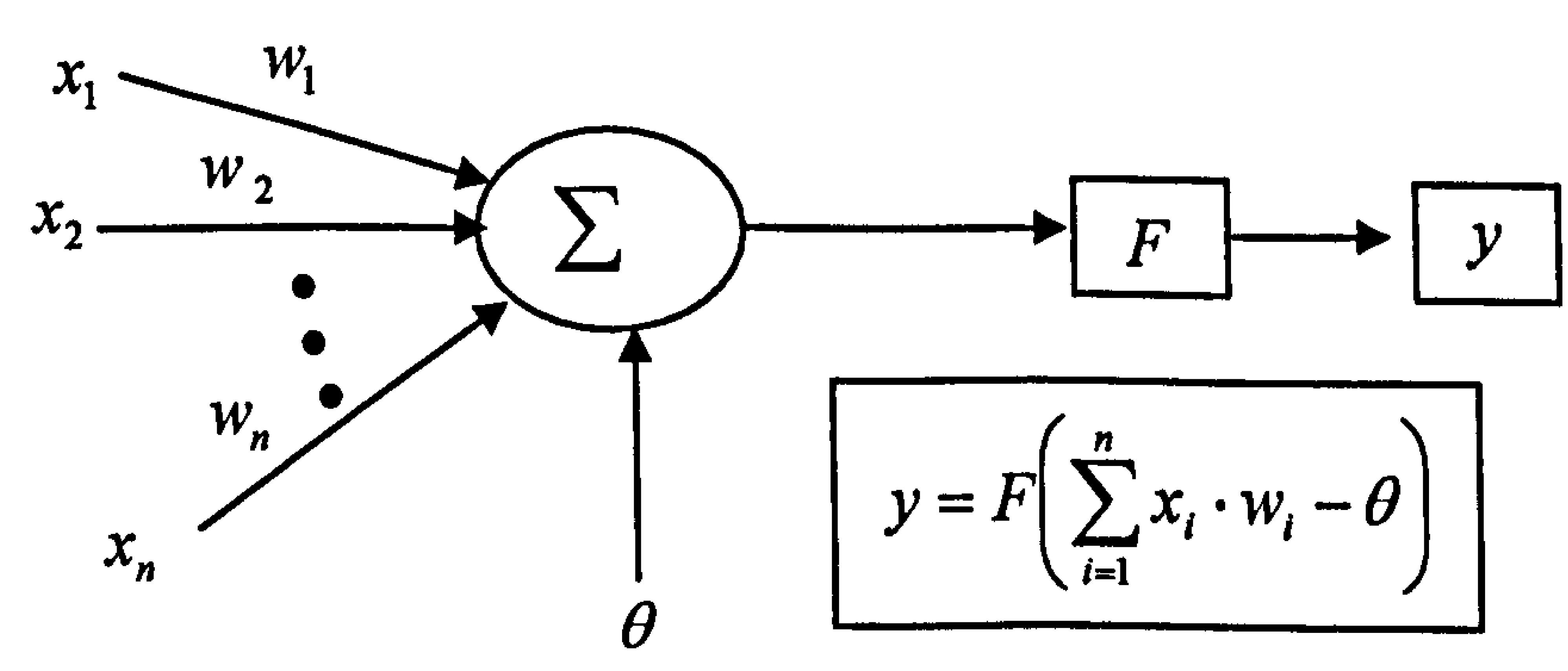

Figure 4.1. The signal processing procedure of a neuron [Gurney, 1997]

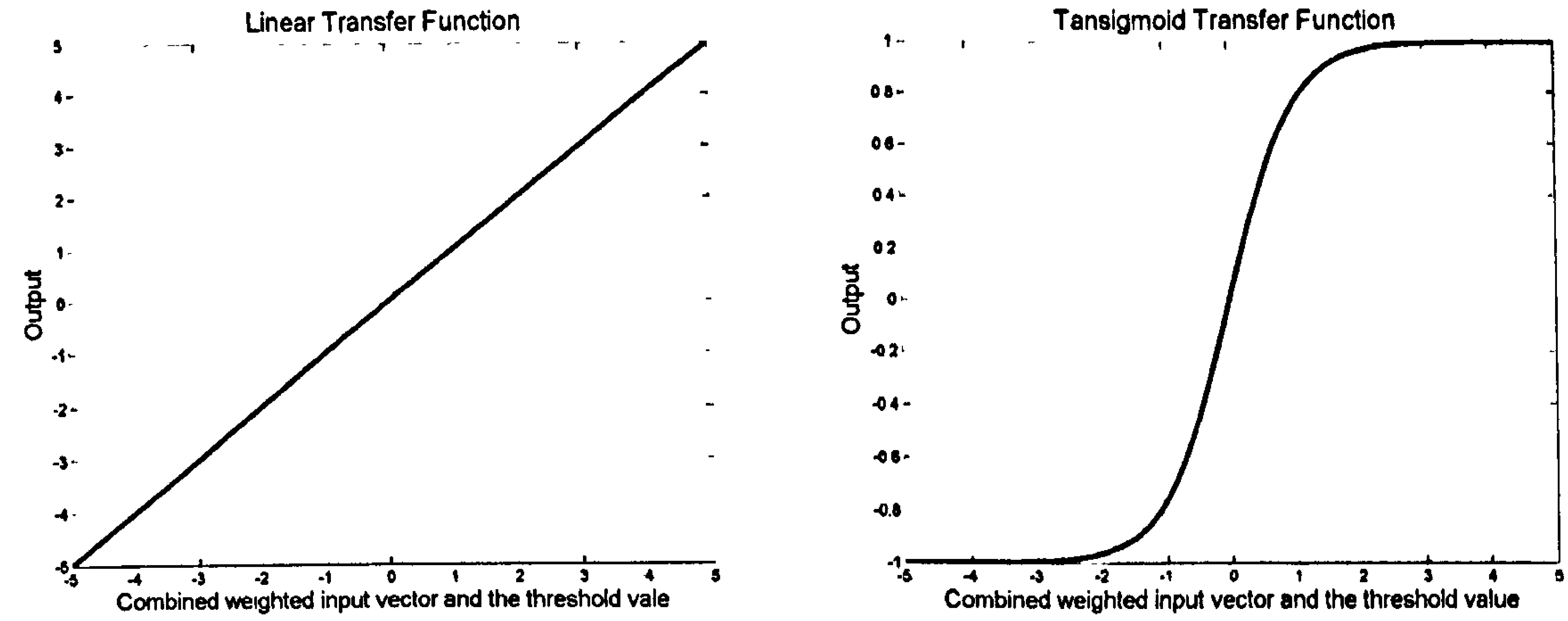

Figure 4.2. The linear and tansigmoid transfer functions [Gurney, 1997]

Figure 4.3 is a two-layer neural network containing two inputs in the input layer, ten neurons in the hidden layer and one output in the output layer. In a supervised training process in which the actual response from output layers is compared with a priori desired output known as the target output [Kartalopoulos, 1996], the goal i.e. the criterion of the error signal, is achieved by adjusting weight vectors. The speed of the training process depends upon an important element, the learning rate. This is because it governs the quantity of the changes to the connection strengths of each neuron. Learning rates between 0.05 to 0.25 are often preferred. The larger the learning rate, the faster the training process. It is noted that a too large learning rate would lead the learning process to become unstable and that it would vary whenever the number of the neurons and layers changes. Therefore, the optimum learning rate should be selected based on experiments. In addition, there are several algorithms capable of assisting ANNs to achieve the goal. The one adopted is the backpropagation algorithm based on the delta rule using the gradient descent technique. The steps of applying such an algorithm associated with the use of the fuzzy set theory are discussed in the next section.

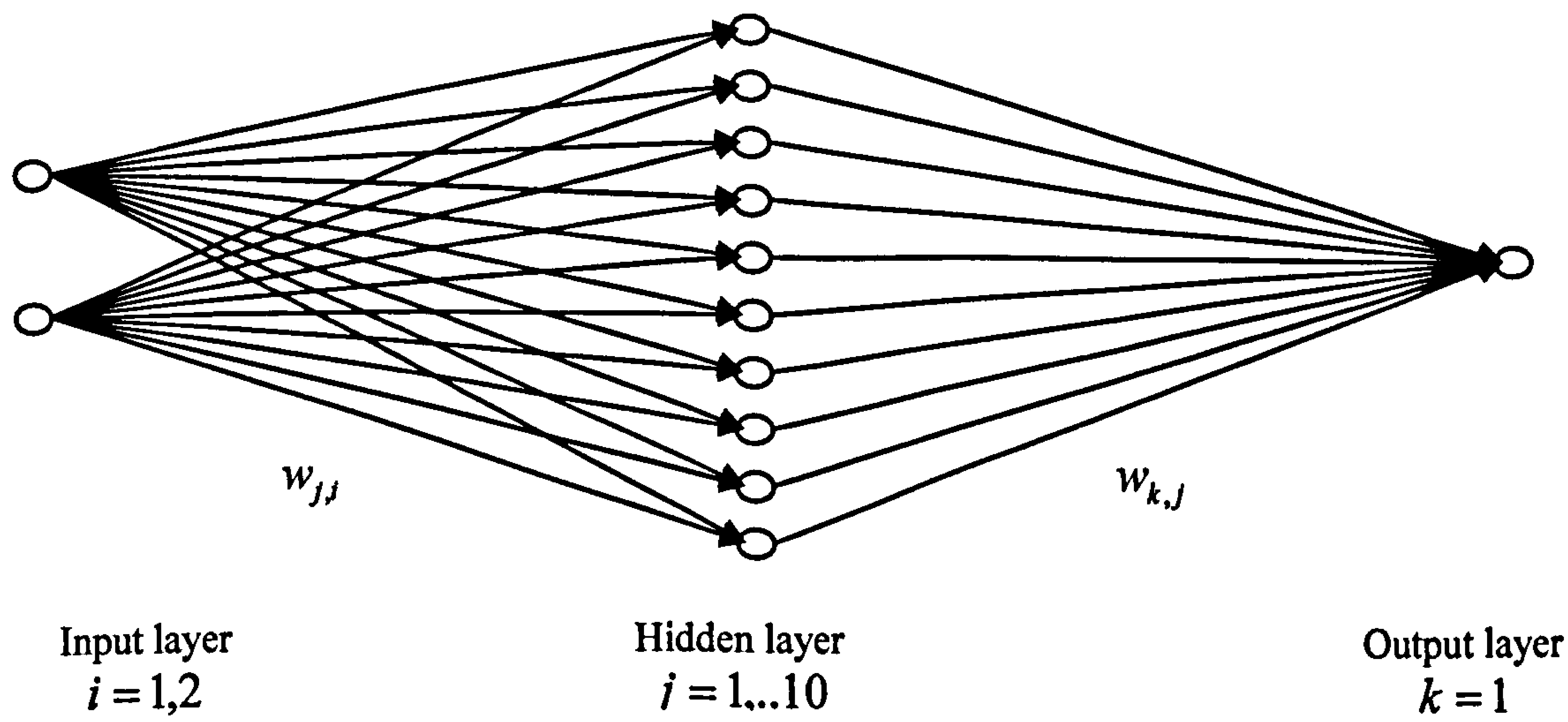

Figure 4.3. A two-layer neural network

In addition, ANN has been employed in many spheres because of its strength in data pattern recognition. These include signal processing [Cichocki and Unbehauen, 1993]; visual image data recognition [Miller, 1994]; communication systems [Kartalopoulos, 1994]; onboard satellite navigation systems, classification of aircraft radar signals; automatic target recognition [Kartalopoulos, 1996]; traffic safety analysis [Abdelwahab and Abdel-Aty, 2002]; the fire safety assessment [Lee *et al.*, 2004], etc. The application of ANNs in the maritime industry is rare in comparison with other industries. Nevertheless, this includes an ANN application to marine systems modelling complex non-linear functions [Roskilly and Mesbahi, 1996]; the prediction as to the likelihood of the type of vessel accidents [Hashemi *et al.*, 1995]; the employment of the statistics of bulk carrier loss predicting the overall risk [Buxton *et al.*, 1997]; the application of a neural network for ship domain assessment [Lisowski, 2000]; the use of an ANN with regard to vessel accidents for pattern recognition [Blanc *et al.*, 2001] and the incorporation of an ANN into a risk estimation model [Wang *et al.*, 2004].

4.3 Research methodology

The research methodology of this study starts with the establishment of the membership functions for the linguistic terms describing the five parameters to be taken into consideration. A fuzzy combination algorithm will subsequently be developed and applied to obtain an overall risk with the crisp-vale property. This is due to the fact that the data fed into neural networks must have numerical characteristics. A batch of training and testing data will then be prepared, followed by the construction of a feedforward ANN model and a training process by introducing the training data into the network. The trained network will be verified as to whether it is capable of predicting reliable results using the testing data prepared. The steps from 3 to 6 (sections 4.3.3-4.3.6) will be repeated until the trained ANN has satisfied the acceptable accuracy established based on expert judgement. Consequently, the ANN so trained will be capable of predicting risk with high reliability. Figure 4.4 shows the flowchart of the research methodology in this study [Ung *et al.*, 2006a].

4.3.1 Establishment of membership function for linguistic terms of each parameter

The membership function is established for the linguistic terms describing the linguistic variables including VTC performance, navigation aids & facilities, pilotage performance, sealane maintenance and weather conditions based on the opinions from multiple experts. The experts involved in a port safety project should be appropriately

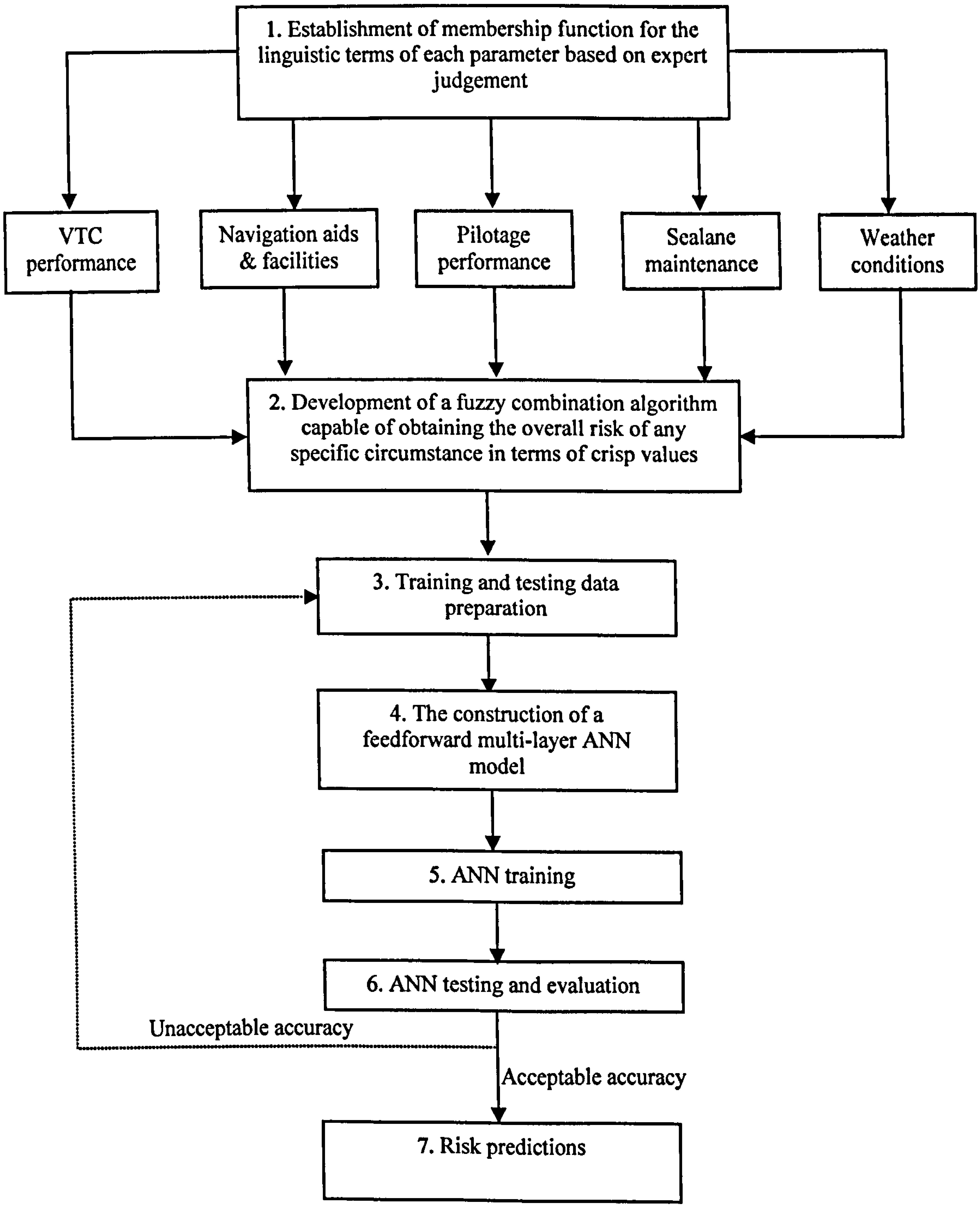

Figure 4.4. The flowchart of the research methodology

selected so that an unrealistic and biased membership function will be avoided [Kuusela *et al.*, 1998]. Each expert is asked to evaluate a proposition 'x belongs to A?'. It is assumed that A is a fuzzy set on X that represents a linguistic term associated with a given linguistic variable and $a_i(x)$ is a value of scores within a certain range in X i.e. $a_i(x) \in$ X (in this study, X is defined as 1-10 categories). In situations where there are n experts and each of them has equal competence, the following formula is applied [Klir and Yuan, 1995]:

$$A(x) = \frac{\sum_{i=1}^{n} a_i(x)}{n} \quad \text{(Equation 4.1)}$$

where $A(x)$ is the final answer (value) after the judgements made by n experts are synthesised, and

$a_i(x)$ is the answer (value) given by the i^{th} expert, $i \in n$.

In the case where the experts have different degrees of competencies, Equation 4.1 is modified as:

$$A(x) = \sum_{i=1}^{n} Comp_i a_i(x) \quad \text{(Equation 4.2)}$$

where $Comp_i$ is the degree of competency of the i^{th} expert,

$$\sum_{i=1}^{n} Comp_i = 1 \quad \text{(Equation 4.3)}$$

It is important to note that the degree of competency for each expert should be determined based on their knowledge and experience in risk assessment as well as in the field of port marine safety.

The triangular membership function is adopted since it has a smooth transition from one linguistic term to the other. On the other hand, it facilitates easy defuzzification of each linguistic term. The membership function for each linguistic term is evaluated within its limits on an arbitrary scale from 0 to 1. Five linguistic terms are employed to describe the parameters in this study, which are 'Excellent', 'Good', 'Moderate', 'Poor' and 'Very Poor'.

4.3.2 Development of a fuzzy combination algorithm capable of obtaining the overall risk of any specific circumstance in terms of crisp values

The linguistic terms adopted in this study are 'Excellent', 'Good', 'Moderate', 'Poor' and 'Very Poor', respectively. Traditionally, the overall risk of a specific event is evaluated by combining the rules developed. However, this study intends to introduce a risk prediction method using a neural network, where the antecedent and consequent of a fuzzy rule must be crisp values. Instead of developing a fuzzy rule base, the antecedent and consequent of each combination of these five parameters are converted from fuzzy expressions to crisp values. It is assumed that the relationship between these linguistic terms is linear. Thus, the numerals of these five linguistic terms assigned arbitrarily for the following input crisp value calculation are 1 for Excellent, 2 for Good, 3 for Moderate, 4 for Poor and 5 for Very Poor. Therefore, the antecedent crisp value of specific linguistic terms and their membership values associated is defined as the product of the membership value (μ_i) and the numeral assigned arbitrarily for that linguistic term as shown in Equation 4.4.

$$A_{parameter} = \frac{\sum \mu_i \cdot N_i}{\sum \mu_i} \qquad \text{(Equation 4.4)}$$

where $A_{parameter}$ is the antecedent crisp value of the parameter in question,

μ_i is the membership value obtained from a fuzzy set i and

N_i is the i^{th} linguistic-term assigned numeral, $i = 1,2,3,4,5$.

Allowing for the relevance that each parameter differs from port to port, an element representing the importance degree of each parameter, W, is introduced. Thus, the numeric value of consequent associated with the combination described above can be defined as the sum of the product of the linguistic-term assigned numeral and the weight of each parameter in question, multiplied by the minimum membership value of the parameters as indicated in Equation 4.5.

$$C_{consequent} = \mu_{\min} \cdot \sum_{j=1}^{5} N_{i,j} \cdot W_j \qquad \text{(Equation 4.5)}$$

where $C_{consequent}$ is the crisp value of the consequent of the combination,

$\mu_{\min}$ is the minimum membership value of the parameters,

$N_{i,j}$ is the i^{th} linguistic-term assigned numeral describing the j^{th} parameter and

W_j is the weight of the j^{th} parameter assigned based on expert judgement.

In this study, an event may have many combinations, depending upon the pattern of the membership functions. The overall risk will be obtained by choosing the maximum membership value attached to each sum of the product of the linguistic-term assigned numeral together with the weight of the parameter belonging to the same category in these combinations as shown in Equation 4.6.

$$R_{overall} = \frac{\sum_{k=1}^{K} \mu_k \cdot C_{k(N \cdot W)}}{\sum_{k=1}^{K} \mu_k} \qquad \text{(Equation 4.6)}$$

where $R_{overall}$ is the value of the overall risk obtained from K categories,

μ_k is the maximum membership value of the minimum membership values of the parameters in $C_{k(N \cdot W)}$,

$C_{k(N \cdot W)}$ is the k^{th} category of the sum of the product of the linguistic-term assigned numeral describing the j^{th} parameter and the weight of the parameter and

$$C_{k(N \cdot W)} = \sum_{j=1}^{5} N_{i,j}^{k} \cdot W_j^k$$

4.3.3 Preparation of training data and testing data

Both training and testing data consist of two elements, namely, inputs and target outputs. The function of training data is that it can be adopted to train the neural network whereas testing data is used to verify the network. Once a neural work has been trained and tested appropriately, it can generate the desired outputs. In general, the training and testing data are chosen from the historical data collection. However, in situations where there are difficulties with regard to obtaining data as the study encounters, the preparation of these two types of data is generated using expert judgement hypothetically made by the author. By virtue of adopting the methods introduced in sections 4.3.1 and 4.3.2, the training and testing data are converted from fuzzy properties to numeric values. Since the neural network can only recognise the inputs and generate the outputs that are similar to the ones it has met during the training process, the training data should be comprehensive, covering all possible and potential situations the port may confront. The size of the testing data should be smaller than the training data and be chosen evenly throughout the whole range of the training data.

The commonly used non-linear transfer functions are the sigmoidal and tanh functions that have saturation values of 0 to 1 and –1 to 1 respectively. If the values of the inputs and outputs in a training data set are not bounded by the saturation range, the neurons will be forced to their saturation points and are unable to respond to the changes in input. Therefore, prior to applying the training data, the data must be normalised between two threshold values [Ebelhart and Dobbins, 1990]. Therefore, in this study the formula in Equation 4.7 is introduced to obtain the normalised values.

$$\text{Normalised value} = \frac{realvalue - \min value}{\max value - \min value} \qquad \text{(Equation 4.7)}$$

where *realvalue* is the crisp value of a specific set of data in a specific parameter to be normalised,

$\max value$ is the maximum value the specific parameter has and

$\min value$ is the minimum value the specific parameter has.

4.3.4 Construction of a feedforward multi-layer ANN model

After obtaining the training and testing data a feedforward multi-layer ANN model capable of predicting risk levels is constructed. Since the use of a single hidden layer is sufficient to approximate any continuous function as closely as requested [Funahashi, 1989] [Hornik *et al.*, 1989], a two-layer feedforward ANN model consisting of one hidden layer and one output layer will be adopted. There is no rule prescribing how the optimum number of neurons in the hidden layer can be decided. Therefore, according to the experience gained by the network practitioners, the appropriate number of neurons in the hidden layer will be selected based on numbers of experiments. Feedforward networks often have hidden layers with sigmoid neurons followed by linear neurons in the output layer. Therefore, the transfer functions adopted for the ANN model in this study will be tanh sigmoid for the hidden layer neurons and pure linear for the output neuron.

4.3.5 ANN training

The training data prepared based on expert judgement will be introduced to the neural network developed. The type of training applied in the network is supervised learning where the actual response from output layers is compared with a priori desired output known as target outputs [Kartalopoulos, 1996]. The training data with regard to the parameters deemed to have great influence to the sealane navigation safety within port areas are the inputs for the model, whereas the overall risk levels are treated as the target outputs. If the actual response differs from the target output, the neural network generates an error signal. The error signal is subsequently used to calculate the adjustment that will be made to the connection weights between the neurons in the output, hidden and input layers. By repeating this process, the error signal between the actual response and the target outputs will be gradually minimised to become an acceptable criterion judged by the practitioner, or even possibly zero. It is noted that each criterion requested in each application is different and it is subject to the practitioners. There are several algorithms that can be applied to minimise the error signal, and the one selected for the network in this study is the backpropagation method. The procedure of calculating the error signal using this method is described in the following subsections.

4.3.5.1 The backpropagation algorithm

The first step of the loop structure of the algorithm is to initialise the weights to small random values which are between 0 to 1. Secondly, each pattern containing inputs and outputs in the training set will be trained. By repeating the process described above, the error will eventually reach the criterion required. The loop structure of the backpropagation algorithm is indicated below:

```
initialise weights
repeat
    for each training pattern
        train on that pattern
    end for loop
until the error is acceptably low
```

One iteration of the 'for' loop is referred to as an epoch resulting in a single presentation of each pattern in the training set. The main step in this structure is "train on that pattern". The training procedure of evaluating the outputs from each layer and adjusting the connection weights associated in order to achieve the goal of the error signal is expanded into the following steps.

4.3.5.1.1 Presentation of the pattern in the input layer

The first step is to present the pattern consisting of inputs and target output in the input layer. The values contained in the inputs and target output are the normalised numerals obtained using Equation 4.7.

4.3.5.1.2 Evaluation of the output from each hidden neuron

In this step, by calculating the difference between the summation of the weighted inputs and the bias value in the hidden neuron and subsequently applying the tanh sigmoid transfer function to the value of the difference, the output value of each hidden neuron will be obtained. Since the type of transfer function introduced is tanh sigmoid, the value is confined from 1 to –1. It is assumed that there are i inputs in the input layer, j hidden nodes in the hidden layer and k outputs in the output layer. The mathematical expression is shown in Equation 4.8.

$$Y_j^{HL} = F\left(\sum x_i \times w_{j,i}^{IL-HL} - b_j\right) = F(s_{input}) \qquad \text{(Equation 4.8)}$$

where $F = \tan sig\left(s_{input}\right) = \dfrac{2}{1+e^{-2\left(s_{input}\right)}} - 1$,

x_i is the signal of the i^{th} input neuron, $w_{j,i}^{IL-HL}$ is the connection weight from the i^{th} input neuron in the input layer to the j^{th} hidden neuron in the hidden layer and b_j is the bias (sometime referred to as threshold) value of the j^{th} hidden neuron,

Y_j^{HL} is the output value of the j^{th} hidden neuron in the hidden layer and

S_{input} is the difference between the summation value of the weighted inputs and the bias value in the j^{th} hidden neuron.

4.3.5.1.3 Evaluation of the output from each output neuron

After calculating the difference between the summation value of the weighted signals from the hidden layer and the bias value in the output neuron, the pure linear transfer function is then adopted to obtain the output value of each output neuron. As a result of the transfer function introduced, the output can take on any value. Equation 4.9 is the mathematical expression of this subsection.

$$Y_k^{OL} = F\left(\sum Y_j^{HL} \times w_{k,j}^{HL-OL} - b_k\right) = F(s_{hidden}) \qquad \text{(Equation 4.9)}$$

where $F = purelin(s_{hidden}) = s_{hidden}$,

Y_j^{HL} is the output value of the j^{th} hidden neuron in the hidden layer, $w_{k,j}^{HL-OL}$ is the connection weight from the j^{th} hidden neuron to the k^{th} output neuron and b_k is the bias or threshold value of the k^{th} output neuron,

Y_k^{OL} is the output value of the k^{th} output neuron in the output layer and

S_{hidden} is the difference between the summation value of the weighted signals from the hidden layer and the bias value in the k^{th} output neuron.

4.3.5.1.4 Introduction of the target value to the output layer and calculation of the contribution that each output neuron makes towards the error

The target value of the pattern is applied to the output layer and subsequently compared with the actual output. The error signals on the output neurons are obtained using Equation 4.10.

$$\delta_k^{t-OL} = F'(s_{hidden})(t - Y_k^{OL}) \qquad \text{(Equation 4.10)}$$

where δ_k^{t-OL} is the contribution that the output neuron k in the output layer makes towards to the error,

$F'(s_{hidden})$ is the derivative of the activation function in the output layer and

$(t - Y_k^{OL})$ is the difference between the target output and the actual output of the k^{th} output neuron.

4.3.5.1.5 Training of each output neuron using the gradient descent method

As mentioned previously the minimum error established by the practitioner can be achieved by updating the connection weights. Therefore, the variation of the weight from each hidden neuron to the output neuron in question is the core issue. By applying the learning rate established, the variation value can be obtained using Equation 4.11.

$$\Delta w_{k,j}^{HL\text{-}OL} = \alpha \delta_k^{t\text{-}OL} Y_j^{HL} \qquad \text{(Equation 4.11)}$$

where $\Delta w_{k,j}^{HL\text{-}OL}$ is the variation of the weight from the hidden neuron j to the output neuron k,

α is the learning rate,

$\delta_k^{t\text{-}OL} = F'(s_{hidden})(t - Y_k^{OL})$ and

Y_j^{HL} is the output value of the j^{th} hidden neuron in the hidden layer.

4.3.5.1.6 Calculation of the contribution that each hidden neuron makes towards the error

The main mission of this step is to evaluate the effect that the hidden neuron can influence the output neuron and via this, the effect that the output neuron affects the error. Therefore, when calculating the effects, the contribution that the output neurons make towards the error and the influence of the hidden neuron on the output neuron, that is, the connection weight, are taken into consideration. The mathematical expression of this step is given in Equation 4.12.

$$\delta_j^{t\text{-}HL} = \sum_{k \in I_j} \delta_k^{t\text{-}OL} w_{k,j}^{HL\text{-}OL} \qquad \text{(Equation 4.12)}$$

where $\delta_j^{t\text{-}HL}$ is the contribution that each hidden neuron makes towards to the error,

I_j is the set of neurons that take an input from the hidden neuron j,

$\delta_k^{t\text{-}OL}$ is the contribution that the output neuron k makes towards to the error, and

$w_{k,j}^{HL\text{-}OL}$ is the connection weight from the j^{th} hidden neuron to the k^{th} output neuron.

4.3.5.1.7 Training of each hidden neuron according to the gradient descent method

Applying a similar method to that described in Step 5 (section 4.3.5.1.5), the variation of the weight from each input neuron to the hidden neuron in question can be acquired, and its mathematical term is expressed in Equation 4.13.

$$\Delta w_{j,i}^{IL-HL} = \alpha F'(s_{input})\delta_j^{t-HL} x_i \qquad \text{(Equation 4.13)}$$

where $\Delta w_{j,i}^{IL-HL}$ is the variation of the weight from the input neuron i in the input layer to the hidden neuron j in the hidden layer,

α is the learning rate,

$F'(s_{input})$ is the derivative of the activation function in the hidden layer,

$\delta_j^{t-HL} = \sum_{k \in I_j} \delta_k^{t-OL} w_{k,j}^{HL-OL}$, and

x_i is the signal of the i^{th} input neuron.

It is often the case that the slope of the transfer function, $F'(s_{input})$, is absorbed into the corresponding δ_j^{t-HL} term. Thus, Equation 4.13 is rewritten to:

$$\Delta w_{j,i}^{IL-HL} = \alpha \delta_j^{t-HL} x_i \qquad \text{(Equation 4.14)}$$

where $\delta_j^{t-HL} = F'(s_{input}) \sum_{k \in I_j} \delta_k^{t-OL} w_{k,j}^{HL-OL}$.

The steps from Steps 1 to 3 (sections 4.3.5.1.1 – 4.3.5.1.3) are regarded as the "Forward Pass" since the signal is flowing forward throughout the network. On the other hand, the procedures from Steps 4 to 7 (sections 4.3.5.1.4 – 4.3.5.1.7) are known as the "Backward Pass".

4.3.5.2 Introduction of the momentum term

The gradient descent method applied to the term requires that the calculating steps taken be infinitesimal. Thus, when establishing the learning rate the stability of the training procedure must be taken into account. A large learning rate may facilitate the training performance to reach the convergence in a stable situation. However, if it is set too high, the training will become unstable, causing oscillation and divergence. Learning rates between 0.05 to 0.25 are often preferred to ensure network convergence [Roskilly and Mesbahi, 1996]. Although a small learning rate guarantees training stability, the time spent on convergence may be long. Therefore, in order to overcome this and facilitate the training, a momentum term is introduced. The modified learning rules for each output and hidden neurons are expressed in Equation 4.15.

$$\Delta w(n) = \alpha\delta(n)I(n) + \lambda\Delta w(n-1) \qquad \text{(Equation 4.15)}$$

where $\Delta w(n)$ is the n^{th} change in weight w,

α is the learning rate,

$\delta(n)$ is the n^{th} contribution that the neuron in question makes towards the error,

$I(n)$ is the n^{th} input signal from the adjacent neuron and

λ is the momentum constant usually set up between 0 and 1.

It can be seen from the learning rule that the weight change depends on the previous weight change. In other words, if the weight changes are consistently of the same sign over a certain run of updates, the weight change will grow larger when the previous weight change contributes cumulatively and consistently towards the current update. The ANN training will be performed using Matlab Neural Network Toolbox since such software enables safety analysts to establish ANNs simply using the codes and functions provided.

4.3.6 ANN testing and evaluation

The ANN trained model will be tested using the testing data prepared to evaluate its performance. Subsequently, the actual output will be compared with the target output. If the risk prediction generated reaches the acceptable accuracy, the model is ready for the mission in the next step. If not the model should be reviewed and modified by repeating Step 3 to Step 6 (sections 4.3.3-4.3.6) until it fulfils the expected criterion. In this study the accuracy criterion of 90% was arbitrarily established.

4.3.7 Risk predictions

The ANN model trained can be utilised to predict the risk level of sealane navigation within port areas. New data will then be able to be fed into the model. The model will then generate the results. A risk ranking can consequently be established which can be used as a reference for the risk assessment practitioners.

4.4 Test Case

4.4.1 Establishment of membership function for linguistic terms of each parameter

The linguistic terms applied to describe the characteristic of each parameter are, namely, 'Excellent', 'Good', 'Moderate', 'Poor' and 'Very Poor', respectively. The values of each linguistic term are obtained using Equation 4.1 based on the assumption that the competence of each expert is equal. The acquirement of the value that fully represents a linguistic term, Moderate, e.g., is achieved by requesting the individual opinion of each expert with regard to which category value can precisely describe the linguistic term. A compromising opinion is obtained using Equation 4.1 as follows (provided that there are four experts and their individual opinions i.e. $a_i(x)$, are 5, 6, 4, 5, respectively):

$$\mathrm{A}(x) = \frac{\sum_{i=1}^{n} a_i(x)}{n} = \frac{(5+6+4+5)}{4} = 5.0$$

Two boundary values as the membership value reaches 0 can also be obtained using Equation 4.1. Figure 4.5 shows the membership functions for the linguistic terms of the parameters of VTC performance, Excellent, Good, Moderate, Poor and Very Poor based on expert judgement hypothetically made by the author. It is noted that in real world case studies, the membership functions of the linguistic terms for each parameter may be different. Since the purpose of this test case is to demonstrate the framework proposed, the membership functions of the linguistic terms in question describing the parameters of the VTC performance, navigation aids and facilities, pilotage performance, sealane maintenance and weather condition are set to identical.

4.4.2 Preparation of the training data using the fuzzy combination algorithm

This step is needed to prepare the training data and testing data. Such data, which is obtained based on the expert judgement hypothetically made by the author, should take into account all possible situations the port may encounter. Thus, this mission could be accomplished by collecting the opinions from the port authority with regard to the historical and potential operations and circumstances of the five parameters in question to ensure that the data gathered is representative. However, since the objective of this study is to demonstrate how the risk predictions can be acquired using fuzzy set theory and a neural network, the data prepared is based on the expert judgements generated by the author. In addition, as neural networks need training and testing data with numerical property, the fuzzy combination algorithm developed in the methodology is subsequently applied to convert the property of these data. The process of obtaining an overall risk with crisp value from a specific set of the training data using the fuzzy combination algorithm is illustrated as follows.

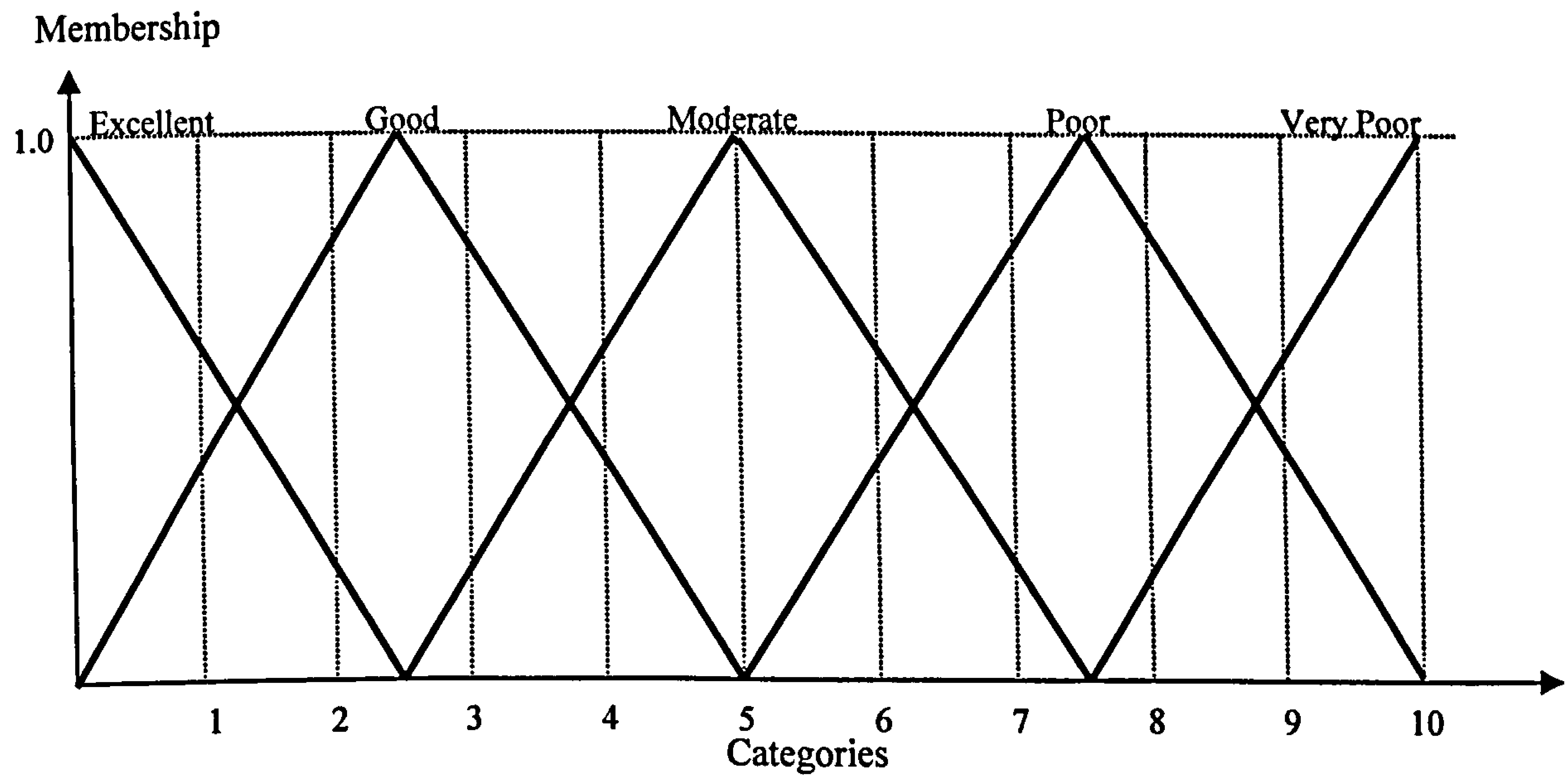

Figure 4.5. Membership function for the linguistic terms describing the VTC performance parameter of sealane navigation safety in port

4.4.2.1 Process of converting the fuzzy training data to crisp-value risk indices

A set of the fuzzy training data listed in Table 4.1 is used to demonstrate the conversion process.

Table 4.1. The fuzzy training data

VTC Performance	Navigation aids & Facilities	Pilotage Performance	Sealane Maintenance	Weather Condition
Very Poor 0.75, Poor 0.25	Very Poor 0.75, Poor 0.25	Very Poor 0.75, Poor 0.25	Very Poor 0.75, Poor 0.25	Very Poor 0.75, Poor 0.25

First, in the VTC performance parameter, since it has two linguistic terms, Very Poor and Poor, describing its characteristics associated with membership values of 0.75 and 0.25 respectively, Equation 4.4 consisting of the elements of the membership values and linguistic-term assigned numeral is applied to obtain its antecedent crisp value:

$$A_{VTC} = \frac{\sum \mu_i \cdot N_i}{\sum \mu_i} = \frac{0.75 \times 5 + 0.25 \times 4}{0.75 + 0.25} = 4.75$$

The other four parameters follow the same pattern illustrated above and the antecedent crisp values for the training data in question are shown in Table 4.2.

Table 4.2. The antecedent crisp values of the training Data

VTC Performance	Navigation aids & Facilities	Pilotage Performance	Sealane Maintenance	Weather Condition
4.75	4.75	4.75	4.75	4.75

Secondly, the minimum membership value among the parameters and the linguistic-term assigned numeral corresponding to each parameter are adopted to acquire the consequent value for each combination. Since there are five parameters, each of which is described by two linguistic terms, the number of consequent combinations is 32. In addition, the importance degree of each parameter, W, is assumed to be equal i.e. 0.2. The calculation below shows the first combination for the training data in question using Equation 4.5. All 32 combinations are listed in Table 4.3.

$$C_{consequent} = \mu_{\min} \cdot \sum_{j=1}^{5} N_{i,j} \cdot W_j = 0.75 \cdot (5 \times 0.2 + 5 \times 0.2 + 5 \times 0.2 + 5 \times 0.2 + 5 \times 0.2) = 0.75 \cdot 5$$

Table 4.3. The combinations of the training data

No. of Combinations	VTC Performance		Navigation aids & Facilities		Pilotage Performance		Sealane Maintenance		Weather Condition		Consequent	
	μ_i	$N_{i,j}$	μ_i	$N_{i,j}$	μ_i	$N_{i,j}$	μ_i	$N_{i,j}$	μ_i	$N_{i,j}$	$\mu_{\min}$	$\sum N_{i,j} \cdot W_j$
1	0.75	5	0.75	5	0.75	5	0.75	5	0.75	5	0.75	5
2	0.75	5	0.75	5	0.75	5	0.75	5	0.25	4	0.25	4.8
3	0.75	5	0.75	5	0.75	5	0.25	4	0.75	5	0.25	4.8
4	0.75	5	0.75	5	0.75	5	0.25	4	0.25	4	0.25	4.6
5	0.75	5	0.75	5	0.25	4	0.75	5	0.75	5	0.25	4.8
6	0.75	5	0.75	5	0.25	4	0.75	5	0.25	4	0.25	4.6
7	0.75	5	0.75	5	0.25	4	0.25	4	0.75	5	0.25	4.6

8	0.75	5	0.75	5	0.25	4	0.25	4	0.25	4	0.25	4.4
9	0.75	5	0.25	4	0.75	5	0.75	5	0.75	5	0.25	4.8
10	0.75	5	0.25	4	0.75	5	0.75	5	0.25	4	0.25	4.6
11	0.75	5	0.25	4	0.75	5	0.25	4	0.75	5	0.25	4.6
12	0.75	5	0.25	4	0.75	5	0.25	4	0.25	4	0.25	4.4
13	0.75	5	0.25	4	0.25	4	0.75	5	0.75	5	0.25	4.6
14	0.75	5	0.25	4	0.25	4	0.75	5	0.25	4	0.25	4.4
15	0.75	5	0.25	4	0.25	4	0.25	4	0.75	5	0.25	4.4
16	0.75	5	0.25	4	0.25	4	0.25	4	0.25	4	0.25	4.2
17	0.25	4	0.75	5	0.75	5	0.75	5	0.75	5	0.25	4.8
18	0.25	4	0.75	5	0.75	5	0.75	5	0.25	4	0.25	4.6
19	0.25	4	0.75	5	0.75	5	0.25	4	0.75	5	0.25	4.6
20	0.25	4	0.75	5	0.75	5	0.25	4	0.25	4	0.25	4.4
21	0.25	4	0.75	5	0.25	4	0.75	5	0.75	5	0.25	4.6
22	0.25	4	0.75	5	0.25	4	0.75	5	0.25	4	0.25	4.4
23	0.25	4	0.75	5	0.25	4	0.25	4	0.75	5	0.25	4.4
24	0.25	4	0.75	5	0.25	4	0.25	4	0.25	4	0.25	4.2
25	0.25	4	0.25	4	0.75	5	0.75	5	0.75	5	0.25	4.6
26	0.25	4	0.25	4	0.75	5	0.75	5	0.25	4	0.25	4.4
27	0.25	4	0.25	4	0.75	5	0.25	4	0.75	5	0.25	4.4
28	0.25	4	0.25	4	0.75	5	0.25	4	0.25	4	0.25	4.2
29	0.25	4	0.25	4	0.25	4	0.75	5	0.75	5	0.25	4.4
30	0.25	4	0.25	4	0.25	4	0.75	5	0.25	4	0.25	4.2
31	0.25	4	0.25	4	0.25	4	0.25	4	0.75	5	0.25	4.2
32	0.25	4	0.25	4	0.25	4	0.25	4	0.25	4	0.25	4

Finally, the overall risk can be obtained by selecting the maximum membership value attached to each sum of the product of the linguistic-term assigned numeral and the weight of the parameter belonging to the same category in the 32 combinations using Equation 4.6. Table 4.4 shows the consequents that fulfil the condition described above.

Table 4.4. The consequent values needed for the acquirement of the overall risk

μ_k	0.75	0.25	0.25	0.25	0.25	0.25
$C_{k(N,W)}$	5	4.8	4.6	4.4	4.2	4

Thus the value of the overall risk of the training data is:

$$R_{overall}=\frac{\sum_{k=1}^{k}\mu_k\cdot C_{k(N\cdot W)}}{\sum_{k=1}^{k}\mu_k}=\frac{0.75\times5+0.25\times4.8+0.25\times4.6+0.25\times4.4+0.25\times4.2+0.25\times4}{0.75+0.25+0.25+0.25+0.25+0.25}=4.625$$

Therefore, the fuzzy training data associated with its overall risk is indicated in Table 4.5.

Table 4.5. The fuzzy training data and the overall risk associated

VTC Performance	Navigation aids & Facilities	Pilotage Performance	Sealane Maintenance	Weather Condition	Overall Risk
Very Poor 0.75, Poor 0.25	Very Poor 0.75, Poor 0.25	Very Poor 0.75, Poor 0.25	Very Poor 0.75, Poor 0.25	Very Poor 0.75, Poor 0.25	4.625

Since only the numerical training data is applicable to neural networks, the training data to be adopted to the network in question is converted to crisp values, which are shown in Table 4.6.

Table 4.6. The crisp-value training data

VTC Performance	Navigation aids & Facilities	Pilotage Performance	Sealane Maintenance	Weather Condition	Overall Risk
4.75	4.75	4.75	4.75	4.75	4.625

There are 857 sets of training data that are applied to the neural network. The first 20 sets of such data are shown in Tables 4.7 and 4.8 with fuzzy and numerical properties respectively. The complete data sets with both properties used to train the neural network are listed in Appendices 2 and 3, presenting the characteristic of the network to be trained. It can be seen from Table 4.7 that the scenarios in which the parameters described by more negative linguistic terms have higher risks than those depicted by more positive terms. This is consistent with the human-being common sense. Furthermore, the difference of the risk level between these scenarios can be appreciated. In addition, it is important to note that when preparing the training data, the difference between the levels of the linguistic terms used describing the parameters of VTC performance, navigation aids and facilities, piltoage performance and sealane maintenance is limited to a certain range. This is based on the assumption that the circumstances of these four parameters are dependent upon the equal resource allocation of a port whereas the weather changes continuously. In other words, it may be unlikely that an efficient port would have Very Poor VTC performance and Good pilotage performance, or Very Poor navigation aids and facilities and Excellent sealane maintenance.

Table 4.7. The first 20 sets of the fuzzy taining data

Data No.	VTC Performance	Navigation aids & Facilities	Pilotage Performance	Sealane Maintenance	Weather Condition	Overall Risk
1	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	4.625
2	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	4.425
3	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Moderate 0.75, Good 0.25	4.225
4	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Good 0.75, Excellent 0.25	4.025
5	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	3.825
6	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	3.625
7	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	3.425
8	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	3.225
9	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	3.025
10	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	2.825
11	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	2.625
12	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	2.425
13	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	V.Poor 0.75, Poor 0.25	2.225
14	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Poor 0.75, Moderate 0.25	2.025
15	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	1.825
16	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	1.625
17	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	4.425
18	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	4.225
19	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Moderate 0.75, Good 0.25	4.025
20	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Good 0.75, Excellent 0.25	3.825

Note: V. Poor means Very Poor

Table 4.8. The first 20 sets of the crisp-value training data

Data No.	VTC Performance	Navigation aids & Facilities	Pilotage Performance	Sealane Maintenance	Weather Condition	Overall Risk
1	4.75	4.75	4.75	4.75	4.75	4.625
2	4.75	4.75	4.75	4.75	3.75	4.425
3	4.75	4.75	4.75	4.75	2.75	4.225
4	4.75	4.75	4.75	4.75	1.75	4.025
5	3.75	3.75	3.75	3.75	4.75	3.825
6	3.75	3.75	3.75	3.75	3.75	3.625
7	3.75	3.75	3.75	3.75	2.75	3.425
8	3.75	3.75	3.75	3.75	1.75	3.225
9	2.75	2.75	2.75	2.75	4.75	3.025
10	2.75	2.75	2.75	2.75	3.75	2.825
11	2.75	2.75	2.75	2.75	2.75	2.625
12	2.75	2.75	2.75	2.75	1.75	2.425
13	1.75	1.75	1.75	1.75	4.75	2.225
14	1.75	1.75	1.75	1.75	3.75	2.025
15	1.75	1.75	1.75	1.75	2.75	1.825
16	1.75	1.75	1.75	1.75	1.75	1.625
17	3.75	4.75	4.75	4.75	4.75	4.425
18	3.75	4.75	4.75	4.75	3.75	4.225
19	3.75	4.75	4.75	4.75	2.75	4.025
20	3.75	4.75	4.75	4.75	1.75	3.825

4.4.3 Preparation of training data

For the purpose of ensuring that the neural network reaches the goal, the training data in each parameter and the overall risk index are normalised using Equation 4.7. The data range associated with the VTC performance parameter, for example, is between 5 and 1; its normalised value in the first data set is calculated as follows:

$$\text{Normalised Value} = \frac{realvalue - \min value}{\max value - \min value} = \frac{4.75 - 1}{5 - 1} = 0.9375$$

The rest of the training data follows the same method mentioned above, and Table 4.9 shows the normalised data of the first 20 sets. Appendix 4 contains the complete normalised training data. It can be seen from Appendix 4 that the values have been converted to a range between zero and one for the purpose of ensuring that the network reaches the goal. In addition, it is worthwhile noting that this computing-intensive data preparation process can be accomplished using computer software such as Excel.

Table 4.9. The first 20 sets of the normalised training data

Data No.	VTC Performance	Navigation aids & Facilities	Pilotage Performance	Sealane Maintenance	Weather Condition	Overall Risk
1	0.9375	0.9375	0.9375	0.9375	0.9375	0.90625
2	0.9375	0.9375	0.9375	0.9375	0.6875	0.85625
3	0.9375	0.9375	0.9375	0.9375	0.4375	0.80625
4	0.9375	0.9375	0.9375	0.9375	0.1875	0.75625
5	0.6875	0.6875	0.6875	0.6875	0.9375	0.70625
6	0.6875	0.6875	0.6875	0.6875	0.6875	0.65625
7	0.6875	0.6875	0.6875	0.6875	0.4375	0.60625
8	0.6875	0.6875	0.6875	0.6875	0.1875	0.55625
9	0.4375	0.4375	0.4375	0.4375	0.9375	0.50625
10	0.4375	0.4375	0.4375	0.4375	0.6875	0.45625
11	0.4375	0.4375	0.4375	0.4375	0.4375	0.40625
12	0.4375	0.4375	0.4375	0.4375	0.1875	0.35625
13	0.1875	0.1875	0.1875	0.1875	0.9375	0.30625
14	0.1875	0.1875	0.1875	0.1875	0.6875	0.25625
15	0.1875	0.1875	0.1875	0.1875	0.4375	0.20625
16	0.1875	0.1875	0.1875	0.1875	0.1875	0.15625
17	0.6875	0.9375	0.9375	0.9375	0.9375	0.85625
18	0.6875	0.9375	0.9375	0.9375	0.6875	0.80625
19	0.6875	0.9375	0.9375	0.9375	0.4375	0.75625
20	0.6875	0.9375	0.9375	0.9375	0.1875	0.70625

4.4.4 Construction of a feed forward multi-layer ANN model

It is in this step that 857 sets of normalised training data are fed into a two-layer neural network. The columns of these five parameters are treated as the inputs, and the overall risk index is used as the target output for the network. After a series of experiments conducted using the Matlab software, the optimum number of the hidden neurons for this test case is chosen at 25 and is associated with a learning rate of 0.0008 and the goal is set to 0.35 SSE (sum square error). The initial connection weight of each neuron in the neural network is selected randomly by the software. In general, learning rates between 0.05 to 0.25 are preferred. However, since there are 857 sets of training data in this study, the neural network does not remain stable until the learning rate is adjusted to 0.0008. The meaning of 0.35 SSE is that the aggregated square errors of 857 training data sets are 0.35. Therefore, the average square error for each set is 4.084×10^{-4} and the average error for the actual output and target output is 0.02. Thus, in theory, the goal established is capable of predicting the risk with high accuracy. It is noted that there are no clear or straightforward solutions to determine the number of hidden layers and neurons [Roskilly and Mesbahi, 1996]. It should also be noted that as the number of the hidden neurons increases, the training time decreases to achieve the same model accuracy and that too many hidden nodes may make the network unable to reach the goal. During the experiments in this study, when the network is trained with 10 hidden neurons, it reaches the goal after 160,201 epochs. Thus the training time is much longer than that with 25 nodes. However, if it is equipped with 30 hidden neurons, the training performance becomes unstable and unable to reach the goal. Figure 4.6 shows the neural network constructed for this study.

4.4.5 ANN Training

The previous section mentioned that after a number of experiments using different combinations of the hidden neurons and the learning rates, the neural network is trained with 25 hidden nodes associated with the learning rate of 0.0008 and is required to reach the goal of 0.35 SSE. Figure 4.7 shows the training performance of the ANN. The dashed line in the Figure is the goal established and the gradient-descent curve indicates the training performance during the process. The neural network reaches the goal requested after 98,103 epochs. Therefore, the network has been trained and will be verified as to whether it is capable of predicting risks by introducing the testing data in the next section.

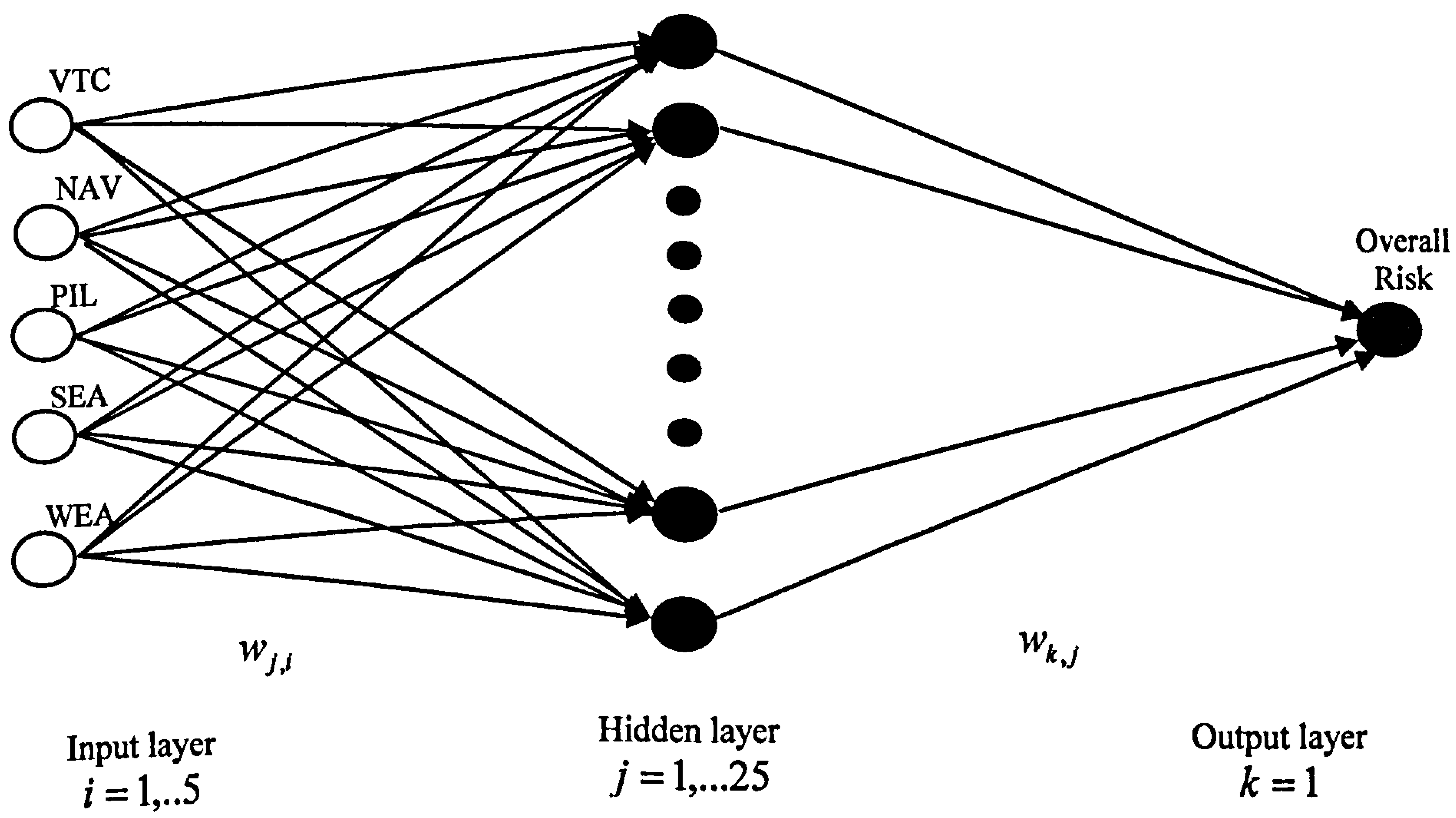

Figure 4.6. The neural network constructed for the study

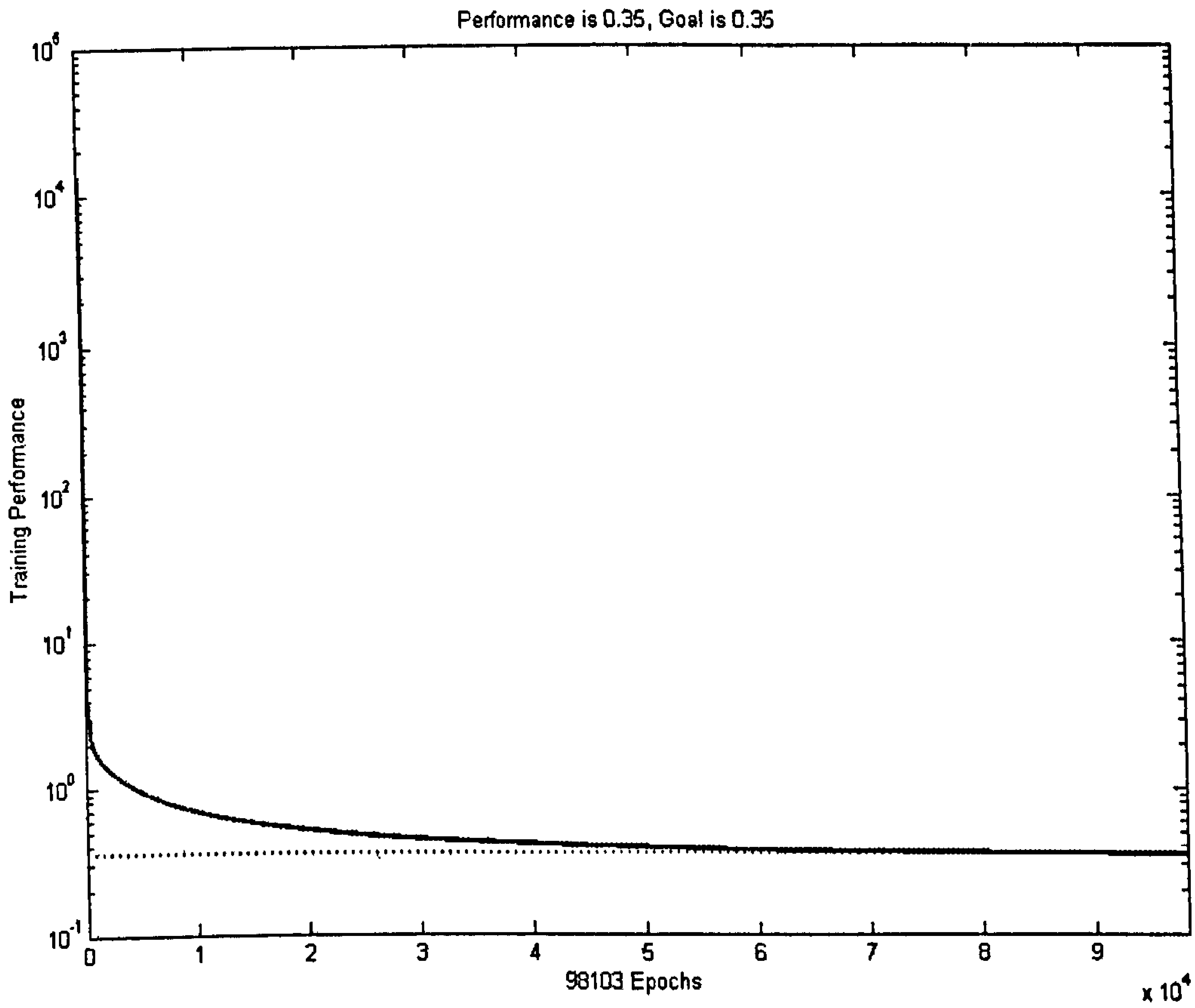

Figure 4.7. The ANN training performance

4.4.6 ANN testing and evaluation

In this step, the trained ANN is verified by introducing 40 sets of testing data. The data is also generated based on the same assumption used to prepare the training data. However, the membership values produced in the testing data are random from 1.0 to 0 whereas the values in the training data are 1.0, 0.75, 0.25 and 0, respectively. Table 4.10 shows the detail of the testing data as well as the results predicted by the network in comparison to the target values conducted using the fuzzy combination algorithm developed. It can be seen that the lowest prediction rate is 92.88% in the set of data numbered 29, which is the only data below 95%. Inspiringly, the average prediction rate of the neural network is over 98% despite the difference between the membership values adopted in the training and testing data. As a result of the average prediction rate generated being greater than the acceptable criterion (90%), there is no need to repeat the steps from 3 to 6 (sections 4.3.3-4.3.6) of the methodology. It can then be concluded that the neural network has been trained appropriately and is capable of predicting risks as long as the training data takes into account any potential circumstance that may be met by the port.

Table 4.10. The detail of the testing data, the ANN prediction value and prediction rate

Data No.	VTC	NAV	PIL	SEA	WEA	T	ANN Value	Prediction Rate (%)
1	V. Poor 0.9, Poor 0.1	V. Poor 0.6, Poor 0.4	V. Poor 0.8, Poor 0.2	V.Poor 0.5, Poor 0.5	V.Poor 0.75, Poor 0.25	4.66	4.69	99.33
2	Poor 0.9, Moderate 0.1	V.Poor 0.8, Poor 0.2	V.Poor 0.8, Poor 0.2	V.Poor 0.7, Poor 0.3	V.Poor 0.75, Poor 0.25	4.49	4.53	99.08
3	Poor 0.9, Moderate 0.1	Poor 0.8, Moderate 0.2	Poor, 0.8, Moderate 0.2	V.Poor 0.7, Poor 0.3	V.Poor 0.2, Poor 0.8	4.02	4.10	98.04
4	Moderate 0.7, Good 0.3	Poor 0.8, Moderate 0.2	Poor 0.8, Moderate 0.2	Moderate 0.7, Good 0.3	Moderate 0.7, Good 0.3	3.04	3.16	96.21
5	V.Poor 0.3, Poor 0.7	Poor 0.4, Moderate 0.6	V.Poor 0.5, Poor 0.5	V.Poor 0.2, Poor 0.8	Good 0.3, Excellent 0.7	3.60	3.55	98.72
6	Moderate 0.3, Good 0.7	Moderate 0.4, Good 0.6	Good 0.5, Excellent 0.5	Moderate 0.2, Good 0.8	V.Poor 0.3, Poor 0.7	2.60	2.53	97.18
7	V.Poor 0.1, Poor 0.9	V.Poor 0.4, Poor 0.6	Poor 0.4, Moderate 0.6	Poor 0.1, Moderate 0.9	Poor 0.3, Moderate 0.7	3.72	3.66	98.56
8	Poor 0.5, Moderate 0.5	Poor 0.4, Moderate 0.6	Poor 0.3, Moderate 0.7	Poor 0.2, Moderate 0.8	Poor 0.3, Moderate 0.7	3.40	3.33	98.08
9	Poor 0.7, Moderate 0.3	Poor 0.8, Moderate 0.2	Moderate 0.7, Good 0.3	Moderate 0.6, Good 0.4	V.Poor 0.8, Poor 0.2	3.43	3.52	97.52
10	Good 0.7, Excellent 0.3	Good 0.8, Excellent 0.2	Moderate 0.7, Good 0.3	Moderate 0.6, Good 0.4	Poor 0.8, Moderate 0.2	2.43	2.50	96.95
11	Poor 0.5, Moderate 0.5	Moderate 0.9, Good 0.1	Moderate 0.7, Good 0.3	Poor 0.6, Moderate 0.4	V.Poor 0.5, Poor 0.5	3.42	3.44	99.32
12	Poor 0.5, Moderate 0.5	Poor 0.9, Moderate 0.1	Moderate 0.7, Good 0.3	Poor 0.6, Moderate 0.4	Good 0.5, Excellent 0.5	3.02	3.06	98.44
13	V.Poor 0.5, Poor 0.5	V.Poor 0.7, Poor 0.3	Poor 0.2, Moderate 0.8	Poor 0.2, Moderate 0.8	Poor 0.5, Moderate 0.5	3.84	3.80	99.16
14	V.Poor 0.5, Poor 0.5	Poor 0.4, Moderate 0.6	Poor 0.7, Moderate 0.3	Poor 0.1, Moderate 0.9	Poor 0.9, Moderate 0.1	3.72	3.71	99.76
15	Moderate 0.5, Good 0.5	Good 0.4, Excellent 0.6	Good 0.5, Excellent 0.5	Good 0.7, Excellent 0.3	Good 0.6, Excellent 0.4	1.73	1.77	97.57
16	Moderate 0.4, Good 0.6	Moderate 0.4, Good 0.6	Good 0.9, Excellent 0.1	Good 0.6, Excellent 0.4	Good 0.6, Excellent 0.4	1.97	1.98	99.83
17	Poor 0.6, Moderate 0.4	Poor 0.8, Moderate 0.2	Poor 0.7, Moderate 0.3	Moderate 0.6, Good 0.4	V.Poor 0.7, Poor 0.3	3.61	3.67	98.40
18	V.Poor 0.1, Poor 0.9	V.Poor 0.8, Poor 0.2	Poor 0.7, Moderate 0.3	Poor 0.6, Moderate 0.4	Moderate 0.8, Good 0.2	3.74	3.79	98.76
19	Poor 0.5, Moderate 0.5	V.Poor 0.8, Poor 0.2	Poor 0.9, Moderate 0.1	Poor 0.6, Moderate 0.4	Good 0.8, Excellent 0.2	3.66	3.71	98.73
20	Moderate 0.5, Good 0.5	Moderate 0.6, Good 0.4	Poor 0.5, Moderate 0.5	Poor 0.9, Moderate 0.1	Moderate 0.7, Good 0.3	3.02	3.02	99.87
21	Moderate 0.2, Good 0.8	Moderate 0.5, Good 0.5	Good 0.3, Excellent 0.7	Good 0.2, Excellent 0.8	V.Poor 0.7, Poor 0.3	2.42	2.36	97.57
22	Good 0.2, Excellent 0.8	Good 0.5, Excellent 0.5	Good 0.3, Excellent 0.7	Good 0.2, Excellent 0.8	V,Poor 0.9, Poor 0.1	2.07	2.03	98.13
23	Poor 0.8, Moderate 0.2	Poor 0.7, Moderate 0.3	Poor 0.6, Moderate 0.4	Poor 0.5, Moderate 0.5	V.Poor 0.9, Poor 0.1	3.85	3.92	98.30
24	Moderate 0.8, Good 0.2	Moderate 0.7, Good 0.3	Moderate 0.6, Good 0.4	Moderate 0.5, Good 0.5	V.Poor 0.9, Poor 0.1	3.05	3.07	99.23
25	Good 0.9,	Moderate 0.7,	Moderate 0.5,	Good 0.9,	Poor 0.9,	2.51	2.58	97.19

	Excellent 0.1	Good 0.3	Good 0.5	Excellent 0.1	Moderate 0.1			
26	V.Poor 0.9, Poor 0.1	V.Poor 0.9, Poor 0.1	V.Poor 0.8, Poor 0.2	V.Poor 0.9, Poor 0.1	Good 0.9, Excellent 0.1	4.17	4.25	98.21
27	Poor 0.2, Moderate 0.8	Poor 0.3, Moderate 0.7	V.Poor 0.5, Poor 0.5	V.Poor 0.1, Poor 0.9	Poor 0.4, Moderate 0.6	3.75	3.68	98.25
28	Moderate 0.6, Good 0.4	Moderate 0.6, Good 0.4	Moderate 0.6, Good 0.4	Good 0.6, Excellent 0.4	Poor 0.6, Moderate 0.4	2.54	2.60	97.75
29	Good 0.9, Excellent 0.1	Good 0.9, Excellent 0.1	Good 0.9, Excellent 0.1	Good 0.9, Excellent 0.1	Good 0.9, Excellent 0.1	1.79	1.91	92.88
30	Good 0.9, Excellent 0.1	Good 0.9, Excellent 0.1	Good 0.6, Excellent 0.4	Moderate 0.2, Good 0.8	V.Poor 0.3, Poor 0.7	2.38	2.36	99.29
31	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.6, Excellent 0.4	Moderate 0.5, Good 0.5	V.Poor 0.7, Poor 0.3	2.75	2.74	99.59
32	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.2, Moderate 0.8	Moderate 0.5, Good 0.5	Poor 0.2, Moderate 0.8	2.80	2.75	98.31
33	V.Poor 0.6, Poor 0.4	Poor 0.5, Moderate 0.5	V.Poor 0.2, Poor 0.8	Poor 0.3, Moderate 0.7	Poor 0.2, Moderate 0.8	3.80	3.75	98.80
34	V.Poor 0.6, Poor 0.4	V.Poor 0.8, Poor 0.2	V.Poor 0.2, Poor 0.8	Poor 0.3, Moderate 0.7	Good 0.2, Excellent 0.8	3.65	3.60	98.65
35	Moderate 0.6, Good 0.4	Moderate 0.8, Good 0.2	Moderate 0.2, Good 0.8	Moderate 0.5, Good 0.5	Good 0.2, Excellent 0.8	2.27	2.27	99.91
36	Good 0.6, Excellent 0.4	Good 0.8, Excellent 0.2	Good 0.2, Excellent 0.8	Good 0.5, Excellent 0.5	V.Poor 0.2, Poor 0.8	2.07	2.07	99.79
37	V.Poor 1	V.Poor 1	V.Poor 1	V.Poor 1	V.Poor 1	5.00	4.93	98.64
38	Poor 1	Poor 1	Poor 1	Poor 1	Poor 1	4.00	4.01	99.81
39	Moderate 1	Moderate 1	Moderate 1	Moderate 1	Moderate 1	3.00	2.99	99.51
40	Good 1	Good 1	Good 1	Good 1	Good 1	2.00	2.01	99.46

Note: T means the target values of the overall risk indices, ANN Values are the values predicted by the neural network after the de-normalising process.

4.4.7 Risk predictions

The neural network trained will be capable of predicting risks with a high degree of reliability if applied. The prediction process can be conducted as follows:

1. The acquirement of the membership values and the linguistic terms associated which describe the circumstance of each parameter.
2. The conversion of the characteristic of each parameter from fuzzy to crisp-value properties using Equations 4.4, 4.5 and 4.6.
3. The adoption of the normalisation process using Equation 4.7.
4. The introduction of the normalised numerical data into the trained neural network.
5. The acquirement of the overall risk predicted by the ANN.
6. The implementation of the de-normalising process transferring the normalised result generated into the crisp-value expression.

Consequently, a risk ranking can be established based on the predicted results generated.

4.5 Conclusion

The traditional fuzzy-rule-base risk assessment technique has been employed in various fields due to the capability of combining different parameters to obtain an overall risk. However, a drawback occurs when the technique is applied in circumstances where there are multiple parameters to be evaluated which are described by multiple linguistic terms. The risk prediction method incorporating fuzzy set theory and neural networks presented in this chapter is capable of avoiding such awkward situations encountered when employing the fuzzy-rule-base technique. However, there is an issue as to whether successful application of this method depends upon the accuracy of the prediction rate, implying the importance of the training data preparation. Therefore, a thorough understanding of the parameters to be evaluated which play important roles in risk analysis is crucial, since neural networks only recognise the patterns similar to the ones they met in the training process. Thus, if a neural network is trained using data which covers more potential circumstances that the port may confront, the result of the prediction generated is more reliable. In addition, the fuzzy combination algorithm developed in this study could also be applied even without the use of neural networks. It would be more computing-intensive if the algorithm were employed independently. Nevertheless, whether the application combining the fuzzy combination algorithm with neural networks or the practice employing the algorithm alone is utilised, the process is computing-intensive. Therefore, the adoption of calculating computer software is highly recommended.

Chapter 5. Human Error Assessment in Port Operations using Fuzzy Analytical Hierarchy Process

Human error accounts for a significant contribution to maritime accidents. There has been growing commitment attempting to tackle such a problem. In this chapter, following a review discussion of traditional HRA methods, a new method of human error assessment using fuzzy set theory and Analytical Hierarchy Process (AHP) is proposed. In assessing the human error risk using the proposed method, the steps in each mission of port operations are compared to each other in terms of the likelihood, failure consequence probability and severity criteria to acquire the relative importance and overall risk priority. The method is demonstrated using a test case of an oil cargo handling process in port, and is capable of avoiding the criticism raised when using traditional HRA techniques.

5.1 Introduction

Human error plays a crucial role in the causes of many major marine accidents. It costs the maritime industry approximately $541m per year according to the UK P&I Club [UK P&I Club, 2003]. Some 62% of the 6,091 major claims spanning a period of 15 years based on the analysis conducted by the Club are attributable to human error. There has been an increasing commitment to explicitly identify and address the impact of such an element upon marine safety in the maritime community since the accidents of Piper Alpha, Braer, Estonia and Herald of Free Enterprise. The examples for such commitments include the evaluations of the role of Human and Organisation Errors (HOEs) in the life cycle of vessels [Moore and Bea, 1995] and in offshore structures [Bea, 1998], the application of the knowledge addressing the HOE in marine operations to tanker loading and discharging operations [Bea *et al.*, 1996], the collection of offshore human error probability data [Basra and Kirwan, 1998], human error assessment and decision making using AHP [Pillay and Wang, 2003], etc. A new method of human error assessment using fuzzy set theory along with AHP is proposed in this study. The method is demonstrated by a test case of an oil cargo handling process in port, and is capable of avoiding the awkward situation met as addressed in section 5.2.3 when applying traditional HRA techniques.

5.2 Background

5.2.1 Human error related accidents in ports

Human error is one of the most important factors contributing to port accidents. This can be verified by the statistics shown in Table 2.11 of this PhD study where human errors make a significant contribution in port operations, consisting of 19.5%. In addition, it can be seen from Table 2.12 that cargo loading and unloading is also an important factor in seaport accidents, comprising 15.1%. With the available information from Major Hazard Incident Data Service (MHIDS), the accidents have been divided into the categories of oils, chemicals, acids, natural gas and others. The greatest proportion of the accidents occurred with oils, of which the percentage is 59% [Darbra and Casal, 2004]. Therefore, because of the quality and quantity of the data available, the test case selected for illustrating the proposed framework of human error assessment is an oil cargo handling process.

5.2.2 Human reliability assessment (HRA)

HRA deals with the risk contributed by human error. Most HRA material is concerned with the quantification of the potential for human error. In general, HRA has three fundamental functions, namely, the identification of human errors, the prediction of their likelihood and reduction of the likelihood if required [Kirwan, 1992a]. The HRA approaches can be divided into two categories, those using a database, and those using expert judgement [Kirwan, 1996]. The approaches falling into the first category apply a database containing generic Human Error Probability (HEP) to the specific circumstance being assessed. The manipulation is often based on the assessment of circumstance related Performance Shaping Factors (PSFs) that modify the probabilities based on environmental and contextual circumstances. The HEPs obtained based on the approaches in the second category are acquired by asking experts directly with regard to the scenario under consideration. Alternatively, some approaches in this category generate HEPs by manipulating and interrogating a quasi database which has some basis in real data from industrial incidents and which is incorporated with expert judgement. Some most widely used HRA techniques in the UK include Technique for Human Error Rate Prediction (THERP) [Swain and Guttmann, 1983], Human Error Assessment and Reduction Technique (HEART) [Kirwan, 1994], Justification of Human Error Data Information (JHEDI) [Kirwan, 1992b], Success Likelihood Index Method using Multi-Attribute Utility Decomposition (SLIM-MAUD) [Gertman and Blackman, 1993], Paired Comparisons [Hunns, 1982], and Absolute Probability Judgement [Seaver and Stillwell, 1983].

5.2.3 The criticisms of HRA

Although HRA has been adopted in various industries, it is not without some problems. The issues addressed below are the drawbacks criticised when applying the HRA approaches [Hollnagel, 1993] [Fields, 2001] [Kirwan, 1994].

1. For the methods such as THERP, the information contained in the database is from a variety of sources. The reliability of such data has always been questioned.

2. The approaches often involve steps of breaking the task into small components, assigning probabilistic estimates to the components and producing the results to provide an overall risk index. The validity of these steps is often criticised.

3. The nature of the sources from which the data is collected may be different from the context to be assigned the HEPs. This may influence the quality of the HRA.

4. The precision of the opinions with regard to relative importance of the PSFs or the HEP predictions is often questioned.

5. Interdependencies existing between the factors under consideration are rarely addressed. The Error Producing Conditions (EPCs) in the HEART method, e.g. interact with each other in complex ways, of which the interdependencies are usually ignored.

5.2.4 Fuzzy set theory

As aforementioned in section 3.2.1 the objective of fuzzy set theory is to help in making decisions characterised by imprecise information [Zadeh, 1965] [Klir and Folger, 1988] [Predrycz and Gomide, 1998]. Again, the strengths and background of fuzzy set theory are available and can be found in section 3.2.1 of this PhD study.

5.2.5 Analytical hierarchy process (AHP)

The AHP proposed by Satty is a multi-criteria decision making approach which can be used to solve complex decision problems [Satty, 1980]. It uses a multi-level hierarchical structure of objectives, criteria and alternatives. The weights and relative importance of the element in each hierarchy can be acquired using the pairwise comparison technique. An overall preference of the alternatives is obtained based on the weights and relative importance calculated. If the comparisons are not perfectly consistent, a mechanism for improving consistency is provided [Anderson *et al.*, 2003]. In general, the AHP consists of the following four steps [Drake, 1998]:

1. The selection of criteria.
2. Evaluation of the relative importance of these criteria using pairwise comparisons.
3. Evaluation of each alternative relative to each other on the basis of each selection criteria using the pairwise comparison technique.
4. Combination of the ratings acquired in steps 2 and 3 to obtain an overall relative rating for each alternative.

5.2.6 The problem with AHP

In the AHP, the pairwise comparison technique is crucial since it is concerned with the quantification of the expert opinions using a scale. The scale is a one-to-one mapping between a set of linguistic expressions and a discrete set of numerals representing the importance of the linguistic expressions. The main problem with it is how to quantify the linguistic expressions selected precisely [Triantaphyllou *et al.*, 1994]. Although there have been two major approaches in developing such scales, a linear scale defined on the interval [9, 1/9] [Satty, 1980], and an exponential scale [Lootsma, 1988, 1990, 1991], the mapping between linguistic terms and discrete numerals is sometimes regarded as too straightforward and its preciseness is questioned.

5.2.7 Fuzzy AHP

The fuzzy AHP method uses the estimation of an underlying rational scale described by membership functions to express fuzzy information. It allows a more accurate description of the decision making process. There have been many fuzzy AHP methods proposed. The earliest fuzzy AHP compared fuzzy ratios using triangular membership functions [Van Laarhoven and Pedrycz, 1983]. Another fuzzy AHP was developed to determine fuzzy priorities of comparison using trapezoidal membership functions [Buckley, 1985]. A more robust approach was applied to normalise the local priorities by modifying the Van Laarhoven-Predrycz approach [Boender *et al*, 1989]. Another approach for handling fuzzy AHP was also introducted, which utilises triangular fuzzy numbers for pairwise comprison scale of fuzzy AHP and applies the extent analysis method for the synthetic extent values of the pairwise comparison [Chang, 1996]. The fuzzy AHP approach has been applied to various fields, including the assessment of alternative production cycles [Weck *et al.*, 1997], the evaluation of weapon systems [Ching-Hsue, 1997] [Cheng *et al*, 1999], the assessment of modular product design [Lee *et al.*, 2001], the determination of the importance of customer requirements in quality function deployment [Kwong and Bai, 2003], the analysis of the financial and non-economic aspect of technology selection [Tola *et al.*, 2005], the reduction of a set of conceptual design alternatives [Ayag, 2005], etc..

5.2.8 The fuzzy AHP proposed

A fuzzy AHP is proposed for resolving the difficulties encountered when conducting HRA as well as the application of the traditional AHP described in sections 5.2.3 and 5.2.6. The method proposed utilises the fuzzy set theory to express the opinions from experts in the pairwise comparison stage rather than using the linear or exponential scales [Ung *et al.*, 2006b]. This provides another concern as to the preciseness with regard to the expert judgement in pairwise comparisons. On the other hand, since the proposed fuzzy AHP does not consider the HEP database as evaluating HRA, it avoids the difficulties encountered when applying traditional HRA approaches. The research methodology of the framework proposed and a test case illustrating its application are presented in the following sections.

5.3 Research methodology

The framework of human error assessment in this study starts with the operational description and mission identification, so enabling a full understanding of the test case in question. Therefore, an AHP structure can be established. In this structure, there will be four hierarchies required, namely, the operation hierarchy, risk factor (criteria), mission and step hierarchies. Since the study incorporates the fuzzy set theory into the AHP method to evaluate human error related risks, a set of linguistic priority terms along with the membership functions describing the relationship between the elements in each hierarchy of the AHP structure will be adopted. Therefore, the pairwise comparisons between the elements in each hierarchy using fuzzy set theory will be able to be established. The fuzzy expressions are subsequently converted to the single crisp values using the appropriate defuzzification method. This is followed by the weighting vector calculation so as to obtain the relative importance of the elements. By repeating the steps aforementioned, the risk of the elements in the step hierarchy in terms of each criteria defined will be acquired based on the normalised weighting vectors calculated. The results obtained from these three criteria will then be synthesised and an overall risk priority will finally be established based on the combined risks. Figure 5.1 shows the research methodology of this study and each step of the framework is discussed in the following subsections.

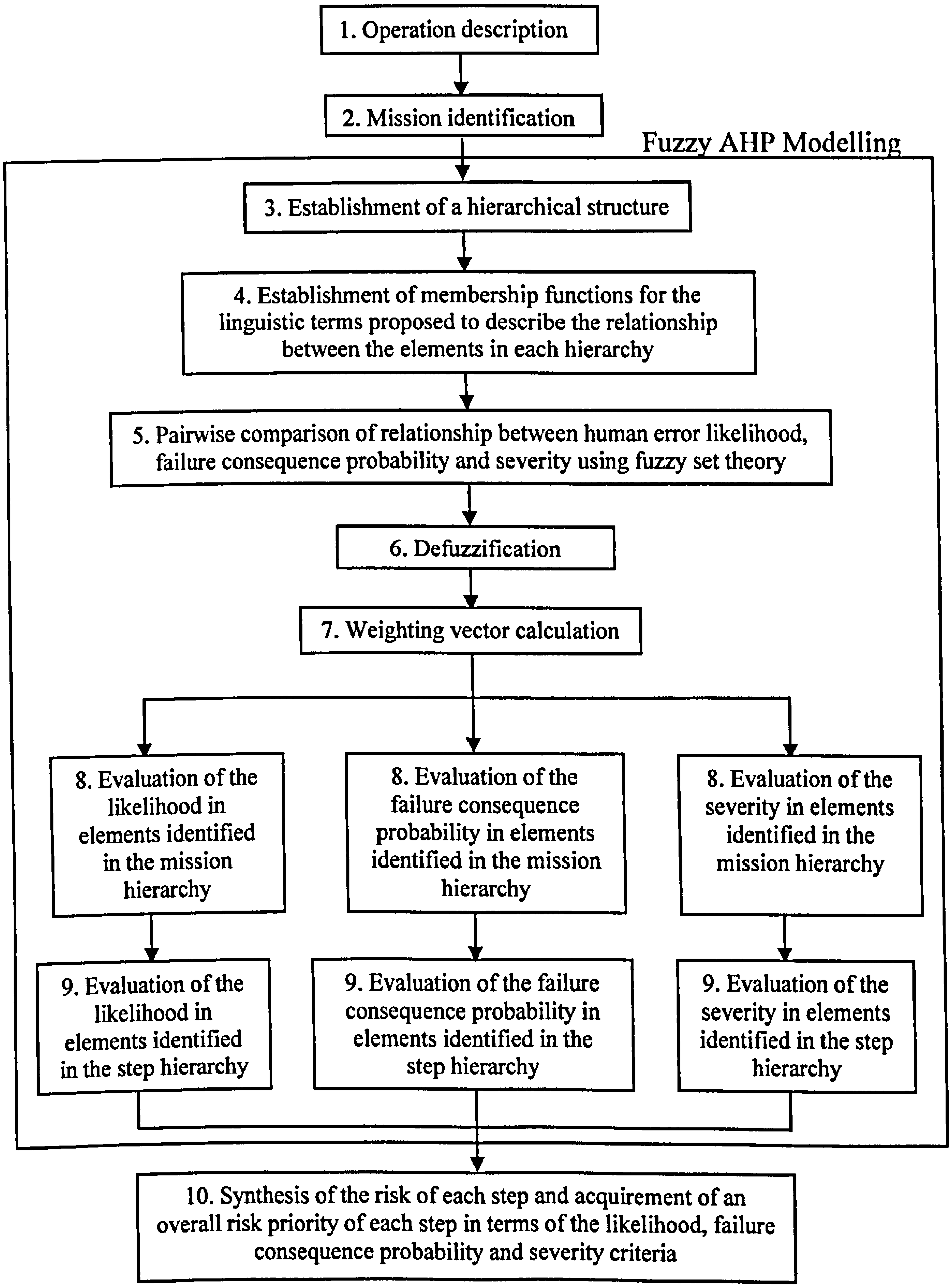

Figure 5.1. The research methodology of human error assessment in port operations

5.3.1 Operation description

The first step in this study is to describe the port operation under consideration in detail. It is noted that the more detailed the procedures of the operation are narrated, the more useful the information about human-related performance that will be obtained.

5.3.2 Mission identification

In this step the missions to be performed will be identified and presented in their appropriate order. The processes contained in each mission are also described. This forms a hierarchical structure enabling an effective application of the AHP method in the subsequent steps.

5.3.3 Establishment of an AHP structure

The AHP structure starts with Hierarchy 1, the port operation statement describing all activities required to take place. The information from sections 5.3.1 and 5.3.2 will be useful references for this step. The elements contained in Hierarchy 2 are the criteria to be used to perform pairwise comparisons in the next levels. These criteria are often identified by brainstorming or experience based on expert judgement. In this study, the criteria are set to be the probability of occurrence, the failure consequence probability and the severity of human errors that might possibly influence port operations. Hierarchy 3 shows the procedure in order whereas Hierarchy 4 contains the steps taking place in each mission. Figure 5.2 shows an example of a hierarchical structure similar to the one to be adopted in this study.

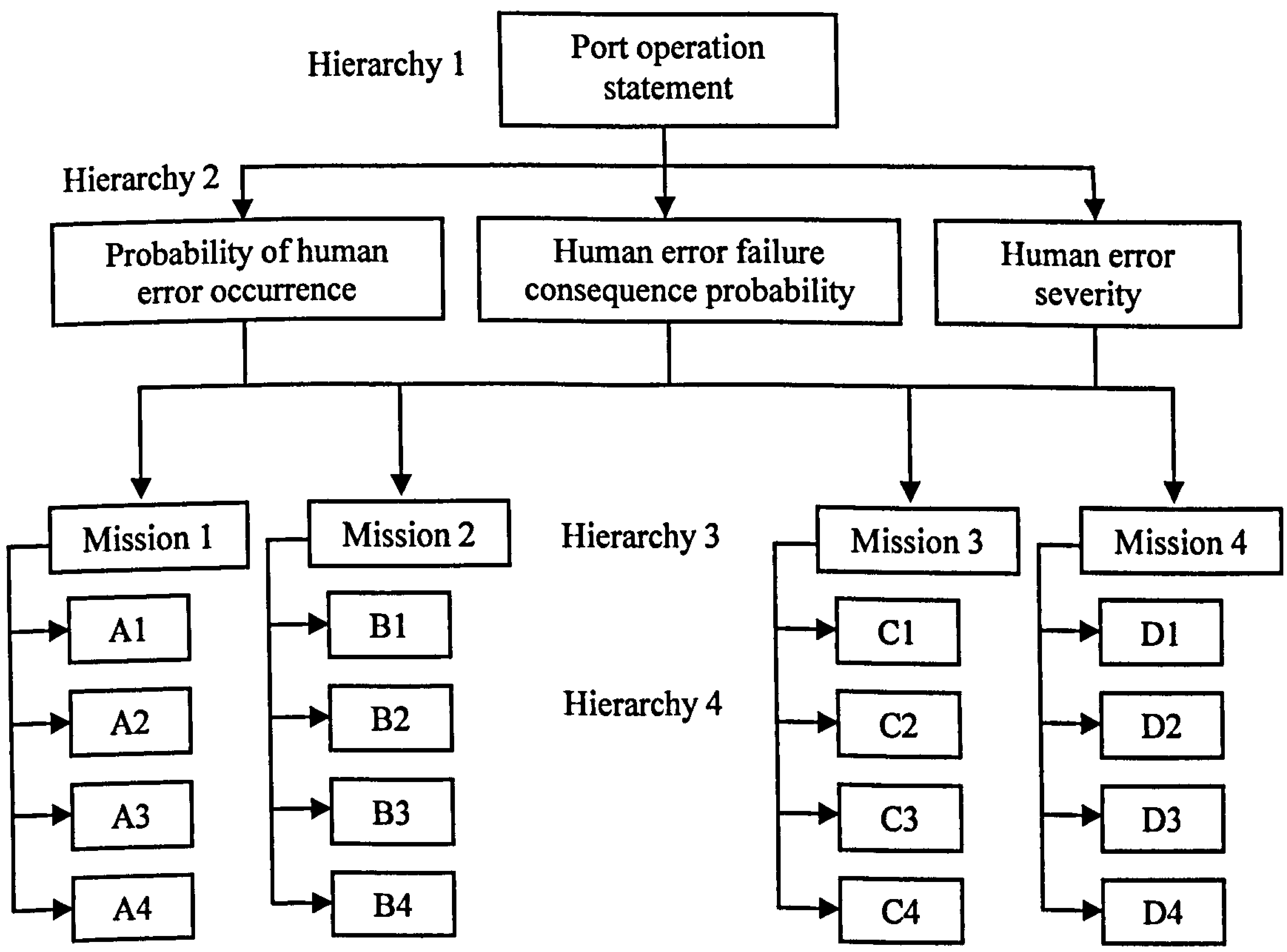

Figure 5.2. An example of an AHP hierarchy structure

5.3.4 Establishment of membership functions for the linguistic priority terms describing the relationship between the elements in each hierarchy

Membership functions are established for linguistic priority terms describing human error probability, failure consequence probability, severity and missions using multiple experts. The experts involved in human error assessment in a port operation project should be appropriately selected so that an unrealistic and biased membership function will be avoided [Kuusela *et al.*, 1998]. Each expert is asked to evaluate a proposition, 'x belongs to A?'. Suppose A is a fuzzy set on X that represents a linguistic priority term associated with a given linguistic variable and $a_i(x)$ is a value of scores within a certain range in X i.e. $a_i(x) \in$ X (in this study, X is defined to be 10 categories i.e. 0-10 categories). In situations where there are n experts and each of them has equal competence, the following formula is applied [Klir and Yuan, 1995]:

$$\mathrm{A}(x) = \frac{\sum_{i=1}^{n} a_i(x)}{n} \qquad \text{(Equation 5.1)}$$

where $\mathrm{A}(x)$ is the final answer (value) after the judgements made by n experts are synthesised, and

$a_i(x)$ is the answer (value) given by the i^{th} expert, $i \in n$.

In the case where the experts have different degrees of competencies, Equation 5.1 is modified as:

$$\mathrm{A}(x) = \sum_{i=1}^{n} Comp_i a_i(x) \qquad \text{(Equation 5.2)}$$

where $Comp_i$ is the degree of competency of the i^{th} expert, and

$$\sum_{i=1}^{n} Comp_i = 1 \qquad \text{(Equation 5.3)}$$

It is important to note that the degree of competency for each of the experts should be determined based on his/her knowledge and experience in human error assessment as well as that in the port operation field.

The triangular membership function is adopted since it has a smooth transition from one linguistic priority term to the other. On the other hand, it facilitates easy defuzzification of each linguistic priority term. The membership function for each linguistic priority term is evaluated within its limits on an arbitrary scale from 0 to 1.

5.3.5 Pairwise comparison of human error probability of occurrence, failure consequence probability and severity

Since the elements of human error probability of occurrence, failure consequence probability and severity are identified as crucial criteria in risk assessment, the relationship between these three factors will be evaluated using the membership functions established in section 5.3.4. This means that the relative importance identified will be described by a membership degree associated with one or more linguistic terms. A pairwise comparison matrix will also be developed. When evaluating the relationship between the elements the membership functions can be determined by either a crisp numerical value (for a single deterministic value), a range (for a closed interval), a most likely value (for a triangular distribution), or a most likely range (for a trapezoidal distribution) limited to the universe of discourse in question [Sii, et. al., 2005]. This depends on the knowledge experience of the experts specialising in port operations.

5.3.6 Defuzzification process

The defuzzification process obtains a single crisp value converted from the fuzzy output describing the relationship between the probability of human error occurrence, failure consequence probability and severity. Several defuzzification algorithms have been developed. The method selected for use in this study is the Weighted Mean of Maximums (WMoM) since it is computationally lighter. The algorithm averages the points of maximum possibility of each fuzzy expression, weighted by their degree of truth at which the membership functions reach their maximum values [Pillay, et. al., 2003]. The formula of WMoM is given as follows:

$$WMoM = \frac{\sum w_i x_i}{\sum w_i} \qquad \text{(Equation 5.4)}$$

where w_i is the degree of truth of the membership function of the i^{th} linguistic priority term, and

x_i is the risk rank at maximum value of the membership function of the i^{th} linguistic priority term.

5.3.7 Weighting vector calculation

After the defuzzification process, the fuzzy pairwise comparison matrices have been converted into a single-value comparison matrix. Suppose the quantified judgement on pairs of criteria C_i and C_j are represented by an $n \times n$ single-value comparison matrix A.

$$A = (a_{ij}) = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \cdot & \cdot & \cdots & \cdot \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \quad \text{(Equation 5.5)}$$

where each a_{ij} is the relative importance of criteria C_i and C_j.

The weighting vector indicating the priority of each element in the pairwise comparison matrix in terms of its contribution to the overall risk can be obtained by a synthesisation procedure [Anderson, et. al., 2003], which consists of the following three steps:

1 Calculating the summation of the values in each column of the pairwise comparison matrix.

2 Dividing each element in the pairwise comparison matrix by its column summation. The resulting matrix is referred to as the normalised pairwise comparison matrix.

3 Computing the average value of the elements in each row of the normalised pairwise comparison matrix. In this section the average values of each element indicate the priority for the criteria under consideration.

The mathematical expression of the synthesisation is shown in Equation 5.6.

$$w_k = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{kj}}{\sum_{i=1}^{n} a_{ij}} \quad \text{(Equation 5.6)}$$

where w_k is the weighting vector of a specific element k in the pairwise comparison matrix, and $k = 1,2.....n$.

The aspect of the consistency of pairwise judgements provided by decision makers is important. When numerous pairwise comparisons are evaluated, perfect consistency may be difficult to achieve, and some degree of inconsistency could be expected to exist in almost any set of pairwise comparisons. The AHP method provides a measure of the consistency for pairwise comparisons by introducing a consistency ratio. The ratio is designed in such a way that a value greater than 0.1 indicates an inconsistency in the pairwise judgements in question, meaning that the comparisons will have to be revaluated. The comparisons will be considered reasonable only if the consistency ratio is equal to or less than 0.1 [Yang, el. al., 2001]. The exact mathematical computation of the ratio is beyond this study, however, an approximation of the ratio can be obtained using the algorithm described in Equation 5.7 below.

$$CR = \frac{CI}{RI} \qquad \text{(Equation 5.7)}$$

where CR is the consistency ratio, RI is the random index for the matrix size, n. The value of RI depends on the number of items being compared and is given in Table 5.1 [Satty, 1980], and CI is the consistency index that can be obtained from Equation 5.8.

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad \text{(Equation 5.8)}$$

where $\lambda_{\max}$ is the maximum eigenvalue of an $n \times n$ comparison matrix A that is calculated using Equation 5.9.

$$\lambda_{\max} = \frac{\sum_{k=1}^{n} \frac{\sum_{k=1,j=1}^{n} w_k a_{kj}}{w_k}}{n} \qquad \text{(Equation 5.9)}$$

Table 5.1. Average random index values

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Note: n is the size of the pairwise comparison matrix.

Source: [Satty, 1980]

5.3.8 Evaluation of human error likelihood, failure consequence probability and severity in the elements identified in the mission hierarchy

In this step, the probability of occurrence, failure consequence probability and severity of human errors that might potentially occur in the missions identified in section 5.3.2 will be evaluated separately. This is achieved by repeating Steps 4-7 (sections 5.3.4-5.3.7) of the research methodology. In other words, the pairwise comparisons in this section will be performed by evaluating the relationship between the elements in the mission hierarchy.

In order to realise the contribution of each element in terms of its probability of occurrence, the failure consequence probability and severity to the overall risk, the weighting vector of each element in the hierarchy is multiplied by the weighting vector obtained in its upper level to acquire the normalised vector.

5.3.9 Evaluation of human error likelihood, failure consequence probability and severity in the elements identified in the step hierarchy

Using the method of pairwise comparison matrices aforementioned, the risk (normalised weighting vector) of each step in the missions evaluated in terms of the criteria of probability of occurrence, failure consequence probability and severity will be obtained.

5.3.10 Synthesis of the risk of each step in terms of the three criteria and establishment of an overall risk priority for all oil cargo handling steps

The results of the normalised vector of each step required to complete the missions in terms of the aforementioned criteria can then be synthesised to obtain the overall risk for each step. Accordingly, the overall risk priority of these steps in port operations will finally be established. After acquiring the result of the overall risk priority of the steps in port operations, the steps with potentially higher human error related risks will be identified and deserve more attention than the others.

5.4 Test case

The test case used to illustrate the idea of assessing human error related risks in port operations is an oil cargo handling process at a terminal. The following sections demonstrate the method using the steps addressed in the research methodology.

5.4.1 Operation description

The oil cargo loading operations of tankers using loading arms include the steps of approach and berthing, connection, start up, steady rate, finishing, disconnection and departure [Bea *et al.*, 1996]. Approach is the movement of vessels from the pilot area to a pier. Berthing is the securing of vessels alongside the pier. The connection process is the attachment operation of manifolds between ships and shore. Start up is the gradual increase in flow rate. The steady rate agreed will be reached when the cargo handling process is examined to be in a perfectly safe circumstance. As the ship tanks are nearly full, the finishing process will commence. Subsequently, the flow rate decreases gradually and will be stopped when the oil loading is successfully completed. The manifolds will then be disconnected, and finally the vessel departs.

5.4.2 Mission identification

As stated in the previous section that the oil cargo loading and discharging operations of tankers consist of approach and berthing, connection, start up, steady rate, finishing, disconnection and departure. The steps needed to achieve each mission are subsequently identified and described in the following sections.

5.4.2.1 Approach and berthing

In general, there are six steps associated with approach and berthing, which are berth selection, the assistance of tugs when approaching, ship positioning with tugs, approaching speed to berth, line handling and final berthing.

5.4.2.2 Connection

Connection is a task that attaches the shore piping system to the tanker piping system. The connection process consists of the missions of pre-transfer conference, flange preparation, loading arm connection and alignment check. The details of the oil transfer are discussed by the personnel that will be involved in the oil cargo handling during the pre-transfer conference. The actions of flange preparation and connection are committed after the pre-transfer conference. Loading arms are moved to the vessel and drains are opened so that any oil product remaining in the arms will be emptied. Face plates are then removed and o-rings are examined before attaching to the ship flanges and will be replaced if worn or damaged. This is followed by securing the arms to the ship flanges. The mission of alignment check will be initiated if necessary so as to ensure that all connections are tight.

5.4.2.3 Start up

In this process the personnel in charge of the vessel, the berth operator and the pump operator play crucial roles. The procedure starts with the open and verification of valves by the receiving party. The initiating party then opens its valves. After the path of the oil product is verified the initiating party requests permission to commence pumping. The oil flow is started at a slow rate and all connections are checked for leaks. Loading arms are observed to ensure the absence of excessive cyclic loading due to fluctuating rates or line hammer due to sudden valve closure. After both the initiating and receiving parties are certain that either side is operating appropriately, the flow rate will be increased.

5.4.2.4 Steady rate

The first step of this process is the increase of the flow to steady rate. The step will be monitored by the personnel involved in the oil cargo handling. When the flow is set in the steady rate condition, the volume of transfer is calculated continuously and verified periodically to ensure that all oil is accounted for. Tiny deviation is to be expected. However, if the deviation is unusually high it is likely that the missing oil is spilling somewhere.

5.4.2.5 Finishing

As the tanks become nearly full, the finishing process takes place. Finishing is the most complex and difficult process in the cargo handling operation. The process begins with the prior warning, which requires timed communication and appropriate control of the critical equipment. The timing of the notification of the finishing is important. The recommended time of the notification is 30 minutes before the transfer is to be completed. In the prior warning step, the receiving party will alert the initiating party to stand by the valves for further notification. Some 15 minutes before the end of the cargo handling, the valves are closed incrementally by the initiating party. Careful and slow manipulations of these valves should be made so that no hydraulic shock will result in line rupturing. The pumps are slowed and then stopped in response to the back pressure on the line as the valve is closed. As receiving the notification to stop the flow, valves are closed completely by the initiating party and the valves under control of the receiving party remain open so that the lines can be drained in preparation for the disconnection process.

5.4.2.6 Disconnection

The process starts with the drain of the lines using drain taps in both headers and arms. Flanges are then disconnected from the bottom around to the top connectors to allow any remaining oil to drain into the containment tray. After the loading arms are disconnected from the vessel, the o-ring is examined and replaced if damaged. The face plates are then secured. Finally, the loading arms are protected with plastic covers to catch any possible drips and then returned to rest position at the berth.

5.4.2.7 Departure

The lines on the vessel are let go and it is pulled away from the terminal by the assisting tugs. Finally, the tanker departs for its next port of call. Table 5.2 shows the detail of the oil cargo handling procedure consisting of the steps of each mission.

Table 5.2. The detail of the oil cargo handling procedure

Processes or missions	Steps needed to achieve the mission
1. Approach and berthing	1. Berth selection 2. Approach with tugs 3. Ship positioning 4. Approaching speed to berth 5. Line handling 6. Final positioning
2. Connection	1. Pre-transfer briefing 2. Removal of face plates 3. Examination of o-rings 4. Loading arms connection 5. Alignment check
3. Start up	1. Valves opened and verified by the receiving party 2. Valves opened and verified by the initiating party 3. Request of permission to commence pumping by the initiating party 4. All connections checked for leaks 5. Observation of loading arms 6. Gradual increase of flow after both parties ensure that either side of the system is functioning properly
4. Steady rate	1. Gradual increase of flow to steady rate 2. Continuous calculation and periodical verification of the volume of transfer
5. Finishing	1. Prior warning 2. Closing valves slowly by the initiating party 3. Shutting down pump 4. Closing valves completely by the initiating party

6. Disconnection	1. Drain of lines using drain taps in both headers and arms 2. Disconnection of flanges 3. Disconnection of loading arms from the ship 4. Examination of o-rings and securing of face plates 5. Use of plastic covers protecting loading arms
7. Departure	1. Ship lines let go 2. Vessel pulled away from the wharf by assisting tugs

Source: [Bea *et al.*, 1996]

5.4.3 Establishment of an AHP structure

Figure 5.3 is the AHP structure established for the cargo handling in an oil terminal. Hierarchy 1 in the AHP structure contains the oil cargo handling operation. The information in section 5.4.1 and 5.4.2 is a useful reference for this. Since the objective of this study is to evaluate human error related risks, the elements adopted in hierarchy 2 are human error probability of occurrence, failure consequence probability and severity, respectively. The processes and steps needed for the oil product transfer procedure have been described in section 5.4.2 and can be presented in a hierarchical structure shown in hierarchies 3 and 4.

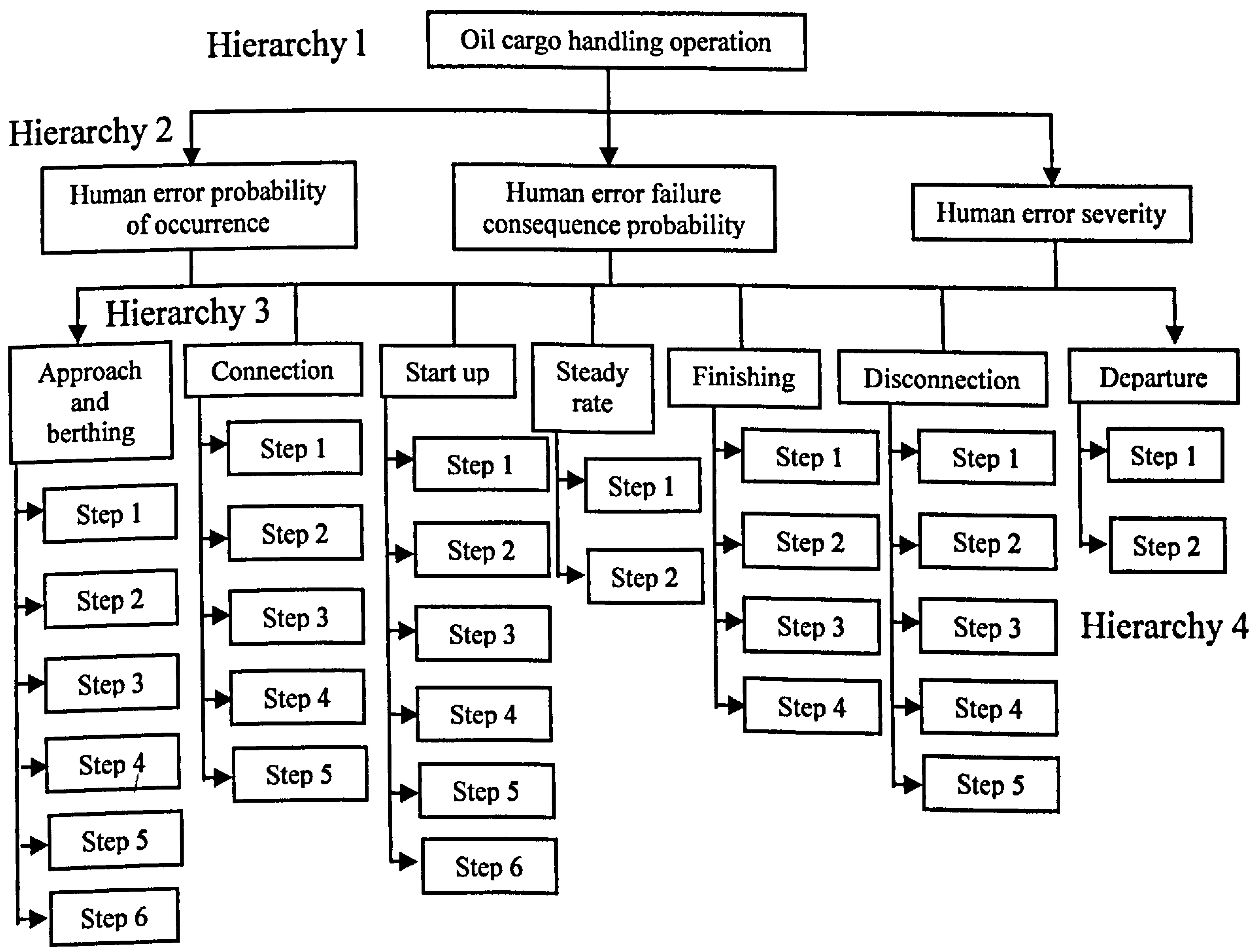

Figure 5.3. The AHP structure of the oil cargo handling operation

5.4.4 Establishment of membership functions for the linguistic priority terms describing the relationship between the elements in each hierarchy

Six linguistic terms are adopted to describe the relative importance of the elements in each hierarchy, namely, 'Equally', 'Slightly', 'Moderately', 'Fairly', 'Strongly' and 'Absolutely' more important. Table 5.3 interprets the definition of the linguistic terms when applied in a pairwise comparison matrix.

Table 5.3. The interpretation of linguistic terms describing the relative importance of human error probability of occurrence, failure consequence probability and severity in pairwise comparison matrices

Linguistic terms	Interpretation
Equally	Both equally important
Slightly	Left slightly more important than top
Moderately	Left moderately more important than top
Fairly	Left fairly more important than top
Strongly	Left strongly more important than top
Absolutely	Left absolutely more important than top

The next step is to establish the membership functions for the linguistic terms. Using Equations 5.2 and 5.3 provided that the weight of each expert is given, the value of $A(x)$ capable of fully representing each linguistic term can be determined. It can be obtained as follows (provided that there are four experts with the weights of 0.2, 0.3, 0.2 and 0.3, associated with their individual answer as to the value that can fully describe the linguistic term, Fairly, e.g. when the membership function reaches 6, 6, 8, and 8, respectively):

$$A(x)_{Fairly} = \sum_{i=1}^{4} C_i a_i(x) = 0.2 \cdot 6 + 0.3 \cdot 6 + 0.2 \cdot 8 + 0.3 \cdot 8 = 7.0$$

The values of two limits of the linguistic term, Fairly, as the membership function reaches 0, can also be obtained using the same pattern described above. Figure 5.4 shows the membership functions established for the six linguistic terms depicting the relative importance between the criteria of likelihood, failure consequence probability and severity based on expert judgement.

The membership functions for the linguistic terms describing the relationship between the elements in the mission and step hierarchies in terms of probability of occurrence, failure consequence probability and severity criteria can be established using the pattern illustrated above. Tables 5.4 and 5.5 present the interpretation of the linguistic terms describing the relationship between the elements in the mission and step hierarchies in terms of the likelihood, failure consequence probability and severity criteria when applied in the pairwise comparison matrices. Likewise, Figures 5.5 and 5.6 show the membership functions established for the linguistic terms employed in terms of the human error likelihood and failure consequence probability as well as severity criteria.

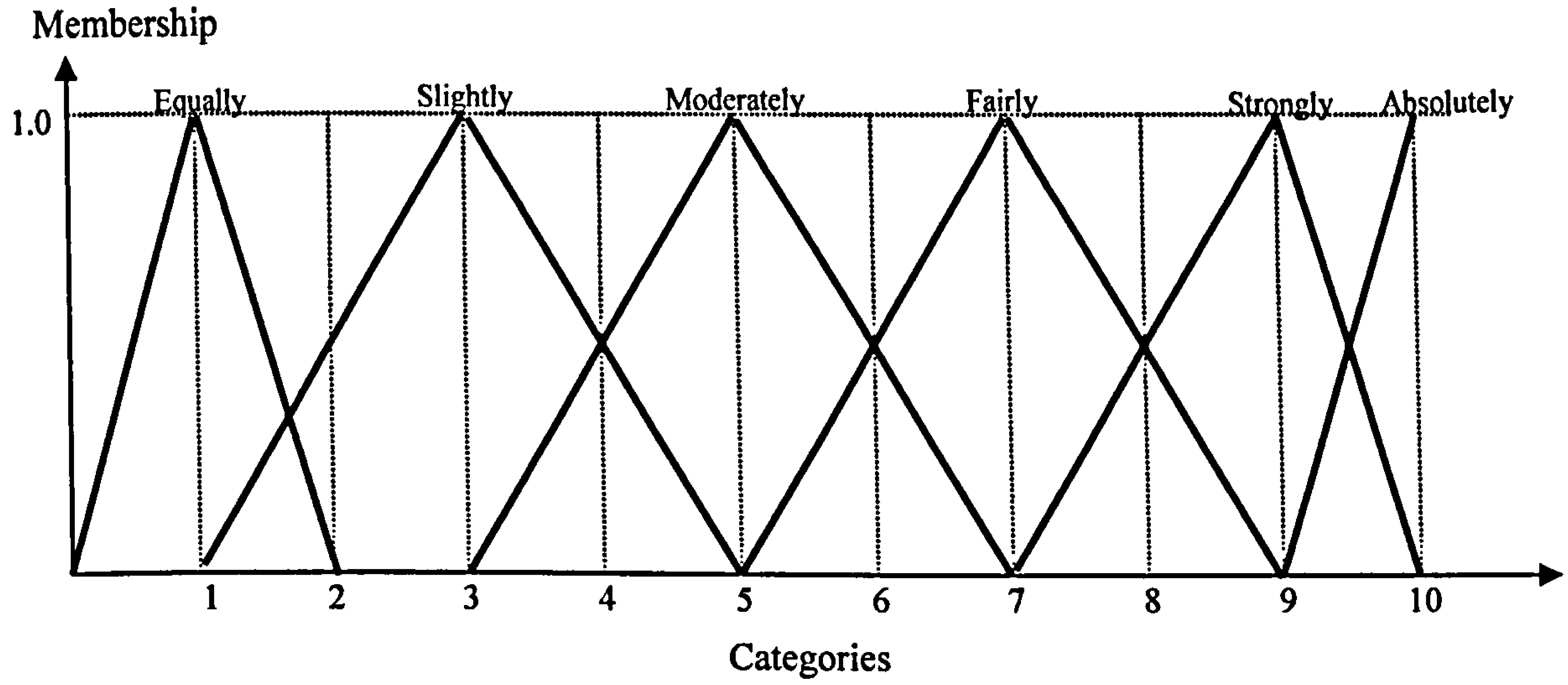

Figure 5.4. Membership function for the linguistic terms describing the relative importance of human error probability of occurrence, failure consequence probability and severity

Table 5.4. The interpretation of the linguistic terms describing the relationship between the elements in the mission and step hierarchies in terms of the human error probability of occurrence and failure consequence probability criteria

Linguistic terms	Interpretation
Equally	Both magnitudes equal
Slightly	Left slightly higher than top
Moderately	Left moderately higher than top
Fairly	Left fairly higher than top
Strongly	Left strongly higher than top
Absolutely	Left absolutely higher than top

Table 5.5. The interpretation of the linguistic terms describing the relationship between the elements in the mission and step hierarchies in terms of the human error severity criteria

Linguistic terms	Interpretation
Equally	Both magnitudes equal
Slightly	Left slightly more serious top
Moderately	Left moderately more serious than top
Fairly	Left fairly more serious than top
Strongly	Left strongly more serious than top
Absolutely	Left absolutely more serious than top

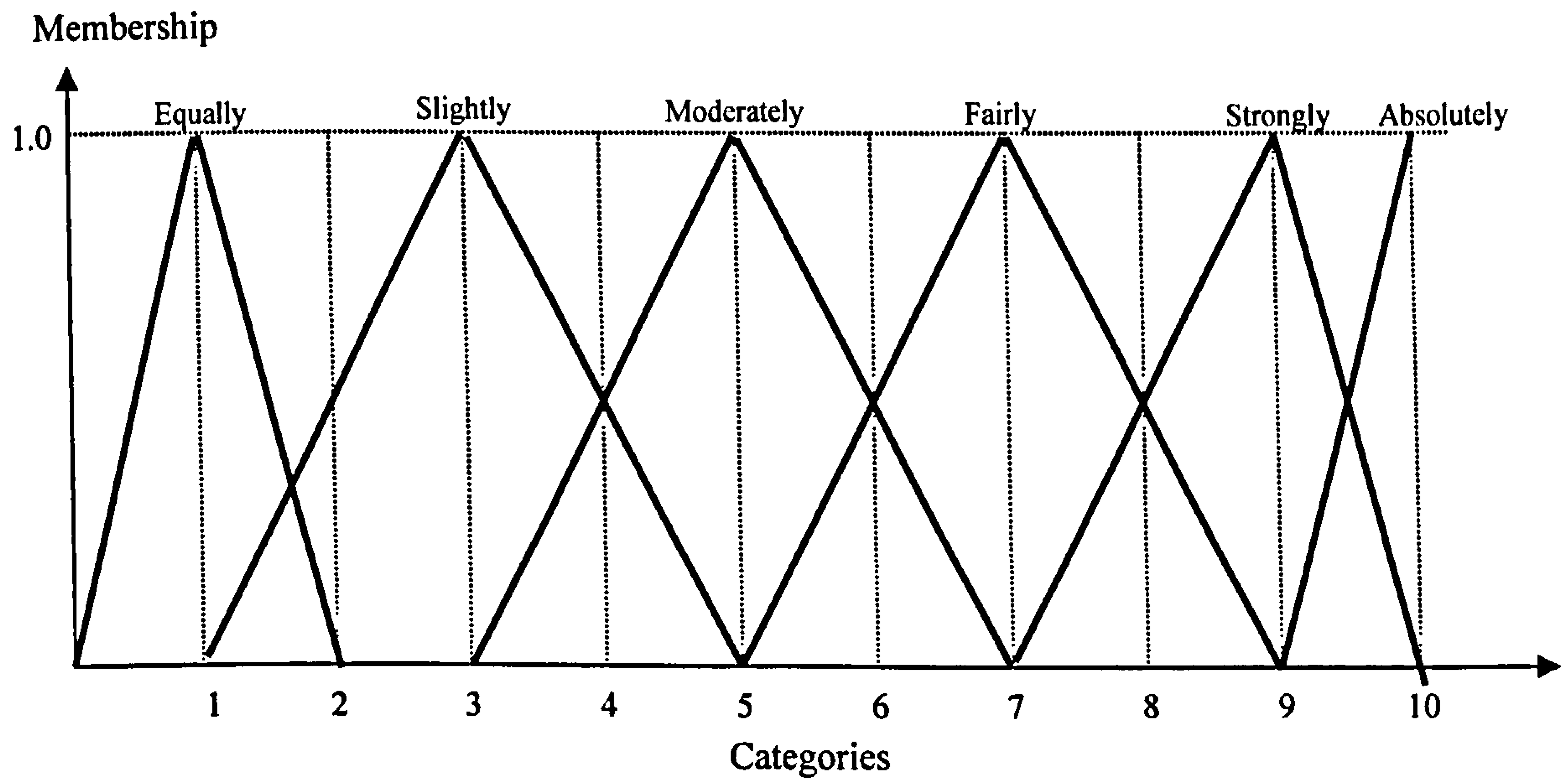

Figure 5.5. Membership function for the linguistic terms describing the relationship between the elements in the mission and step hierarchies in terms of the human error probability of occurrence and failure consequence probability criteria

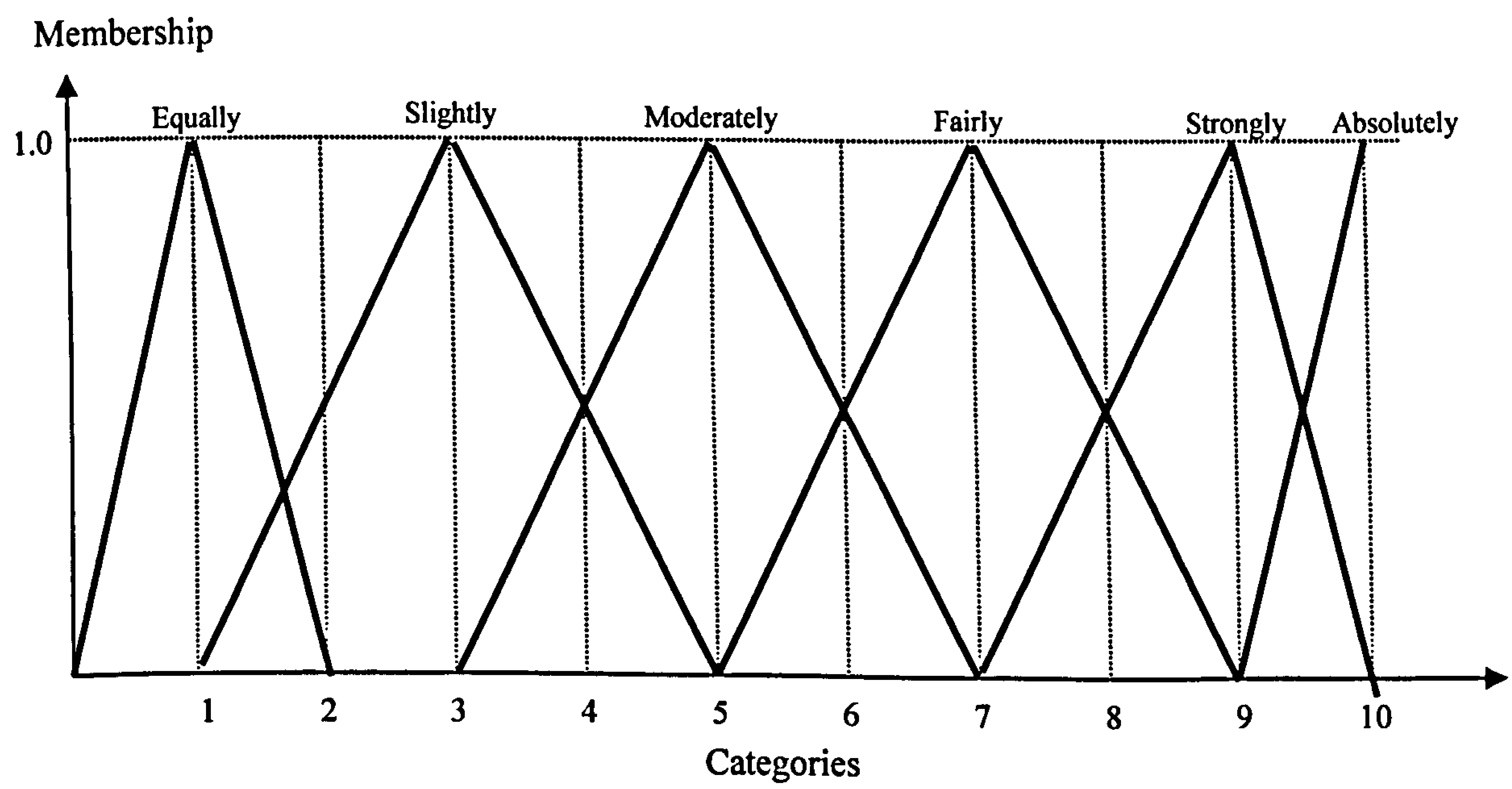

Figure 5.6. Membership function for the linguistic terms describing the relationship between the elements in the mission and step hierarchies in terms of the human error severity criteria

5.4.5 Pairwise comparison of human error probability of occurrence, failure consequence probability and severity in hierarchy 2

The relative importance of the human error likelihood, failure consequence probability and severity is obtained using the membership functions developed. Figure 5.7 shows the relationship with regard to the comparison between the elements of the human error likelihood and failure consequence probability where the single-deterministic-value method is adopted. Thus, the relationship can be described as "the criterion of human error failure consequence probability is 0.5 Moderately and 0.5 Fairly more important than the criterion of likelihood". Tables 5.6 and 5.7 indicate the pairwise relationships between these three criteria using fuzzy set theory.

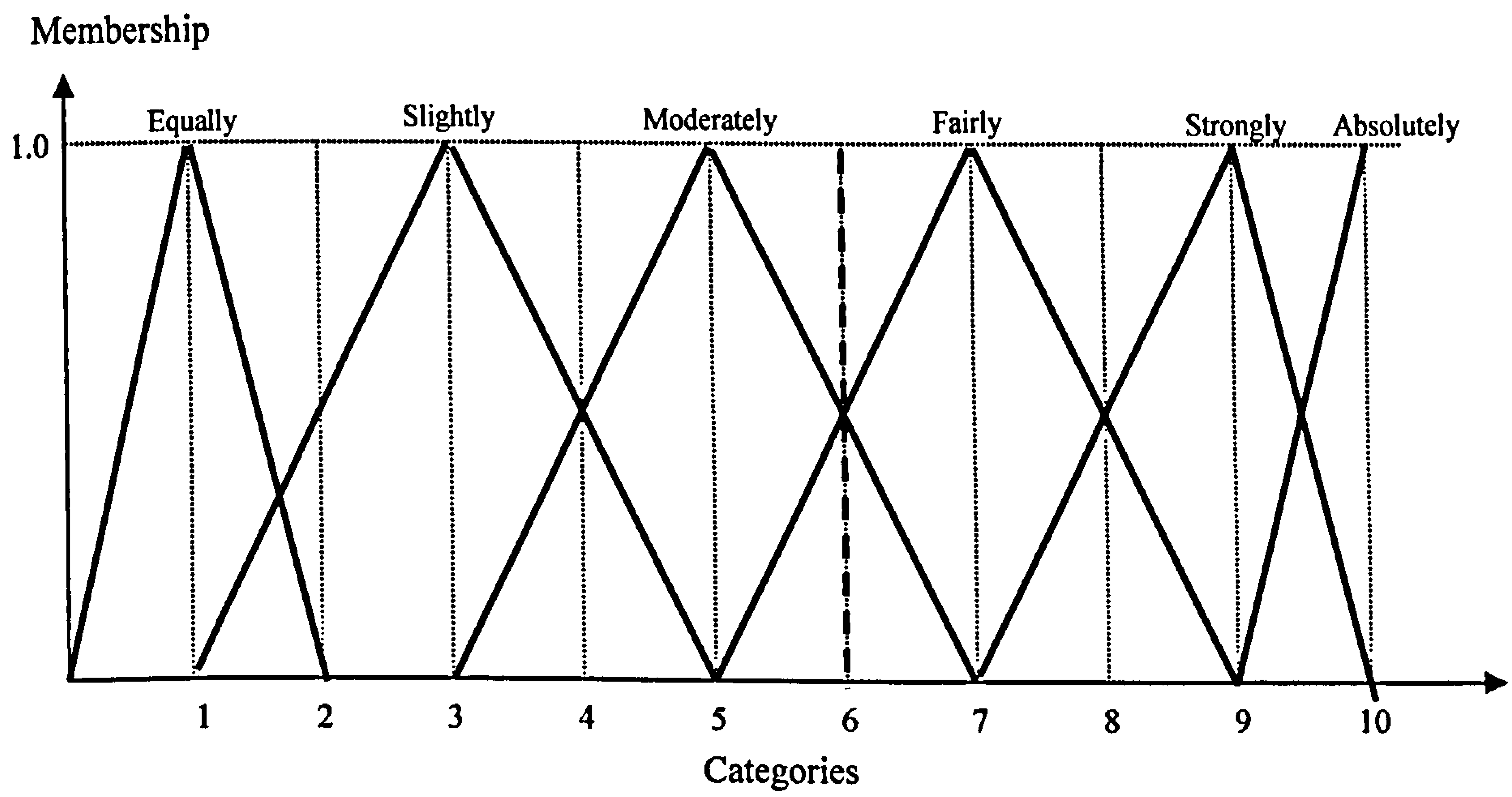

Figure 5.7. The determination of the fuzzy relationship between human error likelihood, failure consequence probability and severity

Table 5.6. The pairwise comparisons of human error likelihood, failure consequence probability and severity using fuzzy set theory

	Probability of occurrence	**Failure consequence probability**	**Severity**
Failure consequence probability	0.5 Moderately, 0.5 Fairly	1.0 Equally important	0.42 Equally, 0.18 Slightly

Table 5.7. The pairwise comparisons of human error severity and probability of occurrence using fuzzy set theory

	Probability of occurrence	**Severity**
Severity	0.5 Slightly, 0.5 Moderately	1.0 Equally important

5.4.6 Defuzzification process

The fuzzy expression in the pairwise comparison shown in Tables 5.6 and 5.7 can be converted to a single crisp value using the WMoM algorithm in Equation 5.4. The fuzzy output, 0.5 Moderately and 0.5 Fairly, is defuzzified as follows:

$$WMoM = \frac{\sum w_i x_i}{\sum w_i} = \frac{0.5 \cdot 5 + 0.5 \cdot 7}{0.5 + 0.5} = 6.0$$

Likewise, the defuzzified values of the other pairwise comparisons with regard to these three criteria can be obtained and shown in Tables 5.8 and 5.9.

Table 5.8. The defuzzified values of the pairwise comparisons of human error likelihood, failure consequence probability and severity

	Probability of occurrence	Failure consequence probability	Severity
Failure consequence probability	6.0	1.0	1.6

Table 5.9. The defuzzified values of the pairwise comparisons of human error severity and probability of occurrence

	Probability of occurrence	Severity
Severity	4.0	1.0

5.4.7 Weighting vector calculation

Since there are three elements that are evaluated in this hierarchy, a 3 by 3 pairwise comparison matrix is developed. A_{PFS} is the pairwise comparison matrix expressing the quantified judgement with regard to the relative importance of human error probability of occurrence, failure consequence probability and severity after the defuzzification process.

$$A_{PFS} = \begin{bmatrix} 1.0000 & 0.1667 & 0.2500 \\ 6.0000 & 1.0000 & 1.6000 \\ 4.0000 & 0.6250 & 1.0000 \end{bmatrix}$$

The weighting vector indicating the priority of each element in the pairwise comparison matrix in terms of its contribution to the overall risk is obtained using Equation 5.6.

$$w_1 = \frac{1}{3}\sum_{j=1}^{3}\frac{a_{1j}}{\sum_{i=1}^{3} a_{ij}} = \frac{1}{3}\cdot\left(\left[\frac{1}{1+6+4}\right]+\left[\frac{0.1667}{0.1667+1+0.625}+\frac{0.25}{0.25+1.6+1.0}\right]\right) \cong 0.0906$$

$$w_2 = \frac{1}{3}\sum_{j=1}^{3}\frac{a_{2j}}{\sum_{i=1}^{3} a_{ij}} = \frac{1}{3}\cdot\left(\left[\frac{6}{1+6+4}\right]+\left[\frac{1}{0.1667+1+0.625}+\frac{1.6}{0.25+1.6+1.0000}\right]\right) \cong 0.5550$$

$$w_3 = \frac{1}{3}\sum_{j=1}^{3}\frac{a_{3j}}{\sum_{i=1}^{3} a_{ij}} = \frac{1}{3}\cdot\left(\left[\frac{4}{1+6+4}\right]+\left[\frac{0.625}{0.1667+1+0.625}+\frac{1}{0.25+1.6+1.0000}\right]\right) \cong 0.3545$$

Therefore, the weighting vector matrix of the hierarchy in level 2, W_{PFS}, is shown below:

$$W_{PFS} = \begin{bmatrix} 0.0906 \\ 0.5550 \\ 0.3545 \end{bmatrix}$$

In order to examine whether the pairwise comparison of the three risk elements achieves the consistency, CR_{PFS} is obtained using Equations 5.7, 5.8, 5.9 and Table 5.1 shown as follows:

$$\lambda_{\max} = \frac{\sum_{k=1}^{n}\frac{\sum_{k=1,j=1}^{n} w_k a_{kj}}{w_k}}{n} = 3.0012,\ CI = \frac{\lambda_{\max}-n}{n-1} = \frac{3.0012-3}{3-1} = 6.0\times10^{-4}$$

$$CR_{MP} = \frac{CI}{RI} = \frac{6.0\times10^{-4}}{0.58} = 1.0345\times10^{-3}$$

Since the value of $CR_{MP} < 0.1$, the pairwise comparisons have achieved the consistency.

5.4.8 Evaluation of human error probability of occurrence, failure consequence probability and severity in the elements identified in the mission hierarchy

There are two hierarchies. Each hierarchy will be evaluated in terms of the criteria of human error likelihood, failure consequence probability and severity, respectively by repeating steps 5-7 (sections 5.3.5-5.3.7) of the research methodology.

5.4.8.1 Evaluation of the elements in the mission hierarchy in terms of the human error likelihood criterion

Tables 5.10-5.15 indicate the fuzzy expressions with regard to the pairwise comparisons between the missions using the membership function developed in Figure 5.5 based on expert judgement. When performing such comparisons, the factors of the number of personnel involved, the workload of each mission and the circumstance surrounding the personnel should be considered in terms of their contributions to human error.

Table 5.10. The pairwise comparisons between the approach & berthing mission and the connection, start-up, steady-rate, finishing, disconnection and departure missions

	Approach & berthing	Connection	Start up	Steady rate	Finishing	Disconnection	Departure
Approach & berthing	1.0 Equally	0.8 Moderately, 0.2 Fairly	0.3 Equally, 0.3 Slightly	0.6 Fairly, 0.4 Strongly	0.5 Slightly, 0.5 Moderately	0.7 Slightly, 0.3 Moderately	0.9 Strongly, 0.1 Fairly

Table 5.11. The pairwise comparisons between the start-up mission and the connection, steady-rate, finishing, disconnection and departure missions

	Connection	Start up	Steady rate	Finishing	Disconnection	Departure
Start up	1.0 Slightly	1.0 Equally	0.5 Moderately, 0.5 Slightly	0.3 Equally, 0.3 Slightly	0.7 Equally, 0.2 Slightly	0.6 Moderately, 0.4 Slightly

Table 5.12. The pairwise comparisons between the disconnection mission and the connection, steady-rate, finishing and departure missions

	Connection	Steady rate	Finishing	Disconnection	Departure
Disconnection	0.7 Equally, 0.2 Slightly	0.7 Slightly	0.9 Equally, 0.1 Slightly	1.0 Equally	0.8 Slightly

Table 5.13. The pairwise comparisons between the finishing mission and the connection, steady-rate and departure missions

	Connection	Steady rate	Finishing	Departure
Finishing	0.8 Equally, 0.1 Slightly	0.6 Slightly	1.0 Equally	0.75 Slightly

Table 5.14. The pairwise comparisons between the connection mission and the steady-rate and departure missions

	Connection	Steady rate	Departure
Connection	1.0 Equally	0.7 Equally, 0.2 Slightly	0.55 Slightly

Table 5.15. The pairwise comparisons between the steady-rate mission and the departure mission

	Steady rate	Departure
Steady rate	1.0 Equally	0.9 Equally, 0.1 Slightly

Subsequently, the fuzzy pairwise comparisons shown in Tables 5.10-5.15 will be defuzzified using Equation 5.4. Tables 5.16-5.21 contain the results after the defuzzification process.

Table 5.16. The single crisp values of the pairwise comparisons between the approach & berthing mission and the connection, start-up, steady-rate, finishing, disconnection and departure missions

	Approach & berthing	Connection	Start up	Steady rate	Finishing	Disconnection	Departure
Approach & berthing	1	5.4	2	7.8	4	3.6	8.8

Table 5.17. The single crisp values of the pairwise comparisons between the start-up mission and the connection, steady-rate, finishing, disconnection and departure missions

	Connection	Start up	Steady rate	Finishing	Disconnection	Departure
Start up	3.0	1.0	4.0	2.0	1.4444	4.2

Table 5.18. The single crisp values of the pairwise comparisons between the disconnection mission and the connection, steady-rate, finishing and departure missions

	Connection	Steady rate	Finishing	Disconnection	Departure
Disconnection	1.4444	2.10	1.20	1.0	2.4

Table 5.19. The single crisp values of the pairwise comparisons between the finishing mission and the connection, steady-rate and departure missions

	Connection	Steady rate	Finishing	Departure
Finishing	1.2222	1.80	1.0	2.25

Table 5.20. The single crisp values of the pairwise comparisons between the connection mission and the steady-rate and departure missions

	Connection	Steady rate	Departure
Connection	1.0	1.4444	1.65

Table 5.21. The single crisp values of the pairwise comparisons between the steady-rate mission and the departure mission

	Steady rate	Departure
Steady rate	1.0	1.2

Therefore, the pairwise comparison matrix can be constructed as shown in A_{MP}.

$$A_{MP} = \begin{bmatrix} 1.0 & 5.4 & 2.0 & 7.8 & 4.0 & 3.6 & 8.8 \\ 0.19 & 1.0 & 0.37 & 1.4444 & 0.74 & 0.67 & 1.65 \\ 0.5 & 3.0 & 1.0 & 4.0 & 2.0 & 1.4444 & 4.2 \\ 0.13 & 0.69 & 0.26 & 1.0 & 0.51 & 0.46 & 1.2 \\ 0.25 & 1.2222 & 0.5 & 1.8 & 1.0 & 0.9 & 2.25 \\ 0.28 & 1.4444 & 0.56 & 2.1 & 1.2 & 1.0 & 2.4 \\ 0.11 & 0.61 & 0.23 & 0.89 & 0.45 & 0.41 & 1.0 \end{bmatrix}$$

The weighting vector W_{MP} and normalised weighting vector W_{NMP} matrices can be obtained as follows:

$$W_{MP} = \begin{bmatrix} 0.4094 \\ 0.0760 \\ 0.2013 \\ 0.0530 \\ 0.1002 \\ 0.1136 \\ 0.0465 \end{bmatrix}, \quad W_{NMP} = W_{MP} \cdot 0.0906 = \begin{bmatrix} 0.0371 \\ 0.0069 \\ 0.0182 \\ 0.0048 \\ 0.0091 \\ 0.0103 \\ 0.0042 \end{bmatrix}$$

It can be seen from Tables 5.6-5.21 and W_{NMP} that the more important parameters described by the linguistic terms have higher normalised weighting vectors. This is consistent with the human-being common sense. Furthermore, the difference of the risk level between these parameters can be appreciated. In addition, in order to examine whether the priority in missions achieves the consistency, CR_{MP} is obtained using Equations 5.7, 5.8, 5.9 and Table 5.1 and evaluated as follows:

$$\lambda_{\max} = \frac{\sum_{k=1}^{n} \frac{\sum_{k=1,j=1}^{n} w_k a_{kj}}{w_k}}{n} \cong 6.9736, \quad CI = \frac{\lambda_{\max} - n}{n-1} = \frac{6.9736 - 7}{7-1} \cong -4.4 \times 10^{-3}$$

$$CR_{MP} = \frac{CI}{RI} = \frac{-4.4 \times 10^{-3}}{1.32} \cong -3.3333 \times 10^{-03}$$

Since the value of $CR_{MP} < 0.1$, the priority of the missions achieves the consistency.

5.4.8.2 Evaluations of the elements in the mission hierarchy in terms of the human error failure consequence probability and severity criterion

The evaluations of the failure consequence probability and severity of human errors that could possibly occur in the missions are conducted based on Figures 5.5 and 5.6 using the same pattern adopted in subsection 5.4.8.1. Tables 5.22 and 5.23 indicate the results in terms of the failure consequence probability and severity criteria between the missions using fuzzy AHP modelling based on the fuzzy expression shown in Appendix 5. It is noted that since the objective of this test case in the study is to demonstrate the methodology proposed, the data is based on the assumption that all pairwise comparisons have achieved the acceptable consistency and such data is set to have the perfect consistency. Thus, the complete pairwise comparisons between each mission and the values of CR associated in the comparisons in terms of the criteria of the failure consequence probability and severity are not given in the

Appendix. In real-world case studies where some degree of inconsistency is encountered, however, the pairwise comparisons between each element and the CR values associated should be conducted using the pattern similar to Tables 5.10-5.21 as well as Equations 5.7, 5.8, 5.9 and Table 5.1, respectively.

Table 5.22. The weighting vectors and normalised weighting vectors of each mission in terms of the failure consequence probability criterion

Missions	Weighting vector	Normalised weighting vector
1. Approach and berthing	0.0314	0.0174
2. Connection	0.0994	0.0552
3. Start up	0.2981	0.1655
4. Steady rate	0.2981	0.1655
5. Finishing	0.1863	0.1034
6. Disconnection	0.0552	0.0306
7. Departure	0.0314	0.0174

Table 5.23. The weighting vectors and normalised weighting vectors of each mission in terms of the severity criterion

Missions	Weighting vector	Normalised weighting vector
1. Approach and berthing	0.1126	0.0399
2. Connection	0.0709	0.0251
3. Start up	0.1126	0.0399
4. Steady rate	0.3829	0.1357
5. Finishing	0.2127	0.0754
6. Disconnection	0.0638	0.0226
7. Departure	0.0445	0.0158

5.4.9 Evaluation of the elements in the step hierarchy in terms of the human error likelihood criterion

The elements in the step hierarchy can be evaluated by repeating the procedure of the pairwise-relationship fuzzification, defuzzification, and weighting vector calculation using the membership functions developed in Figure 5.5. Table 5.24 contains the fuzzy pairwise relationship between the steps in the approach and berthing mission. Table 5.25 shows the single crisp values of the fuzzy expression after the defuzzification process. It is noted, again, that the data is based on the assumption that all pairwise comparisons have achieved the acceptable consistency and such data is set to have the perfect consistency. Thus the complete pairwise comparisons between each step in the mission and the value of CR associated in the comparisons in terms of the human error likelihood criterion are not given.

Table 5.24. The pairwise comparisons of the steps in the approach and berthing mission

	Berth selection	Approach with escort tugs	Ship positioning	Berth approach	Line handling	Final positioning
Berth approach	0.4 Strongly, 0.6 Absolutely	0.6 Moderately, 0.4 Fairly	0.5 Slightly, 0.5 Moderately	1.0 Equally	0.6 Fairly, 0.4 Strongly	0.3 Fairly, 0.7 Strongly

Table 5.25. The single crisp values of the pairwise comparisons of the steps in the approach and berthing mission

	Berth selection	Approach with escort tugs	Ship positioning	Berth approach	Line handling	Final positioning
Berth approach	9.6	5.8	4.0	1.0	7.8	8.4

Therefore, the pairwise comparison matrix indicating the quantified relationship between the steps in the approach & berthing mission is constructed as shown in A_{m1}. Accordingly, the weighting vector W_{m1} and normalised weighting vector W_{nm1} matrices can be obtained and shown below:

$$A_{m1} = \begin{bmatrix} 1.0 & 0.60 & 0.42 & 0.10 & 0.81 & 0.88 \\ 1.66 & 1.0 & 0.69 & 0.17 & 1.34 & 1.45 \\ 2.40 & 1.45 & 1.0 & 0.25 & 1.95 & 2.10 \\ 9.60 & 5.80 & 4.00 & 1.00 & 7.80 & 8.40 \\ 1.23 & 0.74 & 0.51 & 0.13 & 1.0 & 1.08 \\ 1.14 & 0.69 & 0.48 & 0.12 & 0.93 & 1.00 \end{bmatrix}$$

$$W_{m1} = \begin{bmatrix} 0.0587 \\ 0.0972 \\ 0.1409 \\ 0.5638 \\ 0.0723 \\ 0.0671 \end{bmatrix}, \; W_{nm1} = \begin{bmatrix} 0.0022 \\ 0.0036 \\ 0.0052 \\ 0.0209 \\ 0.0027 \\ 0.0025 \end{bmatrix}$$

The quantified pairwise relationship and the associated weighting vectors between the steps in the other six missions can be obtained using the same pattern described above. The fuzzy relationship between the steps of each mission is listed in Appendix 6 based on the assumption that all pairwise comparisons have achieved the acceptable consistency and such data is set to have the perfect consistency. The weighting vectors and normalised weighting vectors of the steps in each mission are calculated and shown in Table 5.26.

Table 5.26. The weighting vectors and normalised weighting vectors of each step in each mission for the probability of occurrence criterion

Mission	Step No.	Weighting vector	Normalised weighting vector
1. Approach and berthing	1.1	0.0587	0.0022
	1.2	0.0972	0.0036
	1.3	0.1409	0.0052
	1.4	0.5638	0.0209
	1.5	0.0723	0.0027
	1.6	0.0671	0.0025
2. Connection	2.1	0.0433	0.0003
	2.2	0.0656	0.0005
	2.3	0.1036	0.0007
	2.4	0.3937	0.0027
	2.5	0.3937	0.0027
3. Start up	3.1	0.1033	0.0019
	3.2	0.1033	0.0019
	3.3	0.0527	0.0010
	3.4	0.4956	0.0090
	3.5	0.1652	0.0030
	3.6	0.0799	0.0015
4. Steady rate	4.1	0.1111	0.0005
	4.2	0.8889	0.0043
5. Finishing	5.1	0.64	0.0058
	5.2	0.16	0.0015
	5.3	0.1	0.0009
	5.4	0.1	0.0009
6. Disconnection	6.1	0.1772	0.0018
	6.2	0.1107	0.0011
	6.3	0.1107	0.0011
	6.4	0.5315	0.0055
	6.5	0.0699	0.0007
7. Departure	7.1	0.1389	0.0006
	7.2	0.8611	0.0036

5.4.9.1 Evaluations of the elements in the step hierarch in terms of the human error failure consequence probability and severity criteria

The risks of each step needed to complete the missions in terms of failure consequence probability and severity criteria are obtained based on Figures 5.5 and 5.6 and the fuzzy outputs in Appendices 7 and 8 after the defuzzification process. They are shown in Tables 5.27 and 5.28. It is noted, again, that the data is based on the assumption that all pairwise comparisons have achieved the acceptable consistency and such data is set to have the perfect consistency. Thus the complete pairwise comparisons between each step in the mission and the values of CR associated in the comparisons in terms of the criteria of the failure consequence probability and severity are not given in the Appendices.

Table 5.27. The weighting vectors and normalised weighting vectors of each step in each mission for the failure consequence probability criterion

Mission	Step No.	Weighting vector	Normalised weighting vector
1. Approach and berthing	1.1	0.0560	0.0010
	1.2	0.4812	0.0084
	1.3	0.1504	0.0026
	1.4	0.1504	0.0026
	1.5	0.0891	0.0016
	1.6	0.0729	0.0013
2. Connection	2.1	0.0625	0.0034
	2.2	0.1343	0.0074
	2.3	0.5374	0.0297
	2.4	0.0867	0.0048
	2.5	0.1791	0.0099
3. Start up	3.1	0.1563	0.0259
	3.2	0.0782	0.0129
	3.3	0.0568	0.0094
	3.4	0.5002	0.0828
	3.5	0.1251	0.0207
	3.6	0.0834	0.0138
4. Steady rate	4.1	0.1667	0.0276
	4.2	0.8333	0.1379
5. Finishing	5.1	0.5538	0.0573
	5.2	0.1385	0.0143
	5.3	0.1538	0.0159
	5.4	0.1538	0.0159
6. Disconnection	6.1	0.6017	0.0184

	6.2	0.1037	0.0032
	6.3	0.1037	0.0032
	6.4	0.1254	0.0038
	6.5	0.0654	0.0020
7. Departure	7.1	0.1389	0.0024
	7.2	0.8611	0.0150

Table 5.28. The weighting vectors and normalised weighting vectors of each step in each mission for the severity criterion

Mission	Step No.	Weighting vector	Normalised weighting vector
1. Approach and berthing	1.1	0.0565	0.0023
	1.2	0.5429	0.0217
	1.3	0.0734	0.0029
	1.4	0.1086	0.0043
	1.5	0.1597	0.0064
	1.6	0.0590	0.0024
2. Connection	2.1	0.1714	0.0043
	2.2	0.1428	0.0036
	2.3	0.0829	0.0021
	2.4	0.5142	0.0129
	2.5	0.0887	0.0022
3. Start up	3.1	0.1509	0.0060
	3.2	0.0755	0.0030
	3.3	0.0549	0.0022
	3.4	0.1150	0.0046
	3.5	0.1207	0.0048
	3.6	0.4830	0.0193
4. Steady rate	4.1	0.1667	0.0226
	4.2	0.8333	0.1131
5. Finishing	5.1	0.5598	0.0422
	5.2	0.2799	0.0211
	5.3	0.0903	0.0068
	5.4	0.0700	0.0053
6. Disconnection	6.1	0.5890	0.0133
	6.2	0.1227	0.0028
	6.3	0.1227	0.0028
	6.4	0.1016	0.0023
	6.5	0.0640	0.0014
7. Departure	7.1	0.1389	0.0022
	7.2	0.8611	0.0136

5.4.10 Synthesis of the risk of each step in terms of the three criteria and establishment of an overall risk priority for all oil cargo handling steps

In this step, the risks evaluated in terms of the aforementioned three criteria are synthesised to obtain the overall risk for the steps required to perform the oil cargo handling. The overall results are acquired by the summation of the normalised weighting vector of each step in terms of the three criteria as shown in Tables 5.26, 5.27 and 5.28. Accordingly, the risk priority is established based on the combined risks obtained as shown in Table 5.29.

Table 5.29. The synthesised risk of each step in terms of three criteria and the overall risk priority of each step

Mission	Step No.	Probability of occurrence criterion	Failure consequence probability criterion	Severity criterion	Overall risk	Overall risk priority
1. Approach and berthing	1.1	0.0022	0.0010	0.0023	0.0055	27
	1.2	0.0036	0.0084	0.0217	0.0337	8
	1.3	0.0052	0.0026	0.0029	0.0107	23
	1.4	0.0209	0.0026	0.0043	0.0278	13
	1.5	0.0027	0.0016	0.0064	0.0107	22
	1.6	0.0025	0.0013	0.0024	0.0062	26
2. Connection	2.1	0.0003	0.0034	0.0043	0.008	24
	2.2	0.0005	0.0074	0.0036	0.0115	21
	2.3	0.0007	0.0297	0.0021	0.0325	10
	2.4	0.0027	0.0048	0.0129	0.0204	16
	2.5	0.0027	0.0099	0.0022	0.0148	18
3. Start up	3.1	0.0019	0.0259	0.0060	0.0338	7
	3.2	0.0019	0.0129	0.0030	0.0178	17
	3.3	0.0010	0.0094	0.0022	0.0126	19
	3.4	0.0090	0.0828	0.0046	0.0964	3
	3.5	0.0030	0.0207	0.0048	0.0285	12
	3.6	0.0015	0.0138	0.0193	0.0346	6
4. Steady rate	4.1	0.0005	0.0276	0.0226	0.0507	4
	4.2	0.0043	0.1379	0.1131	0.2553	1
5. Finishing	5.1	0.0058	0.0573	0.0422	0.1053	2
	5.2	0.0015	0.0143	0.0211	0.0369	5
	5.3	0.0009	0.0159	0.0068	0.0236	14
	5.4	0.0009	0.0159	0.0053	0.0221	15
6. Disconnection	6.1	0.0018	0.0184	0.0133	0.0335	9

	6.2	0.0011	0.0032	0.0028	0.0071	25
	6.3	0.0011	0.0032	0.0028	0.0071	25
	6.4	0.0055	0.0038	0.0023	0.0116	20
	6.5	0.0007	0.0020	0.0014	0.0041	29
7. Departure	7.1	0.0006	0.0024	0.0022	0.0052	28
	7.2	0.0036	0.0150	0.0136	0.0322	11

It can be seen from the Table that steps 4.2 (continuous calculation and periodical verification of the volume of transfer), 5.1 (prior warning), 3.4 (all connections checked for leaks), 4.1 (gradual increase of flow to steady rate) and 5.2 (closing valves slowly by the initiating party) are the processes with higher risks in the oil cargo handling operation. This is because the overall risks of these steps in terms of the criteria are relatively higher than the others. Thus, these steps need to be considered appropriately so that the risks resulting from human error in such steps can be reduced to an acceptable level. In addition, the risk priority established enables decision makers to propose Risk Control Options (RCOs) to the areas needing more attentions in a reasonable order from the risk point of view.

5.5 Conclusion

The technique presented in this chapter illustrates an alternative perspective for evaluating human error assessment. In assessing the human error risk, the steps in each mission are compared to each other in terms of the likelihood, failure consequence probability and severity criteria to acquire the relative importance and overall risk priority. This resolves the difficulty imposed on the traditional human error methods where the human error data is transformed from the source that may not be relevant to the project in question or where human error related risks are purely estimated based on expert judgement due to the scarcity of such data. In addition, the fuzzy AHP method gives the practitioners a flexible and rational fashion upon which to model the relationships between the elements in the pairwise comparison process although such a method may require cumbersome computations if there are many criteria to be considered. However, it should be noted that the experience of the experts consulted is crucial since the core of this research is the professional judgement from such personnel. Furthermore, appropriate quantitative data facilitates the research quality in determining the level of the linguistic terms used to express the relationships between the elements. Thus, although the scarcity of the data causes difficulties in human error research, the acquisition of quantitative data from daily port operations is still recommended.

Chapter 6. Multi-Attribute Decision-Making using Evidential Reasoning

When evaluating Risk Control Options (RCOs), difficulties may be encountered due to the attribute nature of the defined criteria. In this chapter a decision-making model using the Evidential Reasoning (ER) approach is proposed provided that RCOs have been identified. It is the technique aimed at solving the Multiple Attribute Decision Analysis (MADA) problems. This is because of its capability of consistently modelling precise data and subjective judgement with uncertainty under a unified framework. However, a problem occurs in circumstances where a decision-making project is evaluated by multiple experts and various utility appreciation arising from each expert exists when assessing each evaluation grade. This could result in an RCO or general attribute ranking order conflict between the experts. Such a conflict would become obvious if the evaluation grades and belief degrees obtained for each alternative or general attribute were close. The framework proposed in this chapter is capable of solving such a difficulty. This is accomplished by constructing a utility category-evaluation grade matrix for each expert using the belief degree method and synthesising the utility levels contained in the matrices estimated by all experts using the ER approach. The framework is demonstrated by a test case which considers the effects of the security, safety and human error reduction measures in ports. The analysis will be performed in terms of five criteria, namely, effectiveness, cost, time of deployment, resource availability and co-operation level.

6.1 Introduction

Many real world decision analysis problems involve multiple attributes with both a quantitative and qualitative nature. When evaluating RCOs for enhancing security and safety in a port, for instance, there are many parameters that need to be considered other than risk reduction and the ratio of costs and benefits such as time of deployment, existing resources available, etc. Difficulties may be encountered due to the attribute nature of the parameters under consideration. A decision-making process may not be regarded as appropriate if it does not take into account all the attributes in question [Stewart, 1992] [Belton and Stewart, 2002]. Several approaches have been proposed to deal with such MADA problems. The ER approach is one of the techniques that were developed to solve the MADA problems. By using this technique, subjective judgement with uncertainty and precise data can be consistently modelled under a unified framework based on an evaluation analysis model and the Dempster-Shafer (D-S) theory of evidence [Lopez de Mantaras, 1990]. However, a problem occurs in circumstances where a decision-making project is evaluated by multiple experts due to the fact that the utility appreciation of each evaluation grade by the experts could be different. This could result in an attribute or RCO ranking order conflict between the experts. The phenomenon would become obvious if the evaluation grades and belief degrees obtained for each alternative or general attribute were close.

The framework proposed in this study is capable of solving such a difficulty since it contains a systematic mechanism capable of acquiring a combined utility level of linguistic terms. Such consensus assessments with regard to linguistic terms provide the consistence throughout safety management process. It is demonstrated by a test case considering the effects of the security, safety and human error reduction measures in port in terms of five mutually exclusive criteria due to the natures of the attributes, namely, effectiveness, cost, time of deployment, resource availability and co-operation level. Effectiveness is defined as the effectiveness of the RCOs on risk reductions in terms of the security, safety and human error aspects. Cost is the capital that will be consumed once the RCOs are implemented, including initial costs, operational costs, maintaining costs and decommissioning costs. Time of deployment is the time spent in deploying the measures, including the time taken for personnel training and for facility or equipment installations. Resource availability is, regardless of monetary capitals, defined as the existing resource available for the measures such as existing facilities, equipment or skilled personnel capable of accomplishing the missions established. Co-operation level is the level of the diversity in which different departments both within and outside the port need to participate in the activities proposed by the measures, depending upon the functions and complexity of the RCOs. In other words, a specific measure would be preferred if the number of different department participating in the proposed activity was low (e.g. one or two) in terms of the co-operation level criterion.

The previously mentioned problem is solved by first constructing a utility category-evaluation grade matrix for each expert to estimate the utilities of each evaluation grade. This is followed by a synthesis process using the ER algorithm. The synthesised utility level for each evaluation is subsequently applied to the aggregating results obtained also by ER. An RCO priority can then be obtained followed by the conduction of a sensitivity analysis to identify the best RCOs.

6.2 Background

6.2.1 The ER approach

The ER approach was developed in the 1990s to solve the MADA problems characterised by both qualitative and quantitative attributes with various types of uncertainties [Yang and Singh, 1994] [Yang and Sen, 1994] [Yang, 2001] [Yang and Xu, 2002a]. The core of the approach is the development of an ER algorithm based on an evaluation analysis model and the D-S theory of evidence [Lopez de Mantaras, 1990]. This is capable of aggregating the attributes in a multilevel structure. On the basis of the ER framework, attributes are evaluated by a distributed assessment using the belief degree method along with the evaluation grade associated. Therefore, both subjective judgement with uncertainty and precise data can be consistently modelled under a unified framework.

Extensive research aimed at enhancing the ER approach in solving the MADA problems has been conducted in recent years. First, a generalised and extended decision-making matrix was constructed. Then rule and utility based techniques were developed to enhance the ER approach for dealing with the MADA problems of a quantitative and qualitative nature under uncertainties [Yang, 2001]. The framework proposed is capable of transforming various types of information within the matrix for aggregating attributes via the ER procedure. Secondly, the research revealing the nonlinear features of the ER aggregation process by investigating the decision analysis process of the ER approach was conducted, providing a guidance on conducting sensitivity analysis [Yang and Xu, 2002b]. Thirdly, a rigorous and pragmatic ER algorithm was developed to enhance the process of aggregating attributes under uncertainty [Yang and Xu, 2002a]. This revised ER approach is different from the original version, and treats the unassigned belief degree in two parts; one caused by the incompleteness, and the other by the fact that each attribute plays only one part in the whole assessment process according to its relative weight. Utility intervals were proposed to characterise the degrees of incompleteness present in the original approach and describe the impact of ignorance on decision analysis. Using the new version of the ER approach, four synthesis axioms were explored and these provide the theoretical basis for the approach [Yang and Xu, 2002a].

Suppose a two-level evaluation structure contains a general attribute at the top level, with a number of basic attributes at the bottom level. Each basic attribute is assessed with reference to a set of evaluation grades and each can be assessed to a specific or a subset of the evaluation grades with different belief degrees. Then

- If no basic attribute is assessed to a specific evaluation grade at all, the general attribute should not be assessed to that grade either (Basic synthesis theorem).

- If all basic attributes are precisely assessed to a specific grade, the general attribute should also be precisely assessed to the same grade (Consensus synthesis theorem).

- If all basic attributes are completely assessed to a subset of grades, the general attribute should also be completely assessed to the same subset (Complete synthesis theorem).

- If any basic assessment is incomplete either due to the lack of data or the inability of the assessors to provide precise judgement, a general assessment obtained by aggregating the incomplete and complete basic assessments should also be incomplete with a degree of incompleteness (Incomplete synthesis theorem).

Finally, a window-based and graphically designed Intelligent Decision System (IDS) has been developed to employ the ER approach [Yang and Xu, 2002a]. This user-friendly software enables the practitioners an easy and flexible way to model and analyse the MADA problems.

The ER technique has been applied in the engineering and management fields. First, it can be combined with the fuzzy set theory and the fuzzy rule base method to conduct safety analysis and synthesis [Wang *et al.*, 1995, 1996] [Liu *et al.*, 2004, 2005]. Secondly, it has been employed for motorcycle assessment [Yang and Sen, 1994] [Yang, 2001], general cargo ship design [Sen and Yang, 1995], retro-fit ferry design [Yang and Sen, 1997], organisational self-assessment [Yang *et al.*, 2001] [Siow *et al.*, 2001] and contractor selection [Sonmez *et al.*, 2001, 2002]. Finally, a new fuzzy ER algorithm capable of dealing with the MADA problems with probabilistic and fuzzy uncertainties has also been developed [Yang *et al.*, 2006a]. A generic Rule-base Inference Methodology using ER (RIMER) has also been proposed to capture vagueness, incompleteness and nonlinear causal relationships [Yang *et al.*, 2006b].

6.2.2 The problem of the ER approach when applied by multiple experts

When assessing the utilities of the evaluation grades using the ER technique, the probability assignment approach is utilised [Winston, 1994]. This method is appropriate when applied by one expert. However, it may not be practicable in circumstances where a decision-making project is evaluated by multiple experts due to the fact that the utility appreciation of each evaluation grade by the experts could be different. Therefore, the ranking order of the alternatives or the attributes may vary between experts. The phenomenon would become obvious if the evaluation grades and belief degrees obtained for each alternative or general attribute were close. Therefore, it is necessary to develop a framework considering individual expert judgement with regard to the utilities of the evaluation grades when applying the ER approach for multi-attribute aggregation.

6.2.3 The framework proposed

In this study, a framework capable of solving the aforementioned problem is proposed. It will be demonstrated by a test case considering the effects of security, safety and human error reduction measures in port in terms of five criteria provided that such measures have been identified [Ung *et al.*, 2006c]. First, the utilities for the evaluation grades are estimated by each expert using the belief degree method. Subsequently the estimated utilities from each expert are synthesised using the ER algorithm. Finally, the priority of the alternatives can be established. The result obtained will be more reliable since it allows for the attribute assessment and synthesis of the utility levels of the evaluation grades based on the judgement by each expert. Finally, a sensitivity analysis will be conducted to assist decision makers in selecting the best alternatives, thus providing another way of thinking in terms of the different importance in the risk and cost aspects. The methodology of the proposed model is presented in section 6.3.

6.3 Methodology

The framework in this study commences with the identification of the criteria that will be used to assess the RCOs. The Analytical Hierarchy Process (AHP) technique is subsequently employed to determine the relative weight of the criteria identified. The effects of each RCO in terms of the criteria identified will then be evaluated by each expert. This result is then synthesised using the ER approach to acquire the overall aggregating result. This, in turn, is followed by the development of a utility category-evaluation grade matrix for each expert to estimate the utility level of each evaluation grade using the belief degree method. The utility preference of each evaluation grade estimated by each expert is then combined using the ER algorithm and will be normalised. The synthesised utility level of each evaluation grade based on all experts is subsequently employed to the aggregating result of the effects of each RCO. An RCO priority will then be acquired based on the results calculated. Finally, a sensitivity analysis will be conducted to identify the best measures and so provide another way of considering the importance of the various risk and cost aspects. Figure 6.1 shows the framework of the research methodology in this study.

6.3.1 Identification of the criteria to assess the RCOs

The first step in the methodology is to identify the attributes (criteria) that play important roles in evaluating the measures proposed. The mission can be accomplished by brainstorming based on the experience and knowledge of the experts.

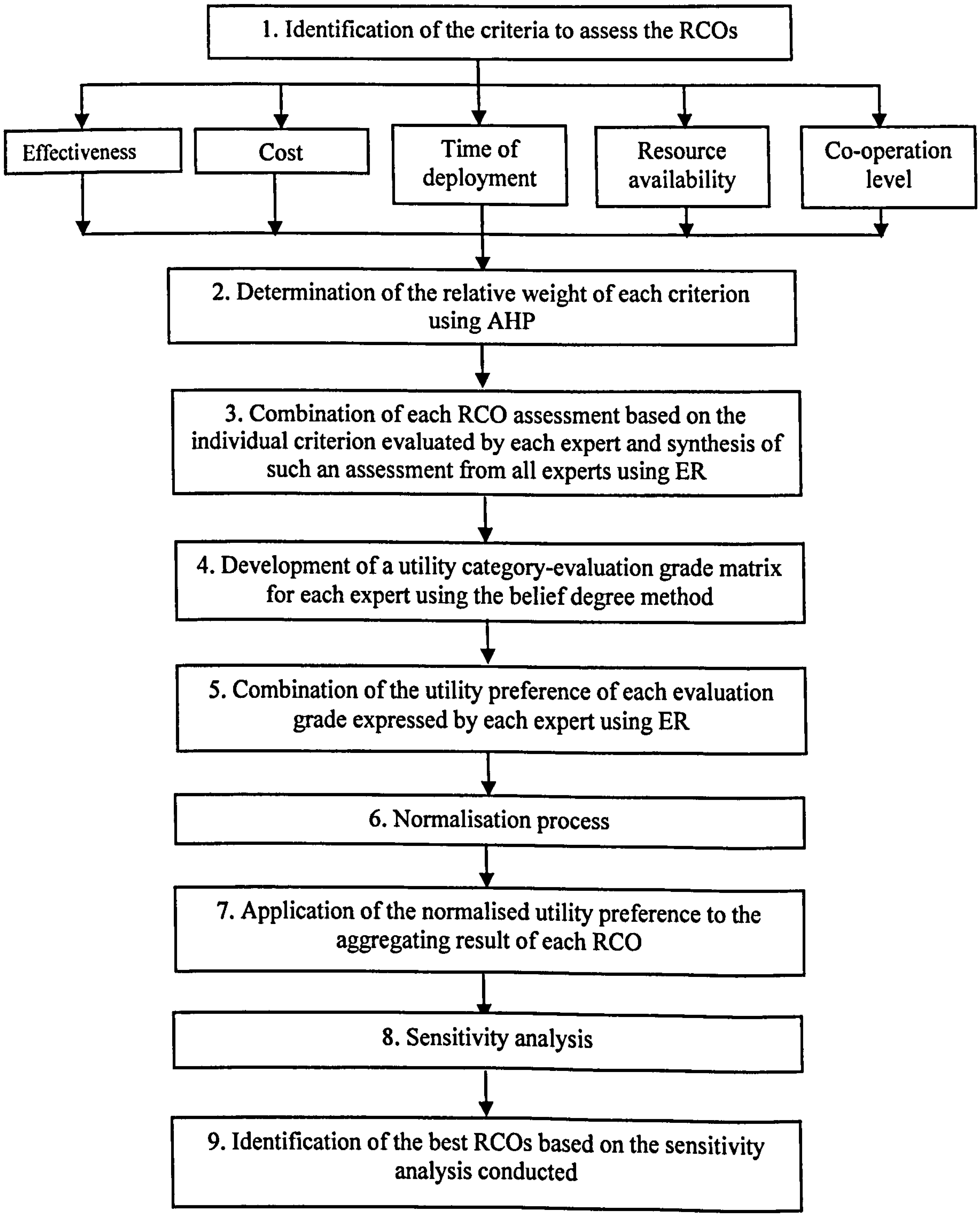

Figure 6.1. The framework of the research methodology

The crucial factors identified in this test case include effectiveness, cost, time of deployment, resource availability and co-operation level, respectively.

6.3.2 Determination of the relative weight of each criterion using AHP

After identifying the criteria to be used to assess the RCOs, the relative weight of each criterion will subsequently be determined. The AHP method will be employed to achieve this aim. Suppose an $n \times n$ comparison matrix A represents the relative importance on pairs of criteria C_i and C_j, then;

$$A = (a_{ij}) = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \cdot & \cdot & \cdots & \cdot \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \qquad \text{(Equation 6.1)}$$

where each a_{ij} is the relative importance of criteria C_i against C_j, and in this test case, n is set to be 5.

The weighting vector indicating the priority of each element in the pairwise comparison matrix in terms of its contribution to the overall decision making can be obtained by a synthesis procedure [Anderson, et. al., 2003]. This consists of the following three steps:

1 Calculating the summation of the values in each column of the pairwise comparison matrix.

2 Dividing each element in the pairwise comparison matrix by its column summation. The resulting matrix is referred to as the normalised pairwise comparison matrix.

3 Computing the average value of the elements in each row of the normalised pairwise comparison matrix. In this section the average values of each element indicate the priority for criteria.

The mathematical expression of the synthesis is shown in Equation 6.2.

$$w_k = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{kj}}{\sum_{i=1}^{n} a_{ij}} \qquad \text{(Equation 6.2)}$$

where w_k is the weighting vector of a specific element k in the pairwise comparison matrix, and $k = 1,2.....n$.

The aspect of the consistency of pairwise judgements provided by decision makers is important. When numerous pairwise comparisons are evaluated, perfect consistency is often difficult to achieve, and some degree of inconsistency could be expected to exist in almost any set of pairwise comparisons. The AHP method provides a measure of the consistency for pairwise comparisons by introducing a consistency ratio. The ratio is designed in such a way that a value greater than 0.1 indicates an inconsistency in the pairwise judgements in question, meaning that the comparisons will have to be revaluated. The comparisons will be considered reasonable only if the consistency ratio is equal to or less than 0.1 [Yang *el al.*, 2001]. The exact mathematical computation of the ratio is beyond this study. However, an approximation of the ratio can be obtained using the algorithm listed in Equation 6.3:

$$CR = \frac{CI}{RI} \qquad \text{(Equation 6.3)}$$

where CR is the consistency ratio, RI is the random index for the matrix size, n. The value of RI depends on the number of items being compared and is given in Table 6.1 [Satty, 1980] and CI is the consistency index that can be obtained from Equation 6.4.

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad \text{(Equation 6.4)}$$

where $\lambda_{\max}$ is the maximum eigenvalue of an $n \times n$ comparison matrix A that is calculated using Equation 6.5.

$$\lambda_{\max} = \frac{\sum_{k=1}^{n} \frac{\sum_{k=1,j=1}^{n} w_k a_{kj}}{w_k}}{n} \qquad \text{(Equation 6.5)}$$

Table 6.1. Average random index values

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Note: n is the size of the pairwise comparison matrix.
Source: [Satty, 1980]

6.3.3 Combination of each RCO assessment based on the individual criterion evaluated by each expert and synthesis of such an assessment from all experts using ER

After determining the relative importance of each criterion, the RCO assessment based on the individual criterion will be conducted by each expert. When evaluating the RCO in terms of the criteria identified, the effect of each RCO will be described by one or more specific evaluation grades associated with the corresponding belief degrees. The ER method applied in this study is the revised version proposed in 2002 [Yang and Xu, 2002]. Suppose there are L basic attributes (criteria) e_i $(i = 1,2,...L)$, each of whose relative importance is denoted by w_i ($i = 1,2...L$), M alternatives (RCOs) a_l $(l = 1,2...M)$ and N distinctive and mutually exclusive evaluation grades H_n ($n = 1,2...N$) to be employed in assessing the RCOs in terms of the criteria identified. Then a multi-attribute decision problem is modelled as follows:

$$S(e_i(a_l)) = \{(H_n, \beta_{n,i}(a_l)), n = 1,2...N\}, i = 1,2,...L, l = 1,2...M \qquad \text{(Equation 6.6)}$$

where $\beta_{n,i}(a_l)$ is a degree of belief. $\beta_{n,i}(a_l) \geq 0$ and $\sum_{n=1}^{N} \beta_{n,i}(a_l) \leq 1$.

Let y be a general attribute expressing an RCO assessment by an expert and $m_{n,i}$ be a basic probability mass estimated by that expert representing the degree to which the i th basic attribute, e_i, supports the hypothesis that y is assessed to the n th evaluation grade, H_n. Also let $m_{H,i}$ be a remaining probability mass unassigned to any individual evaluation grade after all N grades have been taken into account for assessing y as far as e_i is concerned. $m_{n,i}$ and $m_{H,i}$ can be acquired using Equations 6.7 and 6.8.

$$m_{n,i} = w_i \beta_{n,i} \qquad \text{(Equation 6.7)}$$

where $\sum_{i=1}^{L} w_i = 1$.

$$m_{H,i} = 1 - \sum_{n=1}^{N} m_{n,i} = 1 - w_i \sum_{n=1}^{N} \beta_{n,i} \qquad \text{(Equation 6.8)}$$

The remaining probability mass is subsequently considered separately in terms of the relative weights of attributes and the incompleteness in the assessment. Therefore, $m_{H,i}$, is decomposed into two parts:

$$m_{H,i} = \overline{m}_{H,i} + \widetilde{m}_{H,i} \quad \text{(Equation 6.9)}$$

$$\overline{m}_{H,i} = 1 - w_i \quad \text{(Equation 6.10)}$$

$$\widetilde{m}_{H,i} = w_i\left(1 - \sum_{n=1}^{N} \beta_{n,i}\right) \quad \text{(Equation 6.11)}$$

$\overline{m}_{H,i}$ is the remaining probability mass that is not yet assigned to individual evaluation grades since e_i only plays one part in the assessment depending upon its relative weight, w_i. It represents the degree to which other attributes can play a role in the assessment. $\widetilde{m}_{H,i}$ is the other remaining probability mass unassigned to individual evaluation grades that is caused by an incomplete assessment. The value of $\widetilde{m}_{H,i}$ will be zero if $S(e_i(a_l))$ is complete, otherwise it will be positive.

Suppose $m_{n,I(i)}$, $\overline{m}_{H,I(i)}$ and $\widetilde{m}_{H,I(i)}$ are the probability masses obtained from $S(e_i(a_l))$ using Equations 6.7, 6.10 and 6.11. The aggregation of the attribute i and the attribute $i+1$ can be acquired using Equations 6.12, 6.13, 6.14, 6.15 and 6.16, respectively.

$$m_{n,I(i+1)} = K_{I(i+1)}\left(m_{n,I(i)}m_{n,i+1} + m_{H,I(i)}m_{n,i+1} + m_{n,I(i)}m_{H,i+1}\right) \quad \text{(Equation 6.12)}$$

$$m_{H,I(i)} = \overline{m}_{H,I(i)} + \widetilde{m}_{H,I(i)} \quad \text{(Equation 6.13)}$$

$$\overline{m}_{H,I(i+1)} = K_{I(i+1)}\left(\overline{m}_{H,I(i)}\overline{m}_{H,i+1}\right) \quad \text{(Equation 6.14)}$$

$$\widetilde{m}_{H,I(i+1)} = K_{I(i+1)}\left(\widetilde{m}_{H,I(i)}\widetilde{m}_{H,i+1} + \overline{m}_{H,I(i)}\widetilde{m}_{H,i+1} + \widetilde{m}_{H,I(i)}\overline{m}_{H,i+1}\right) \quad \text{(Equation 6.15)}$$

$$K_{I(i+1)} = \left(1 - \sum_{t=1}^{N}\sum_{\substack{j=1 \\ j\neq t}}^{N} m_{t,I(i)}m_{j,i+1}\right)^{-1} \quad \text{(Equation 6.16)}$$

where $m_{n,I(i+1)}$ denotes the probability mass representing the degree to which the basic attributes e_i and e_{i+1} support the hypothesis that y is assessed to the n th evaluation grade H_n,

$m_{H,I(i+1)}$ is the combined remaining probability mass unassigned to any individual evaluation grade after all N grades have been taken into account for assessing y as far as e_i and e_{i+1} are concerned,

$\overline{m}_{H,I(i+1)}$ represents the combined remaining probability mass that is not yet assigned to individual grades due to the fact that e_i and e_{i+1} only play some parts in the assessment,

$\tilde{m}_{H,I(i+1)}$ is the combined remaining probability mass unassigned to individual evaluation grades that is caused by an incomplete assessment, and

$K_{I(i+1)}$ is a normalising factor so that $\sum_{n=1}^{N} m_{n,I(i+1)} + m_{H,I(i+1)} = 1$, and $i = 1,2,...L-1$.

Once all attributes have been aggregated, the combined belief degrees are generated by using Equations 6.17 and 6.18.

$$\beta_n = \frac{m_{n,I(L)}}{1 - \overline{m}_{H,I(L)}} \qquad \text{(Equation 6.17)}$$

$$\beta_H = \frac{\tilde{m}_{H,I(L)}}{1 - \overline{m}_{H,I(L)}} \qquad \text{(Equation 6.18)}$$

where β_n denotes a belief degree to which H_n is assessed, and

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

The assessment for the general attribute, y, can be represented using the following equation.

$S(y) = \{(H_n, \beta_n), n = 1,2..., N\}$ (Equation 6.19)

Equation 6.19 establishes that y is assessed to the evaluation grade H_n with the belief degree of β_n.

After obtaining $S(y)$ of each RCO by each expert, all assessments of $S(y)$ of each RCO evaluated by all experts will subsequently be synthesised using Equations 6.7-6.19. The aggregating result will be listed. A table similar to Table 6.2 will be established.

Table 6.2. An example of a list of the aggregating result of each RCO

	H_1	H_2	...	H_n
RCO_1	β_{1,RCO_1}	β_{2,RCO_1}	...	β_{n,RCO_1}
RCO_2	β_{1,RCO_2}	β_{2,RCO_2}	...	β_{n,RCO_2}
RCO_3	β_{1,RCO_3}	β_{2,RCO_3}	...	β_{n,RCO_3}
...	...	...	...	...
RCO_m	$\beta_{1,RCOm}$	$\beta_{2,RCOm}$	...	$\beta_{n,RCOm}$

6.3.4 Development of a utility category-evaluation grade matrix for each expert using the belief degree method

The objective of this step is to determine the utility of each evaluation grade expressed by each expert. A utility category-evaluation grade matrix will be developed. It contains 11 utility categories from zero to 10, each of which is used to express the utility level to which a specific evaluation grade is assessed by each expert using the belief degree method. It is noted that the summation of the belief degrees from categories zero to 10 are smaller than or equal to 1. Suppose there are N evaluation grades, then a utility category-evaluation grade matrix will be established and completed by an expert as shown in Table 6.3:

Table 6.3. The utility levels of N evaluation grades expressed by an expert using the belief degree method

	0	1	2	3	4	5	6	7	8	9	10
H_1	$\beta_{0,1}$	$\beta_{1,1}$	$\beta_{2,1}$	$\beta_{3,1}$	$\beta_{4,1}$	$\beta_{5,1}$	$\beta_{6,1}$	$\beta_{7,1}$	$\beta_{8,1}$	$\beta_{9,1}$	$\beta_{10,1}$
H_2	$\beta_{0,2}$	$\beta_{1,2}$	$\beta_{2,2}$	$\beta_{3,2}$	$\beta_{4,2}$	$\beta_{5,2}$	$\beta_{6,2}$	$\beta_{7,2}$	$\beta_{8,2}$	$\beta_{9,2}$	$\beta_{10,2}$
...	...	...	...	...	...	...	...	...	...	...	...
H_n	$\beta_{0,n}$	$\beta_{1,n}$	$\beta_{2,n}$	$\beta_{3,n}$	$\beta_{4,n}$	$\beta_{5,n}$	$\beta_{6,n}$	$\beta_{7,n}$	$\beta_{8,n}$	$\beta_{9,n}$	$\beta_{10,n}$

It should be noted that the utility category 10 denotes the maximum utility whereas utility category 0 represents the minimum in assessing a specific evaluation grade H_n.

6.3.5 Combination of the utility preference of each evaluation grade expressed by each expert using ER

The mission of this stage is to combine the utility preference of each evaluation grade expressed by each expert. This is accomplished by repeating Equations 6.7 to 6.19. After considering the utility preference of each evaluation grade of all experts, the result will be expressed using Equation 6.20.

$$U_o(H_n) = \{(C_i, \beta_i), i = 0,1,2...,10\} \qquad \text{(Equation 6.20)}$$

where $U_o(H_n)$ expresses the original utility preference of the evaluation n,

C_i is the ith utility category in question, and

β_i denotes the belief degree to which C_i is assessed.

By assigning the values of 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 to the categories 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10, respectively, the quantitative utility preference of each evaluation grade can be obtained using Equation 6.21.

$$U(H_n) = \sum_{i=0}^{10} V_{c_i} \beta_{i,n} \qquad \text{(Equation 6.21)}$$

where $U(H_n)$ denotes the quantitative utility preference of the evaluation grade n,

V_{ci} is the value of the category i assigned, and

$\beta_{i,n}$ is the belief degree to which the evaluation grade n is assessed to the category i.

6.3.6 Normalisation process

A normalisation process will take place to convert $U(H_n)$ obtained from section 6.3.5 to the normalised numerical values using Equation 6.22.

$$U(H_n)_{nm} = \frac{U(H_n) - \min U(H_n)}{\max U(H_n) - \min U(H_n)}$$ (Equation 6.22)

where $U(H_n)_{nm}$ is the normalised utility of the evaluation grade H_n,

$U(H_n)$ represents the quantitative utility preference of the evaluation grade n,

$\max U(H_n)$ denotes the maximum original value of $U(H_n)$, and

$\min U(H_n)$ is the minimum original value of $U(H_n)$.

6.3.7 Application of the normalised utility preference developed to the aggregating result of each RCO

Let $U(H_n)_{nm}$ be the normalised utility of the evaluation grade H_n as stated in section 6.3.6 and $U(H_{n+1})_{nm} > U(H_n)_{nm}$ if H_{n+1} is preferred to H_n. When all assessments are complete, the value of β_H is zero. Therefore, the expected utility of the general attribute y can be obtained using Equation 6.23.

$$U(y) = \sum_{n=1}^{N} \beta_n U(H_n)_{nm}$$ (Equation 6.23)

If $U(y(a_i)) > U(y(a_j))$, then the alternative i is preferred to the alternative j.

When any of the basic attribute assessments is incomplete, β_H will be positive. The revised ER algorithm is capable of providing the upper and lower bounds of the belief degrees using the results from Equations 6.17 and 6.18. In other words, β_n represents the lower bound of the belief degree, and $(\beta_n + \beta_H)$ denotes the upper bound of the belief degree based on the concepts of the belief measure and also the plausibility measure in the D-S theory of evidence. Therefore, $[\beta_n, (\beta_n + \beta_H)]$ provides the range of the belief degree to which y is assessed to H_n, that is, the value of $U(y)$ could be anything in the belief interval $[\beta_n, (\beta_n + \beta_H)]$. Three measures have been defined to characterise $U(y)$, namely, the minimum, maximum and average expected utilities shown in the following equations. Let H_1 be the least preferred evaluation grade representing the lowest utility and H_N be the highest preferred grade denoting the highest utility. Then

$$U_{\max}(y) = \sum_{n=1}^{N-1} \beta_n U(H_n)_{nm} + (\beta_N + \beta_H)U(H_N)_{nm} \quad \text{(Equation 6.24)}$$

$$U_{\min}(y) = (\beta_1 + \beta_H)U(H_1)_{nm} + \sum_{n=2}^{N} \beta_n U(H_n)_{nm} \quad \text{(Equation 6.25)}$$

$$U_{avg}(y) = \frac{U_{\max}(y) + U_{\min}(y)}{2} \quad \text{(Equation 6.26)}$$

In summary, the priority of the RCOs will be obtained based on the result of $U(y)$ of each RCO if all assessments are complete or the values of $U_{\max}(y)$, $U_{\min}(y)$ and $U_{avg}(y)$ when any of incomplete assessment exists.

6.3.8 Sensitivity Analysis

A sensitivity analysis of the RCOs will be conducted by modifying the weights of the effectiveness and cost criteria since these two elements play crucial roles in this study. It is noted that when conducting the sensitivity analysis, the importance of the other three criteria will remain unchanged. The outcome of the analysis will be scrutinised in the following section.

6.3.9 Identification of the best RCOs based on the sensitivity analysis conducted

In this step, the best measures are identified by investigating the priority orders of each RCO when changing the weights in the criteria. On the other hand, the sensitivity analysis conducted will be capable of providing another way of thinking in terms of different importance in the risk and cost aspects. This will enable the management to have a more flexible decision-making in the RCO selection from different aspects.

6.4 Test Case

6.4.1 Identification of the criteria to assess the RCOs

Since the test case selected in this study is the decision making of the security, safety and human error reduction measures within a port, the factors playing important roles identified are, namely, effectiveness, cost, time of deployment, resource availability and co-operation level.

6.4.2 Determination of the relative weight of each criterion using AHP

First, a comparison scale for the importance of the criteria is developed based on expert judgement as shown in Table 6.4. A 5×5 comparison matrix representing the relative importance of the criteria based on the comparison scale developed is subsequently established in Table 6.5. The matrix has drawn on industry expert judgement. This is because of the difficulty of acquiring real industrial data as discussed in section 1.4. It is noted that C_E, C_C, C_T, C_R and C_{CL} denote the criteria of effectiveness, cost, time of deployment, resource availability and co-operation level, respectively.

Table 6.4. Comparison scale for the importance of criteria

Verbal judgement	Numerical rating
Extremely more important	9
	8
Very strongly more important	7
	6
Strongly more important	5
	4
Moderately more important	3
	2
Equally important	1

Table 6.5. The pairwise comparisons of the relative weight between each criterion

	C_E	C_C	C_T	C_R	C_{CL}
C_E	1.00	1.00	6.00	4.00	8.00
C_C	1.00	1.00	6.00	4.00	8.00
C_T	0.17	0.17	1.00	0.67	1.33
C_R	0.25	0.25	1.50	1.00	2.00
C_{TE}	0.13	0.13	0.75	0.50	1.00

The synthesisation procedure is then applied to obtain the weighting vector of each criterion using Equation 6.2. Table 6.6 shows the results calculated.

Table 6.6. The relative weighting vector of each criterion

	C_E	C_C	C_T	C_R	C_{CL}
w_k	0.39	0.39	0.07	0.10	0.05

In order to examine whether the pairwise comparisons of the relative importance of each criterion achieve the constancy, $CR_{Criteria}$ is obtained as 0.0186 using Equations 6.3, 6.4 and 6.5 and Table 6.1. Since $CR_{Criteria} < 0.1$, the pairwise comparisons have achieved the consistency.

6.4.3 Combination of each RCO assessment based on the individual criterion evaluated by each expert and synthesis of such an assessment from all experts using ER

A set of evaluation grades consisting of five linguistic terms has been developed and applied to describe the criteria in this test case. The definitions of each evaluation grade for each criterion when investigating each RCO are listed in Table 6.7. It is noted that the identification of a threshold for each evaluation grade in terms of different criteria may facilitate the RCO assessment process although it is not the case in this study. If using the evaluation of a specific RCO in terms of the cost criterion as an example, the thresholds identified for the evaluation grades of 'Excellent', 'Good', 'Moderate', 'Poor' and 'Worst' could be 0-10,000, 10,001-25,000, 25,001-40,000, 40,001-55,000 and over 55,000 GBP, respectively. It is noted that the unit of the thresholds for the evaluation grades in terms of the criteria may be different, e.g., the threshold unit for the effectiveness criterion could be a risk index and the unit for the cost criterion could be monetary values.

Table 6.7. The definitions of each evaluation grade for each criterion

Evaluation grade	Definition for each criterion
Worst	Worst effectiveness, highest cost, longest time of deployment, worst resource availability and very extensive co-operation level
Poor	Poor effectiveness, higher cost, longer time of deployment, poor resource availability and extensive co-operation level
Moderate	Moderate effectiveness, moderate cost, moderate time of deployment, moderate resource availability and moderate co-operation level
Good	Good effectiveness, lower cost, lower time of deployment, higher resource availability and limited co-operation level
Excellent	Excellent effectiveness, lowest cost, lowest time of deployment, highest resource availability and very limited co-operation level

In this test case, 15 alternatives (RCOs) are set to be evaluated by 4 experts and are shown in Table 6.8 provided that such RCOs are mutually exclusive. The combined assessment of each RCO based on the individual criterion from each expert can be acquired using ER. The following calculations demonstrate the combining process provided that such data have been given by Expert 1 with regard to RCO 1 assessment as shown in Table 6.9.

Table 6.8. The RCOs for the test case

RCO 1	Procurement of high-tech detecting facilities (security)
RCO 2	Development of an onshore safety management system reducing the human errors in the oil cargo handling performance (human error)
RCO 3	Deployment of an additional pilot on board vessels (port marine safety)
RCO 4	Reinforcement of the communications between pilots and traffic control units (port marine safety)
RCO 5	Deployment of an additional team auditing the cargo handling performance periodically (human error)
RCO 6	Reinforcement of the maintenance regarding to sealanes and navigation aids & facilities (port marine safety)
RCO 7	Deployment of additional crew for oil cargo handling (human error)
RCO 8	Training of pilots (port marine safety)
RCO 9	Deployment of additional personnel in traffic control units (port marine safety)
RCO 10	Training of the existing onshore personnel (human error)
RCO 11	Reinforcement of the communications between port and public security agencies (security)
RCO 12	Training of security related personnel (security)
RCO 13	Procurement of new facilities reducing the workload of the personnel involved in the cargo handling procedure (human error)
RCO 14	Installation of alarm systems (security)
RCO 15	Employment of additional security crew (security)

Table 6.9. The evaluation of RCO 1 based on each criterion by Expert 1

$S(e_1(a_{RCO1})) = (H_3, 0.2, H_4, 0.7, H_5, 0.1)$
$S(e_2(a_{RCO1})) = (H_1, 0.2, H_2, 0.7, H_3, 0.1)$
$S(e_3(a_{RCO1})) = (H_2, 0.1, H_3, 0.6, H_4, 0.3)$
$S(e_4(a_{RCO1})) = (H_2, 0.2, H_3, 0.8,)$
$S(e_5(a_{RCO1})) = (H_3, 0.2, H_4, 0.3, H_5, 0.5)$

❖ It is noted that throughout this study, the symbols of the attributes, e_1, e_2, e_3, e_4 and e_5 denote the criteria of effectiveness, cost, time of deployment, resource availability and co-operation level and the evaluation grades H_1, H_2, H_3, H_4 and H_5 denote the linguistic terms of 'Worst', 'Poor', 'Moderate', 'Good' and 'Excellent', respectively.

Therefore, the probability masses of $m_{n,i}$, $\overline{m}_{H,i}$ and $\widetilde{m}_{H,i}$ are obtained using Equations 6.7, 6.10 and 6.11 and the results of w_k shown in Table 6.6 and the belief degrees in Table 6.9.

$m_{1,1} = m_{2,1} = 0$, $m_{3,1} = 0.078$, $m_{4,1} = 0.273$, $m_{5,1} = 0.039$, $\overline{m}_{H,1} = 0.61$, $\widetilde{m}_{H,1} = 0$

$m_{1,2} = 0.078$, $m_{2,2} = 0.273$, $m_{3,2} = 0.039$, $m_{4,2} = m_{5,2} = 0$, $\overline{m}_{H,2} = 0.61$, $\widetilde{m}_{H,2} = 0$

$m_{1,3} = 0$, $m_{2,3} = 0.007$, $m_{3,3} = 0.042$, $m_{4,3} = 0.021$, $m_{5,3} = 0$, $\overline{m}_{H,3} = 0.93$, $\widetilde{m}_{H,3} = 0$

$m_{1,4} = 0$, $m_{2,4} = 0.02$, $m_{3,4} = 0.08$, $m_{4,4} = m_{5,4} = 0$, $\overline{m}_{H,4} = 0.9$, $\widetilde{m}_{H,4} = 0$

$m_{1,5} = m_{2,5} = 0$, $m_{3,5} = 0.01$, $m_{4,5} = 0.015$, $m_{5,5} = 0.025$, $\overline{m}_{H,5} = 0.95$, $\widetilde{m}_{H,5} = 0$

Let $m_{n,1}$, $\overline{m}_{H,1}$ and $\widetilde{m}_{H,1}$ be $m_{n,I(1)}$, $\overline{m}_{H,I(1)}$ and $\widetilde{m}_{H,I(1)}$, the attribute 1 and the attribute 2 can be aggregated using Equations 6.12, 6.13, 6.14, 6.15 and 6.16 respectively.

$$K_{I(2)} = \left[1 - \begin{pmatrix} m_{3,1}m_{1,2} + m_{3,1}m_{2,2} + m_{4,1}m_{1,2} + m_{4,1}m_{2,2} + m_{4,1}m_{3,2} + \\ m_{5,1}m_{1,2} + m_{5,1}m_{2,2} + m_{5,1}m_{3,2} \end{pmatrix}\right]^{-1} = 1.1752$$

$$m_{1,I(2)} = K_{I(2)}\left(m_{1,I(1)}m_{1,2} + m_{H,I(1)}m_{1,2} + m_{1,I(1)}m_{H,2}\right) = 0.0559$$

$$m_{2,I(2)} = K_{I(2)}\left(m_{2,I(1)}m_{2,2} + m_{H,I(1)}m_{2,2} + m_{2,I(1)}m_{H,2}\right) = 0.1957$$

$$m_{3,I(2)} = K_{I(2)}\left(m_{3,I(1)}m_{3,2} + m_{H,1}m_{3,2} + m_{3,I(1)}m_{H,2}\right) = 0.0874$$

$$m_{4,I(2)} = K_{I(2)}\left(m_{4,I(1)}m_{4,2} + m_{H,I(1)}m_{4,2} + m_{4,1}m_{H,2}\right) = 0.1957$$

$$m_{5,I(2)} = K_{I(2)}\left(m_{5,I(1)}m_{5,2} + m_{H,I(1)}m_{5,2} + m_{5,I(1)}m_{H,2}\right) = 0.0280$$

$$\overline{m}_{H,I(2)} = K_{I(2)}\left(\overline{m}_{H,I(1)}\overline{m}_{H,2}\right) = 0.4373$$

$$\widetilde{m}_{H,I(2)} = K_{I(2)}\left(\widetilde{m}_{H,I(1)}\widetilde{m}_{H,2} + \overline{m}_{H,1}\widetilde{m}_{H,2} + \widetilde{m}_{H,I(1)}\overline{m}_{H,2}\right) = 0$$

By repeating Equations 6.12-6.16, the combined probability masses are obtained as follows:

$m_{1,I(5)} = 0.05029$ $m_{2,I(5)} = 0.19310$ $m_{3,I(5)} = 0.14919$ $m_{4,I(5)} = 0.19771$

$m_{5,I(5)} = 0.33874$ $\overline{m}_{H,I(5)} = 0.36805$ $\tilde{m}_{H,I(5)} = 0$.

The combined belief degrees of each evaluation grade in terms of the criteria considered can be obtained based on Equations 6.17, 6.18 and 6.19 and is shown below:

$$S(y)_{Expert1} = \begin{Bmatrix} (Worst, 7.96\%)(Poor, 30.56\%)(Moderate, 23.61\%)(Good, 31.29\%) \\ (Excellent, 5.36\%) \end{Bmatrix}$$

The evaluation of 15 RCOs based on each criterion by Expert 1 is listed in Table A9.1 of Appendix 9. The aforementioned windows-based programme, IDS [Yang and Xu, 2002a], is employed to perform such calculations to obtain the combined belief degrees of each evaluation grade in terms of the criteria for each RCO. Table A9.2 contains the results calculated from the software. Furthermore, Appendix 10 shows the evaluation of the RCOs by the rest of three experts. Tables A10.1, A10.3 and A10.5 contain the evaluations of each RCO based on each criterion by Experts 2, 3 and 4 and Tables A10.2, A10.4 and A10.6 list the combined belief degrees of all criteria of each RCO by the Experts. Table 6.10 shows the synthesised evaluation of 15 RCOs by the experts.

Table 6.10. The synthesised evaluation of the RCOs by the experts (%)

	H_1	H_2	H_3	H_4	H_5
RCO 1	10.88	29.42	24.16	31.60	3.94
RCO 2	1.12	16.52	70.44	8.23	3.69
RCO 3	7.07	84.14	7.50	1.29	0
RCO 4	0	1.51	54.98	15.63	27.88
RCO 5	13.08	69.77	16.98	0.17	0
RCO 6	0	7.21	84.58	8.20	0
RCO 7	42.05	6.20	10.48	5.11	36.17
RCO 8	0	33.31	18.96	46.93	0.80
RCO 9	86.05	11.39	2.56	0	0
RCO 10	0	0	2.56	17.18	80.27
RCO 11	0	5.10	89.59	5.30	0
RCO 12	0	0	9.17	82.98	7.85
RCO 13	2.32	81.74	15.95	0	0
RCO 14	0	0	6.0	33.81	60.19
RCO 15	0	36.70	9.25	37.02	17.03

6.4.4 Development of an utility category-evaluation grade matrix for each expert using the belief degree method

A utility category-evaluation grade matrix is developed. Each expert is required to determine the utility levels (from 0 to 10) of each evaluation grade based on the belief degree method. Table 6.11 contains the utility levels of the evaluation grades expressed by Expert 1. Appendix 11 lists the utility levels of the evaluation grades determined by the remaining three experts.

Table 6.11. The utility levels of the evaluation grades expressed by Expert 1 using the belief degree method

	0	1	2	3	4	5	6	7	8	9	10
H_1	1.0	0	0	0	0	0	0	0	0	0	0
H_2	0	0	0.1	0.7	0.2	0	0	0	0	0	0
H_3	0	0	0	0	0.2	0.8	0	0	0	0	0
H_4	0	0	0	0	0	0	0.1	0.1	0.8	0	0
H_5	0	0	0	0	0	0	0	0	0	0	1.0

6.4.5 Combination of the utility preference of each evaluation grade expressed by each expert using ER

In this step, the combined utility preference of each evaluation grade determined by the experts is obtained using Equations 6.7 to 6.19. Table 6.12 shows the results calculated.

Table 6.12. The combined utility preference of each evaluation grade of all experts using the belief degree method (%)

	0	1	2	3	4	5	6	7	8	9	10
H_1	100	0	0	0	0	0	0	0	0	0	0
H_2	0	2.0	10.62	67.78	17.60	2.0	0	0	0	0	0
H_3	0	0	0	1.88	16.64	77.65	3.83	0	0	0	0
H_4	0	0	0	0	0	0	5.88	7.98	78.23	7.91	0
H_5	0	0	0	0	0	0	0	0	0	0	100

The utility preference of each evaluation grade is obtained based on the values assigned to each category using Equation 6.21. Table 6.13 lists the results calculated. The utility level of, 'Moderate', for instance is acquired as follows:

$U(H_3) = 0.0188 \times 3 + 0.1664 \times 4 + 0.7765 \times 5 + 0.0383 \times 6 = 4.8343$

Table 6.13. The utility preference of each evaluation grade based on the value assigned to each category

	H_1	H_2	H_3	H_4	H_5
Utility Preference	0	3.0698	4.8343	7.8817	10

6.4.6 Normalisation process

The utility preference degrees calculated are subsequently normalised using Equation 6.22 and are presented in Table 6.14.

Table 6.14. The normalised utility preference of each evaluation grade based on the value assigned to each category

	H_1	H_2	H_3	H_4	H_5
Utility Preference	0	0.30698	0.48343	0.78817	1

6.4.7 Application of the normalised utility preference to the aggregating result of each RCO

The utility of each RCO can be obtained based on the normalised utility preference shown in Table 6.14 and the aggregating result calculated in Table 6.10 using Equation 6.23. Table 6.15 lists the results with each RCO being ranked according to its utility level. It is noted that all assessments in this test case are set to be complete. In situations where any of incomplete assessments exists, Equations 6.24, 6.25 and 6.26 should be applied.

It can be seen from Table 6.15 that the first 5 RCOs are RCOs 10, 14, 12, 4 and 15. This is due to the fact that the belief degrees of the positive evaluation grades (Good and Excellent) of these RCOs are relatively higher than the others. On the other hand, the RCOs ranked in the last 5 are ROCs 7, 13, 3, 5, and 9, and this is because their belief degrees assigned to negative grades are relatively higher compared to the rest of the alternatives.

Table 6.15. The utility and rank of each RCO

	H_1	H_2	H_3	H_4	H_5	Utility Level
RCO 10	0.0000	0.0000	0.0256	0.1718	0.8027	0.9505
RCO 14	0.0000	0.0000	0.0600	0.3381	0.6019	0.8974
RCO 12	0.0000	0.0000	0.0917	0.8298	0.0785	0.7769
RCO 4	0.0000	0.0151	0.5498	0.1563	0.2788	0.6724
RCO 15	0.0000	0.3670	0.0925	0.3702	0.1703	0.6195
RCO 8	0.0000	0.3331	0.1896	0.4693	0.0080	0.5718
RCO 6	0.0000	0.0721	0.8458	0.0820	0.0000	0.4956
RCO 1	0.1088	0.2942	0.2416	0.3160	0.0394	0.4956
RCO 2	0.0112	0.1652	0.7044	0.0823	0.0369	0.4930
RCO 11	0.0000	0.0510	0.8959	0.0530	0.0000	0.4905
RCO 7	0.4205	0.0620	0.1048	0.0511	0.3617	0.4717
RCO 13	0.0232	0.8174	0.1595	0.0000	0.0000	0.3280
RCO 3	0.0707	0.8414	0.0750	0.0129	0.0000	0.3047
RCO 5	0.1308	0.6977	0.1698	0.0017	0.0000	0.2976
RCO 9	0.8605	0.1139	0.0256	0.0000	0.0000	0.0473

6.4.8 Sensitivity Analysis

The sensitivity analysis of RCOs is conducted by investigating the ranking difference due to the weight changes in the effectiveness and cost criteria while others remain the same. Table 6.16 shows the RCO priority when effectiveness is twice as important as cost whereas Table 6.17 lists the rank when cost is twice as important as effectiveness.

Table 6.16. Sensitivity analysis 1 (Effectiveness is twice as important as Cost)

	H_1	H_2	H_3	H_4	H_5	Utility Level
RCO 10	0.0000	0.0000	0.0160	0.2011	0.7829	0.9491
RCO 14	0.0000	0.0000	0.0660	0.4029	0.5311	0.8806
RCO 12	0.0000	0.0000	0.1035	0.8337	0.0628	0.7699
RCO 4	0.0000	0.0107	0.3752	0.1523	0.4617	0.7665
RCO 15	0.0000	0.1857	0.0518	0.5003	0.2621	0.7386
RCO 7	0.1975	0.0431	0.0970	0.0688	0.5936	0.7079
RCO 1	0.0528	0.1428	0.2722	0.4861	0.0461	0.6046
RCO 6	0.0000	0.0817	0.8300	0.0883	0.0000	0.4959
RCO 11	0.0000	0.0508	0.9012	0.0480	0.0000	0.4891

RCO 8	0.0000	0.4976	0.2094	0.2890	0.0040	0.4858
RCO 2	0.0103	0.2417	0.6608	0.0681	0.0190	0.4664
RCO 13	0.0257	0.8642	0.1101	0.0000	0.0000	0.3185
RCO 3	0.0655	0.8402	0.0784	0.0160	0.0000	0.3084
RCO 5	0.1854	0.6640	0.1490	0.0016	0.0000	0.2771
RCO 9	0.8285	0.1377	0.0338	0.0000	0.0000	0.0586

Table 6.17. Sensitivity analysis 2 (Cost is twice as important as Effectiveness)

	H_1	H_2	H_3	H_4	H_5	Utility Level
RCO 10	0.0000	0.0000	0.0355	0.1485	0.8160	0.9502
RCO 14	0.0000	0.0000	0.0557	0.2800	0.6644	0.9119
RCO 12	0.0000	0.0000	0.0826	0.8185	0.0989	0.7839
RCO 8	0.0000	0.1797	0.1612	0.6473	0.0119	0.6551
RCO 4	0.0000	0.0177	0.7013	0.1484	0.1326	0.5940
RCO 2	0.0102	0.0959	0.7377	0.0994	0.0568	0.5213
RCO 15	0.0000	0.5573	0.1289	0.2307	0.0831	0.4983
RCO 6	0.0000	0.0665	0.8539	0.0796	0.0000	0.4959
RCO 11	0.0000	0.0520	0.8869	0.0611	0.0000	0.4929
RCO 1	0.1672	0.4601	0.1897	0.1553	0.0277	0.3830
RCO 13	0.0210	0.7604	0.2187	0.0000	0.0000	0.3391
RCO 5	0.0878	0.7212	0.1895	0.0015	0.0000	0.3142
RCO 3	0.0797	0.8399	0.0710	0.0094	0.0000	0.2995
RCO 7	0.6503	0.0703	0.0932	0.0291	0.1571	0.2466
RCO 9	0.8867	0.0938	0.0195	0.0000	0.0000	0.0382

6.4.9 Identification of the best RCOs based on the sensitivity analysis conducted

It can be seen from Table 6.16 that the first 5 RCOs remain unchanged as compared with Table 6.15 whereas the ranking order of the others has been rearranged. The positions of RCOs 7, 1 and 11 have been promoted, ranking at 6, 7 and 9, since the belief degrees of the RCOs assigned by the experts in the effectiveness criterion are relatively higher than in the cost criterion. Likewise, the first 3 RCOs in Table 6.17 remain the same in comparison to Table 6.15. However, RCOs 8, 2, 11, 13 and 5 have become more important since the belief degrees of the RCOs assigned by the experts in the cost criterion are relatively higher than in the effectiveness criterion. Thus, it can be concluded that the best RCOs in this study are RCOs 10, 14 12 and 4, respectively. It should be noted that there is no rule to judge which priority order in

Tables 6.15, 6.16 and 6.17 has the most appropriate rank. The priority is dependent upon whether the management is a risk and cost equalitarian, or either a risk or cost adverse advocator.

6.5 Conclusion

When evaluating RCOs, difficulties may be encountered due to the attribute nature of the defined criteria. In this chapter a decision-making model using the ER algorithm is proposed provided that RCOs have been identified. The approach has been applied in the engineering and management fields since the 1990s due to its capability of consistently modelling precise data and subjective judgement with uncertainty under a unified framework. However, a problem occurs in circumstances where a decision-making project is evaluated by multiple experts and where various utility realisations from each expert exist when assessing each evaluation grade. This could result in an RCO or general attribute ranking order conflict between the experts. Such a conflict would become obvious if the evaluation grades and belief degrees obtained for each alternative or general attribute were close. Using the framework proposed and the test case demonstrated, such a difficulty can be resolved. This is accomplished by first, constructing a utility category-evaluation grade matrix for each expert using the belief degree method. Secondly, the utility levels contained in the matrices estimated by all experts are synthesised using the ER approach. Finally, after the normalisation process, the synthesised utility level is employed to acquire the aggregating result for each RCO. Therefore, the priority of the RCOs can be established based on the aggregating result calculated. A sensitivity analysis is employed to identify the best measures and also to provide another way of thinking in terms of the various importance in the risk and cost aspects. Consequently, the management is able to have the measures implemented based on the sensitivity analysis conducted. On the other hand, the assignment of the evaluation grades and the associated belief degrees to RCOs is crucial for this decision-making framework. The more realistic the RCO assessment is, the more reliable the decision-making result. Therefore, the identification of a threshold for each evaluation grade in terms of different criteria is also recommended since it is capable of facilitating the RCO assessment process.

Chapter 7. Quality Assurance of the Efficiency of Port Security and Safety Measures

Nowadays, more and more security and safety regulations and policies have been adopted and implemented in the port industry. The objective of this is to ensure that the international trade could be safely expedited without undue safety practices nor threat from intentional crime activities. Nevertheless, more regulations and measures sometimes paradoxically imply an increased probability of inefficiency affecting port operations. In this chapter, following the introduction of the Six Sigma method, a methodology for improving the quality of port security and safety measures is proposed. A test case is then used to demonstrate the proposed methodology. It is concluded that to achieve this, it is crucial to distinguish each step of a security or safety process clearly from the outset. Furthermore, gathering quantitative data at each stage is the first priority for ports attempting to enhance the measures implemented.

7.1 Introduction

In this PhD study, novel techniques of risk assessment and safety management have been employed to evaluate the security and safety of port operations. After the decision-making process discussed in Chapter 6, the best measures have been identified and a Risk Control Option (RCO) priority can be established depending upon the opinions from the management with regard to the relative importance between the safety and cost criteria. Accordingly, a port implements the RCOs based on the results acquired from the decision-making process. Thus, additional measures are put into action to enhance safety and security. This may sometimes cause delay or other unwanted events to port users. In addition, more and more security and safety regulations and policies have been adopted and implemented in the port industry. The objective of this is certainly to ensure that the international trade can be safely expedited without undue safety practices or threats from intentional crime activities. This, however, may also undermine the efficiency of port operations. It is therefore necessary to incorporate the various opinions with regard to the implementation of security and safety measures from port customers, such as vessel owners and traders having businesses within port areas. The purpose of this is to achieve customer satisfaction based on the opinions gathered to improve the quality of security and safety measures adopted so as to ensure that the efficiency of port operations is either improved or maintained. Thus, the objective of this quality assurance study is to establish a methodology capable of improving and maintaining the quality of port measures. This will be achieved using a quality assurance approach, namely, Six Sigma and demonstrated by a test case of a port security process [Ung *et al.*, 2006d]. The proposed framework may enable ports to stand in a competitive position in the shipping industry.

7.2 Background of Six Sigma

7.2.1 Fundamental Theory

Six Sigma was originated at Motorola in 1987 and was widely adopted by General Electric (GE) in 1995, as a quality improvement tool. It is becoming accepted by many companies suffering from the costs of rework and other aspects of poor quality. It contains four components, namely, Total Quality Management (TQM), Statistical Process Control (SPC), customer satisfaction and customer needs analysis, and a new paradigm of total customer satisfaction [Tennant, 2001]. The key elements in the technique are customer needs analysis and employee performance without which the quality improvement will be meaningless.

Six Sigma can be defined as a methodology, based on the statistical analysis of total customer satisfaction, by which the quality of a process can be improved. It is capable of identifying root causes using measurable methods and rigorous statistical techniques to improve and sustain the quality of processes. Since statistics is concerned with the collection, analysis, interpretation and presentation of data [Goh, 1999], Six Sigma projects are regarded as data-driven whereas TQM ones are often based on unproven assumptions or questionable data [Revere and Black, 2003]. Therefore, this approach eliminates the thoughts of “I think” and “I feel” when attempting to improve the quality of a process [Murphy, 1998].

Any process is affected by natural and non-natural variations. Natural variations occur when a number of inherent factors are random and independent of each other. Such variations can only be measured, controlled and reduced but they can never be eliminated completely. Non-natural variations happen while a small number of non-random factors influence the process, which can be totally eliminated once the causes are identified. Most performances of business processes are attributable to natural variations and have the same characteristics and shape if plotted. The bell curve shown in Figure 7.1 is a typical shape for the performance of any process being affected by natural variations. In the statistics field, there is a powerful tool dealing with such natural variations, namely, normal distribution. It has a characteristic that most of the examples in a set of data are close to the "average" although relatively few examples tend to be at one extreme or the other.

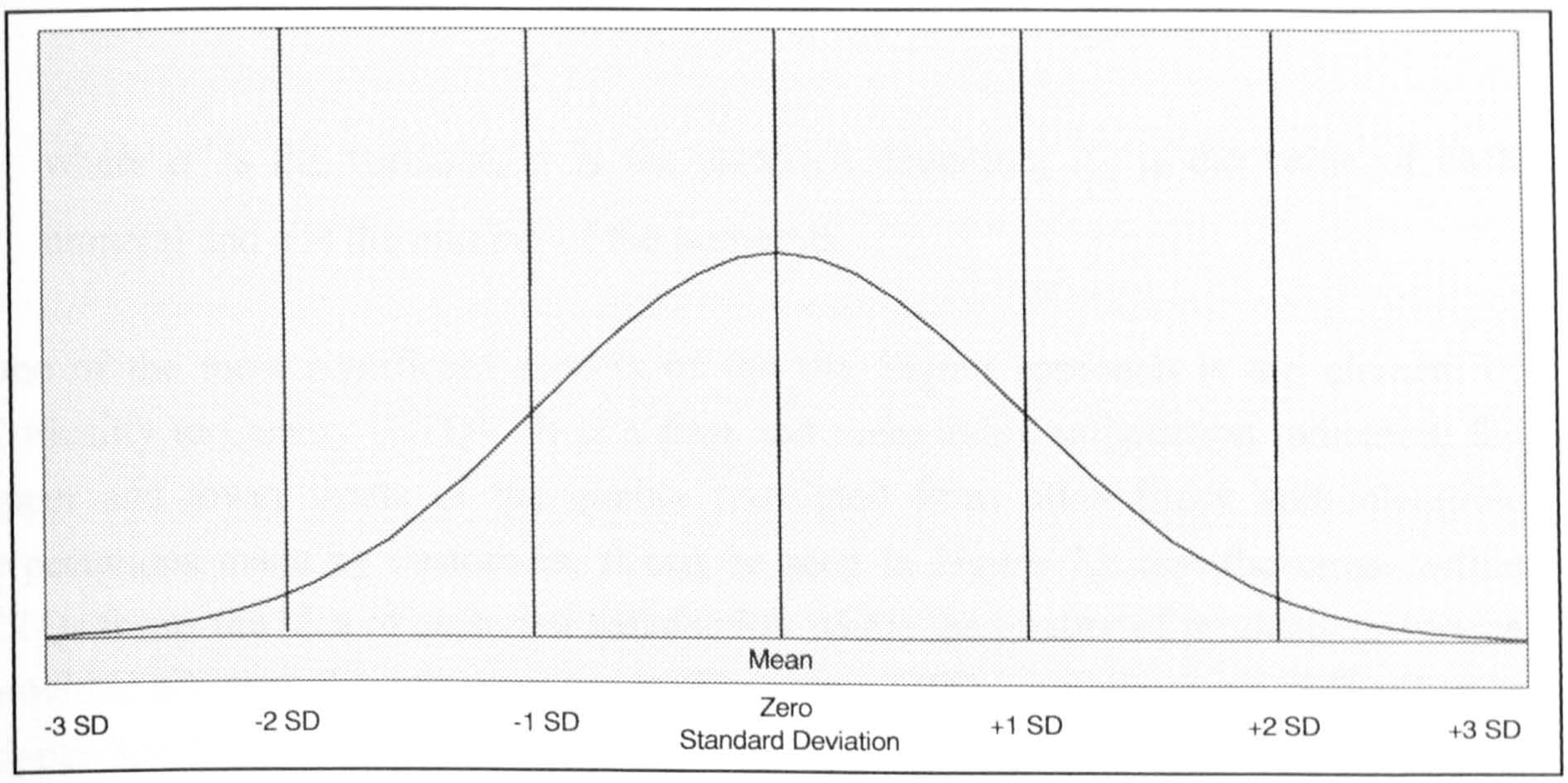

Figure 7.1. A typical bell curve of normal distribution [Ung *et al.*, 2006d]

As Six Sigma is based on the normal distribution, the mean (μ) (sometimes expressed as $\overline{X}$) and standard deviation (σ) are employed. The value of mean is defined as a quotient that is obtained from the value of the summation aggregated by a certain number of numerals and then divided by the number of the numerals in question. The average sum of the square number of the difference between each value of the numeral and mean is regarded as a variance (σ^2). The square root of the variance is the standard deviation. The mathematical expressions of mean, variance and standard deviation are indicated below.

Mean:

$$\overline{X} = \frac{1}{n}(X_1 + X_2 + ... + X_n) = \frac{1}{n}\sum_{i=1}^{n} X_i \qquad \text{(Equation 7.1)}$$

Variance:

$$\sigma^2 = \frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{n} \qquad \text{(Equation 7.2)}$$

Standard deviation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{n}} \qquad \text{(Equation 7.3)}$$

where σ^2 is the variance, σ is the standard deviation, X_i is the value of each numeral and n is the number of the numerals.

One of the most significant aspects of the Six Sigma approach is the element of Criticality to Quality (CTQ). It is a firm and measurable satisfaction indicating the upper and lower limits of the quality translated from often fuzzy and intangible expectations made by customers. It can be seen in Figure 7.2 that the range within CTQs forms the idea of customer satisfaction where the quality of products or service provided achieves the customer needs. These two CTQs sometimes are referred to as Upper Specification Limit (USL) and Lower Specification Limit (LSL). The process measurement and improvement will begin in earnest only if a set of CTQs is well defined. The objective of Six Sigma is therefore to minimise the value of the standard deviation in each process by identifying the root causes so that the process sigma metric (the unit of the distance between CTQ limits and μ if plotted in a normal distribution figure as shown in Figure 7.3) is able to achieve the level of six σ. If a process attains a six sigma level, the number of defects (the unacceptable quality of performances realised by customers) that occur per million opportunities (DPMO) will be no more than 3.4.

7.2.2 Belt system

The personnel involved in a belt system implementing Six Sigma projects include Champions, Master Black Belt, Black Belt and Green Belt. The Champions of a Six Sigma project team should be the delegated persons coming from the senior management. They are the personnel who well understand the Six Sigma methodology associated with the authority and ability to drive the vision of customer quality. Below these champions are the experts who have extensive knowledge and skills required to perform the projects. They are often called Master Black Belts, whose roles are to act as internal consultants, trained experts, teachers, leaders and coaches. Full time practitioners of Six Sigma are called Black Belts who support several quality projects simultaneously. A Black Belt in the team ensures that the communications between staff performing the same project are organised and the project is running efficiently and effectively. The person also provides the necessary technical skill for each project he supports. Part-time practitioners are generally called Green Belts who might only be responsible for one project and complete the mission delegated by Black Belts. A generic deployment of personnel in port to implement Six Sigma is shown in Table 7.1 after being trained properly. Although the belt system participants have the overriding responsibility for the Six Sigma projects, it is recommended that the personnel not involved in the belt system shall have a basic understanding of Six Sigma and the idea of quality because of the interactive function imposed on each staff member. The more people appreciate it, the better the quality improvement that will be achieved.

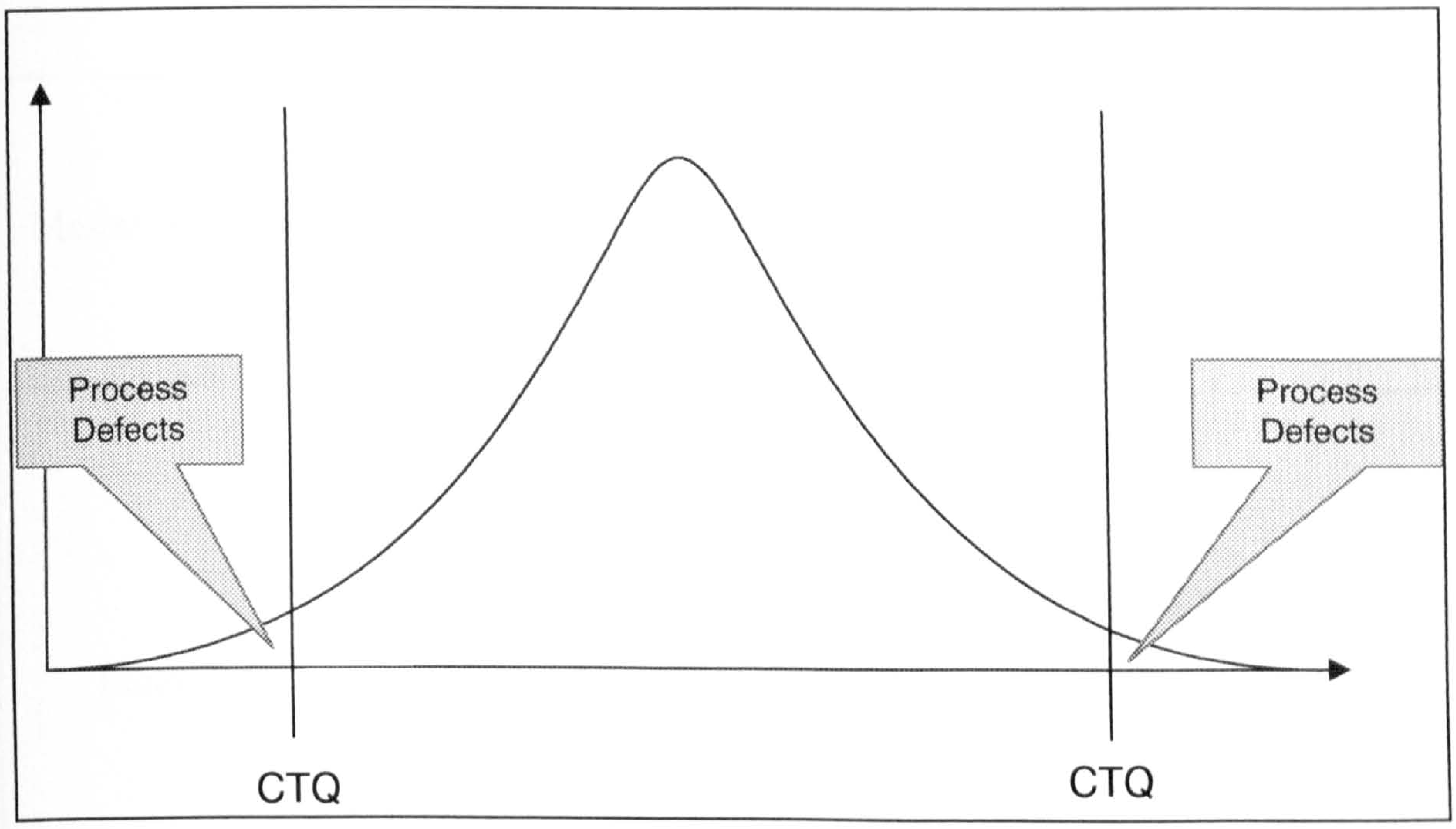

Figure 7.2. CTQ and customer satisfaction [Ung *et al.*, 2006d]

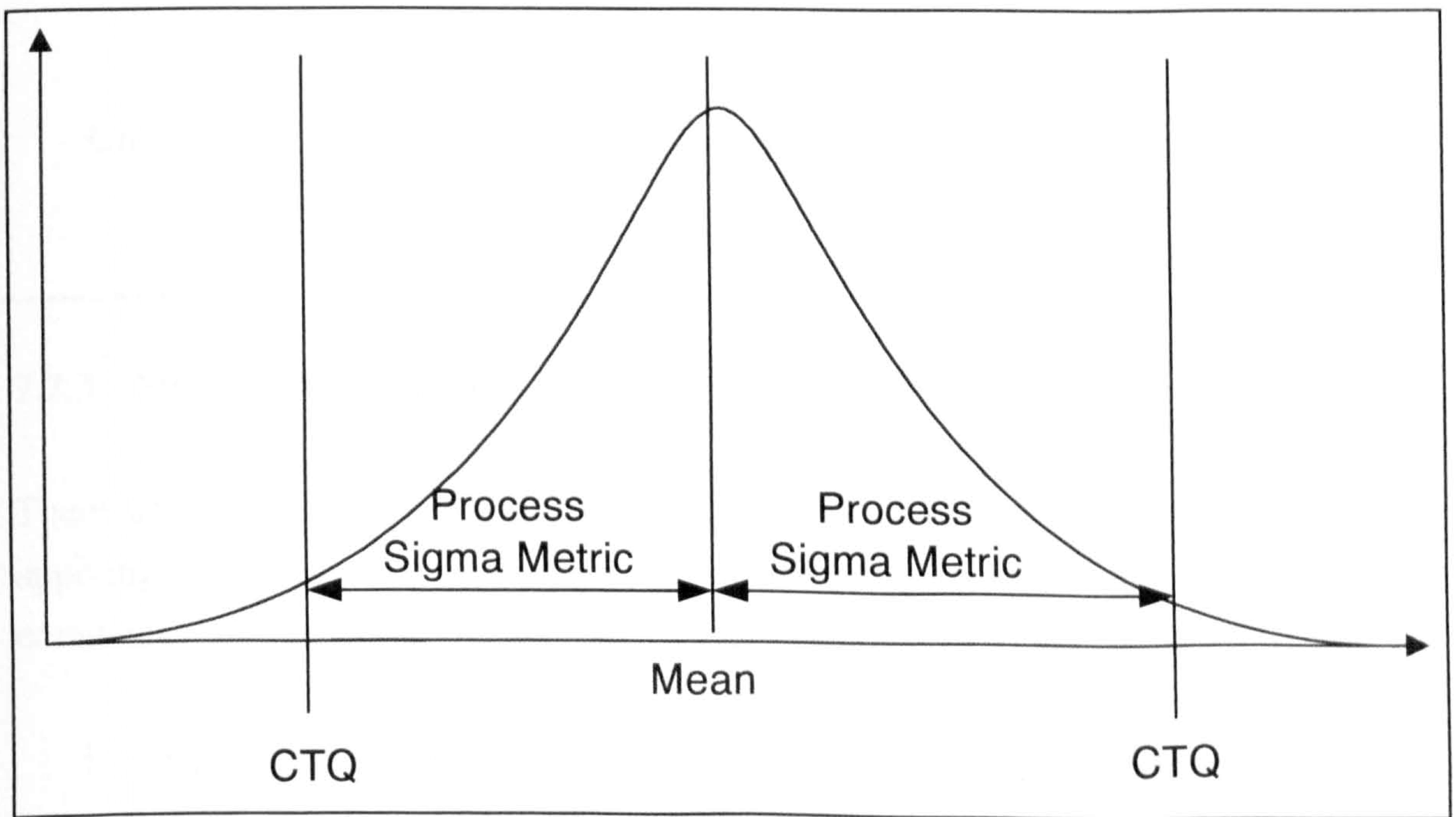

Figure 7.3. Process sigma metric [Ung *et al.*, 2006d]

Table 7.1. A generic deployment of personnel in port to implement Six Sigma

Name of Personnel Types	Definition of Personnel Types	Most Likely Port Personnel
Champions	Senior management with authority to drive the vision of customer quality or the personnel responsible for policy issues, positioning of business, capital expenditure and cost control	Directors of operations, finance, personnel and marketing.
Master Black Belts	Acting as internal consultants; trained experts; teachers; leaders; coaches and experts in specific fields, involved in special projects.	Senior managers of safety, security, terminals and marine groups within operations.
Black Belts	Full time practitioners supporting several quality projects simultaneously, ensuring that the communication betweens between staff performing on the same project are organised and the project is running properly and providing the necessary technical skill for each project.	The managers of the container, bulk, oil and Ro/Ro terminals plus say pilot manager.
Green Belts	Those responsible for one project and completing tasks set by Black belts.	Shift managers of container, bulk, oil or Ro/Ro terminals or contractors working on these terminals.

7.2.3 Success of Six Sigma

There are some factors which are essential to the success of Six Sigma. When applying Six Sigma to port security, those elements identified and realised from the companies implementing the approach should be considered and are discussed below.

1. **Upper management support, involvement and commitment.** This is the most important factor addressed by those who have applied the approach to their businesses [Henderson and Evans, 2000]. This is in line with a survey

conducted in the UK industry in 2002 [Antony and Coronodo, 2002] since any successful initiative requires top management commitment and provision of appropriate resources and training. In Six Sigma success stories like Motorola, GE and Allied Signal, the Chief Executive Officers (CEOs) support, participate and are actively involved and dedicated themselves to this initiative [Coronado and Antony, 2002]. In addition, implementing quality improvement initiatives is a part of the job for every single person involved in the project, including top management and senior managers. Without such support, involvement and commitment, the success of Six Sigma will be difficult to foresee.

2. **Training.** In order to make the belt system effective, the role and responsibility of each participant must be identified and appreciated using training programmes. This work should be associated with providing Six Sigma knowledge, tools and techniques needed for these belts depending upon the group that they are located to.

3. **Linking Six Sigma to business strategy.** Six Sigma needs to be integrated into port operations rather than just the usage of a few tools and techniques for quality improvement [Dale, 2000]. Since the objective of such an application objective is to improve the quality of performance and consequently gain the profits, the link between every single project and the business strategy should be established.

4. **Linking Six Sigma to customers.** Customer satisfaction is the key element of Six Sigma. By equipping with CTQs, the approach is capable of reducing the gap of expectations between the port authority applying Six Sigma and its customers provided that the key customers crucial to the port operations have been identified.

5. **Culture change.** A successful application and implementation of Six Sigma requires a change to the culture of the company and a reform to the attitude of its employees. Employees have to be responsible for the quality of their own work. This, however, sometimes leads to fears of change and of not achieving the new standards. The organisations that have successfully overcome the culture change have stated that the best solution is through increased and sustained communications, motivations and education [Antony and Coronodo, 2002].

6. **Organisation infrastructure.** The formation of the personnel participating and implementing Six Sigma in a company is divided into five groups, including Champions, Master Black Belts, Black Belts, Green Belts and

individuals supporting specific projects in their areas [Harry and Schroeder, 2000]. Therefore, if a port authority intends to apply Six Sigma fully to its business, the issue of adjusting its infrastructure should be taken into account.

7.2.4 Applications

By using Six Sigma Motorola has acquired $16 billion in savings over the past 12 years while Ford reports more than $1 billion saved since 2000 [Heuring, 2004]. Additionally due to its flexibility, it can be applied to various characteristics of companies, where substantial cost savings have been reported. Apart from Table 2.13, these include the Service Master Company in Chicago U. S. using the approach to improve credit card processing [AFP Exchange, 2004], the Scranton Parts Manufacturing Center of Flowserve Corp. converting the facility into a sizable and efficient plant for the production of new parts [Modern Applications News, 2004], Carlson Companies in Minnesota applying it to cut the supply chain costs [Porter, 2004], as well as Virtua Health in New Jersey adopting the tool to improve the patient satisfaction, operation throughput, nurse retention and reduce medication errors [Ettinger, 2001]. Therefore, it seems sensible to utilise Six Sigma for the improvement and maintenance of the quality of port operations.

7.3 Methodology

When implementing a Six Sigma project to improve the quality of a process, there are five steps which should be taken, namely, Define, Measure, Analyse, Improve and Control. In the definition step, the unit of the measurement that will be used to judge the performance of the quality of a process should first be decided. Secondly, the goal of the quality and the value of the CTQ must be identified. Thirdly, the term "defect" needs to be defined. The mission of the measurement step will be to evaluate the current performance of the efficiency of a port process. At the analysis stage, the root causes of poor quality that may occur due to excessive variation contributing to the defects unacceptable for customers are identified and analysed. A sensitivity analysis will also be conducted to identify appropriate solutions. In the improvement step, the solutions aimed at reducing the root causes identified in the analysis step can be generated. Accordingly, the quality of port security and safety measures can be improved. After the implementation of the solutions, the actual improvement of the quality of the process will be realised and acquired in the final step. Figure 7.4 illustrates the research methodology of this study.

7.3.1 Definition of the measuring unit, CTQ and defect of the quality with regard to port security and safety measures

At the first stage, the unit of measurement that will be used to judge the performance of the quality of a process should first be decided. Secondly, the goal of the quality and the value of the CTQ must be identified. Thirdly, the term "defect" needs to be defined. In the manufacturing industries, "defect" is easy to understand and has been applied widely. However, if adopted in the port industry, it should be converted to an "unacceptable performance". Therefore, the third mission on this stage is the definition of the unacceptable performances. It is noted that since the objective of this study is to demonstrate the applicability of Six Sigma when introducing it to ports, the value of CTQ will be given by expert judgements. In the real world, CTQs may be obtained from customer requirements through a comprehensive survey and analysis and then converted to a measurable unit for the process. The goal for the project is set on the basis of the definition of defects (or unacceptable performances in the port industry) and customer CTQs for the purpose of achieving total customer satisfaction.

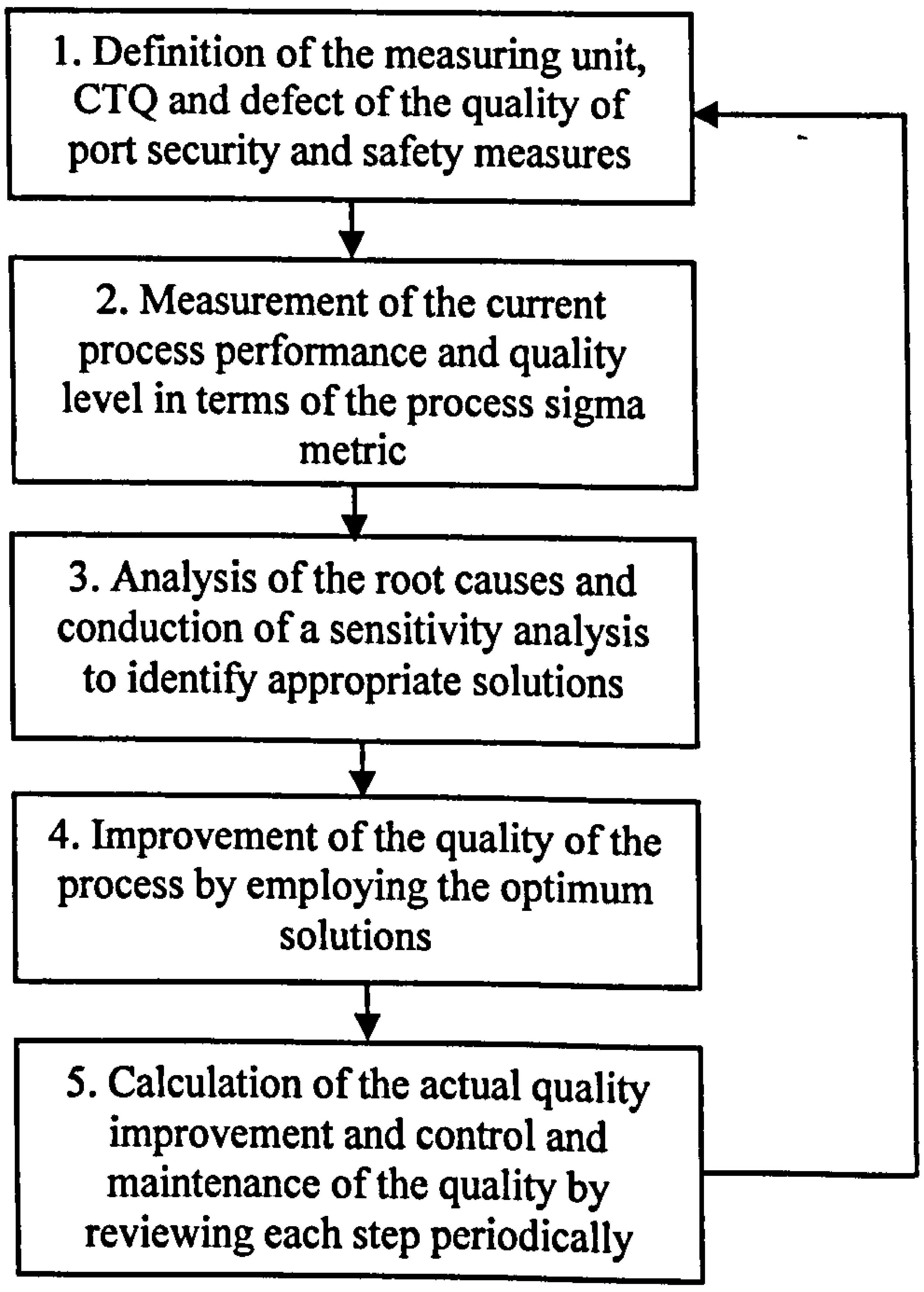

Figure 7.4. Research methodology

7.3.2 Measurement of the current process performance and the quality level in terms of the process sigma metric

The objective of this step is to add facts to the project, enabling the initial or current short term process sigma metric to be calculated and therefore provide valuable information for the next step. The following calculations are needed in this stage:

1. Calculate the values of Mean (μ) and Standard Deviation (σ) from the data gathered using Equations 7.1, 7.2 and 7.3.

2. Convert each customer limit i.e. USL and LSL to a standardized normal variate referred to as a value of Z [Oakland, 1999] when the normal distribution is standardized as shown in Equations 7.4 and 7.5.

$$Z_{USL} = \frac{(USL - \overline{X}_{current})}{\sigma_{current}} \quad \text{(Equation 7.4)}$$

$$Z_{LSL} = \frac{(LSL - \overline{X}_{current})}{\sigma_{current}} \quad \text{(Equation 7.5)}$$

where Z_{USL} is the converted Z value derived from USL,

USL is the Upper Specification Limit expressed by the customers,

Z_{LSL} is the converted Z value derived from LSL,

LSL is the Lower Specification Limit requested by the customers,

$\overline{X}_{current}$ is the Mean of the current performance of the process, and

$\sigma_{current}$ is the Standard Deviation of the current performance of the process.

3. Calculate the successful probability that the process in question is able to achieve the customer needs referred to as $P(Z_{satisfied})$. It is the difference between $P(Z_{USL})$ and $P(Z_{LSL})$. These two values can be obtained from the Standard Normal Probability Distribution Table as shown in Appendix 12 [Yin, 2001].

$$P(Z_{satisfied}) = P(Z_{USL}) - P(Z_{LSL}) \quad \text{(Equation 7.6)}$$

where $P(Z_{satisfied})$ is the probability that the performance of the process satisfies the customers,

$P(Z_{USL})$ is the probability that the process performance is within the upper specification limit, and

$P(Z_{LSL})$ is the probability that the process performance is outside the lower specification limit.

4. Obtain the probability that the process performance fails to satisfy the customers, which is regarded as the defect rate, $P(Z_{defect})$.

$$P(Z_{defect}) = 1 - P(Z_{satisfied}) \qquad \text{(Equation 7.7)}$$

5. Calculate the DPMO using Equation 7.8. Having acquired the value of the DPMO the current short term process sigma metric can be obtained from the DPMO-To-Process Sigma Conversion Table. If a DPMO of a process performance was 192,200, it would mean that the number of defects that the process would commit per million opportunities is 192,200. The current short term process sigma metric then can be obtained, being 2.37 based on the value of the DPMO using the DPMO-To-Process Sigma Conversion Table as shown in Appendix 13 [Tennant, 2001].

$$DPMO_{current} = 1{,}000{,}000 \times P(Z_{defect}) \qquad \text{(Equation 7.8)}$$

It is important to note that the early work with the process performing at the three-sigma level in the manufacturing industries showed that over a period of time, the output from a process would change. Either the mean of the distribution would shift to sideways a little or the standard deviation would become greater [Tennant, 2001]. It has become an accepted practice to devalue the three sigma ideally by 1.5 sigma (so called 1.5 sigma shift) [Stanard, 2001]. Thus, throughout the study such a process sigma metric mentioned is referred to as a short-term process sigma metric.

For ports, the mission of this step would be the collection of the data from daily operations where the process in question is tasked. By identifying the value of the process sigma metric, the extent of improvement to achieve will be realised if necessary.

7.3.3 Analysis of the root causes and conduction of a sensitivity analysis to identify preferable solutions

It is at this stage that the root causes of poor quality that may occur due to excessive variations contributing to the defects unacceptable for customers are analysed. The mission in this step can be accomplished by employing rigorous statistical techniques. Inferential statistical analysis such as confidence intervals, hypothesis tests and regression and correlation analysis along with the practical analysis of a process mapping are the typical tools used to identify the root causes of a defective process [Tennant, 2001]. In this study, once the root causes are identified, the conduction of a sensitivity analysis is recommended. By changing the parameters of Mean and Standard Deviation individually or both at the same time, the result of the distribution will be understood and used to compare with the process performance without any solution placed. The appropriate solutions will be identified based on the comparison between the performances of the improved and original processes by calculating the quality improvement using the Equations presented below.

1. Calculate the values of Mean (μ) and Standard Deviation (σ) of the data gathered from the improved process using Equations 7.1 and 7.3.

2. Convert each customer limit i.e. USL and LSL to a standardized normal variate (i.e. Z) [Oakland, 1999] when the normal distribution is standardized as shown in Equations 7.9 and 7.10.

$$Z_{iUSL} = \frac{(USL - \overline{X}_{improved})}{\sigma_{improved}} \qquad \text{(Equation 7.9)}$$

$$Z_{iLSL} = \frac{(LSL - \overline{X}_{improved})}{\sigma_{improved}} \qquad \text{(Equation 7.10)}$$

where Z_{iUSL} is the improved converted Z value derived from USL,

USL is the Upper Specification Limit expressed by the customers,

Z_{iLSL} is the improved converted Z value derived from LSL,

LSL is the Lower Specification Limit requested by the customers,

$\overline{X}_{improved}$ is the Mean of the improved performance of the process, and

$\sigma_{improved}$ is the Standard Deviation of the improved performance of the process.

3. Calculate the improved probability that the process in question is able to achieve the customer needs referred to as $P(Z_{isatisfied})$. It is the difference between $P(Z_{iUSL})$ and $P(Z_{iLSL})$ and can be obtained using Equation 7.11.

$$P(Z_{isatisfied}) = P(Z_{iUSL}) - P(Z_{iLSL}) \qquad \text{(Equation 7.11)}$$

where $P(Z_{isatisfied})$ is the improved probability that the process performance satisfies the customers,

$P(Z_{iUSL})$ is the improved probability that the process performance is within the upper specification limit, and

$P(Z_{iLSL})$ is the improved probability that the process performance is outside the lower specification limit.

4. Obtain the improved probability that the process performance fails to satisfy the customers, which is regarded as the defect rate, $P(Z_{idefect})$.

$$P(Z_{idefect}) = 1 - P(Z_{isatisfied}) \qquad \text{(Equation 7.12)}$$

5. Calculate the improved DPMO. Having acquired the value of the improved DPMO the improved short term process sigma metric can be obtained from the DPMO-to-Process Sigma Conversion Table listed in Appendix 13. The quality improvement will then be obtained using Equation 14.

$$DPMO_{improved} = 1{,}000{,}000 \times P(Z_{idefect}) \qquad \text{(Equation 7.13)}$$

$$PSM_i = PSM_{improved} - PSM_{original} \qquad \text{(Equation 7.14)}$$

where PSM_i is the quality improvement of the process after having the solutions implemented,

$PSM_{improved}$ is the improved process sigma metric, and

$PSM_{original}$ is the original process sigma metric without any solution in place

7.3.4 Improvement of the quality of the process by employing the optimum solutions

As aforementioned, once the root causes have been identified, the solutions aimed at reducing them can be generated. Accordingly, the quality of port security and safety measures can be improved.

7.3.5 Calculation of the actual quality improvement and control and maintenance of the quality by reviewing each step periodically

After the implementation of the solutions, the actual improvement of the quality of the process will be acquired. Any improvements in performance will only be sustained if the process operations are periodically monitored and controlled. The actual improved sigma metric of the process performance can be obtained and the quality improvement will therefore be identified by employing the equations shown in the Analysis Stage. Furthermore, the only way of maintaining the quality level of the process is to continuously review the performance in each step and adopt any measure available to improve the quality if necessary.

7.4 Test case

The objective of this study is to demonstrate how the quality of port security and safety measures can be measured and improved by applying Six Sigma. The test case in this research selected is the transport process of ship stores (foodstuff) in a port as recommended by American Bureau of Shipping (ABS) Consulting when developing a Port Facility Security Plan [Casada *et al.*, 2003]. Since the berthing time is important for vessels calling at ports and stores suppliers providing goods needed for vessels, the time taken during the process is used as a measuring index when investigating the quality of the security measures. It should be noted that the values of average time and standard deviation in each step are determined based on expert judgement.

7.4.1 Definition of the measuring unit, CTQ and defect of the quality with regard to the port security measures

7.4.1.1 The security process of ship stores transport

According to the Guide for Port Security proposed by ABS Consulting [Casada *et al.*, 2003], the security process should be conducted in the following way provided that the registration of such transport has been organised in advance. The process can be separated into five steps as illustrated in Figure 7.5.

1. On arrival, Gate Security will verify the vehicle carrying stores and driver details and then notify the Ship Security Officer (SSO), who will subsequently arrange crewmembers to meet the vehicle at the staging area.

2. The store vehicle will then be escorted to the designated vehicle staging area which is separated from the restricted area by appropriate physical barriers.

3. When the vehicle is permitted for delivery, it will subsequently be escorted to the shipside for unloading.

4. Unloading the goods.

5. After discharging the goods the vehicle will again be escorted to the gate and finally leave the port. It should be noted that without appropriate escorts, the vehicle is not allowed to move within the port area.

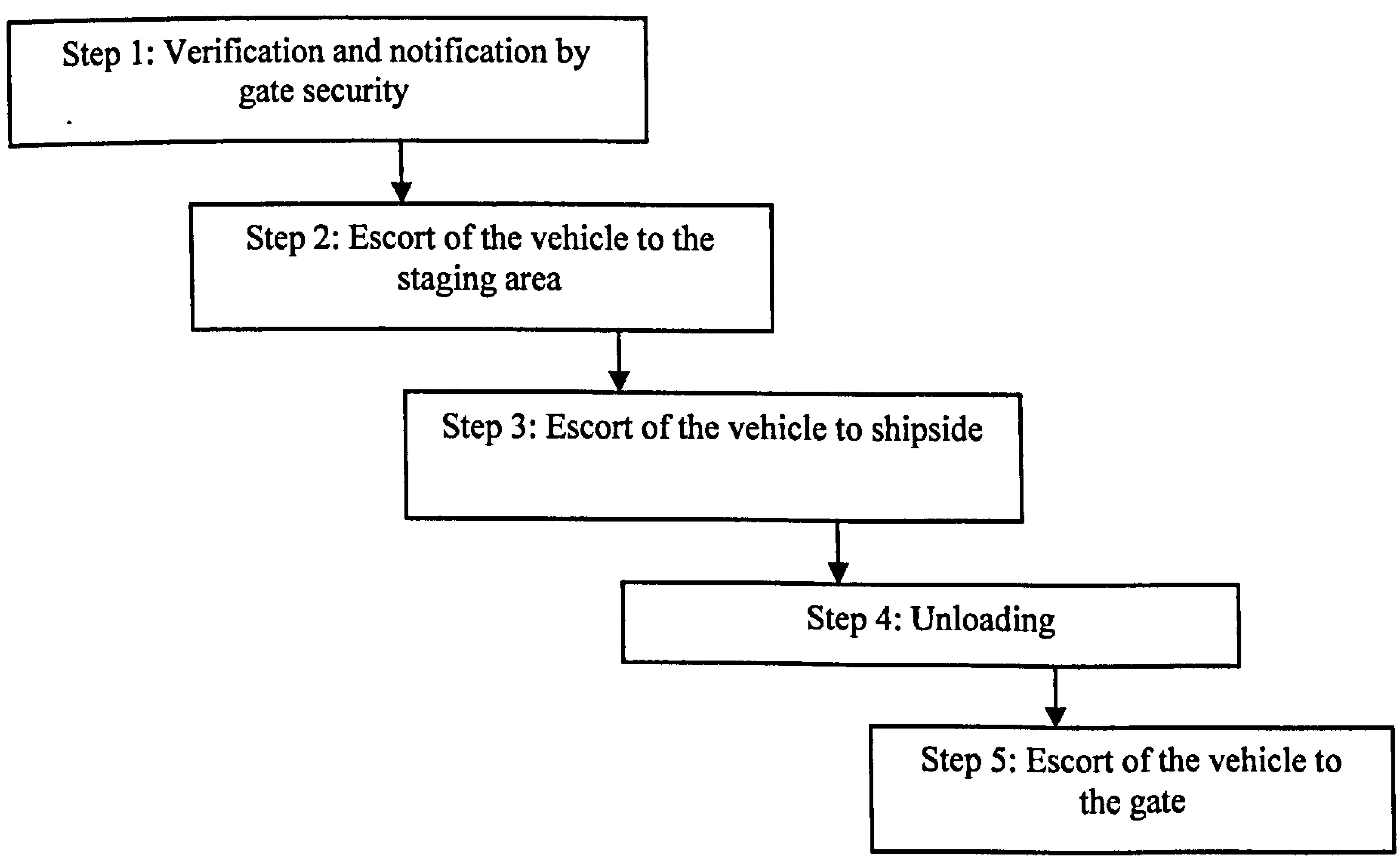

Figure 7.5. The security process of ship stores transport [Casada *et al.*, 2003]

7.4.1.2 Definition of time

In the test case, the time spent in the process is used as a measuring index so as to calculate the process sigma metric. The time definitions of each step are presented below.

- Step 1: the time of verifying the vehicle and driver details and the notification of the SSO.
- Step 2: the time spent when escorting the vehicle to the designated staging area and waiting for the permit for delivery.
- Step 3: the period of escorting the vehicle to shipside.
- Step 4: the unloading time.
- Step 5: the time required to escort of the vehicle to the gate.

7.4.1.3 Identification of CTQ

Prior to assessing the quality of the process, it is important to identify the CTQ for the process. It is assumed that the CTQ is 50 minutes, meaning that the time limit requested by the traders organising the foodstuff supply takes no longer than 50 minutes. If the time of completing the whole security process is greater than CTQ, it will be an unacceptable performance i.e. a defect. Accordingly, the traders may lose business elsewhere since the berthing time is critical for vessels and thus it leads to dissatisfied customers (traders). Thus, in this test case it is defined that the unacceptable performance occurs if the time spent in the security process exceeds 50 minutes. Allowing for the statistical significance, the sample number is assumed to be 100, that is, the frequency of measuring the mission time of the security process is 100. This is because if the sample was set too low, for instance, 30, the characteristic of the population, i.e. the quality performance, would not be appropriately observed and identified. Such a difficulty can only be resolved by increasing the sample. Therefore, by rising the sample from 30 to 100, the statistical significance can be improved substantially.

7.4.2 Measurement of the current process performance and the quality level in terms of the process sigma metric

In the real world case studies, the mission at this stage is to gather the data needed. However, since the objective of this test case is to demonstrate the methodology proposed, the values of the time spent in each step in the test case were generated randomly based on normal distribution by using Microsoft Excel. Table 7.2 shows the Mean (μ) and Standard Deviation (σ) in each step acquired based on expert judgement and the μ and σ values for the whole process. Figure 7.6 illustrates the value (time) distribution of each security process after 100 simulations, indicating the quality of the current security measure for the transport of foodstuff.[1] It can be seen from the Figure that the most frequent numbers i.e. the time spent in the process in 100 simulations are 34, 44 and 45 respectively, each frequency of which is 7.

Table 7.2. The Mean and Standard Deviation in each step and the whole process

	Mean (μ)	Standard Deviation (σ)
Step 1	8	3.0
Step 2	14	6.5
Step 3	5	2.0
Step 4	10	2.0
Step5	5	1.5
The whole process	42.39	8.56

Unit: minutes

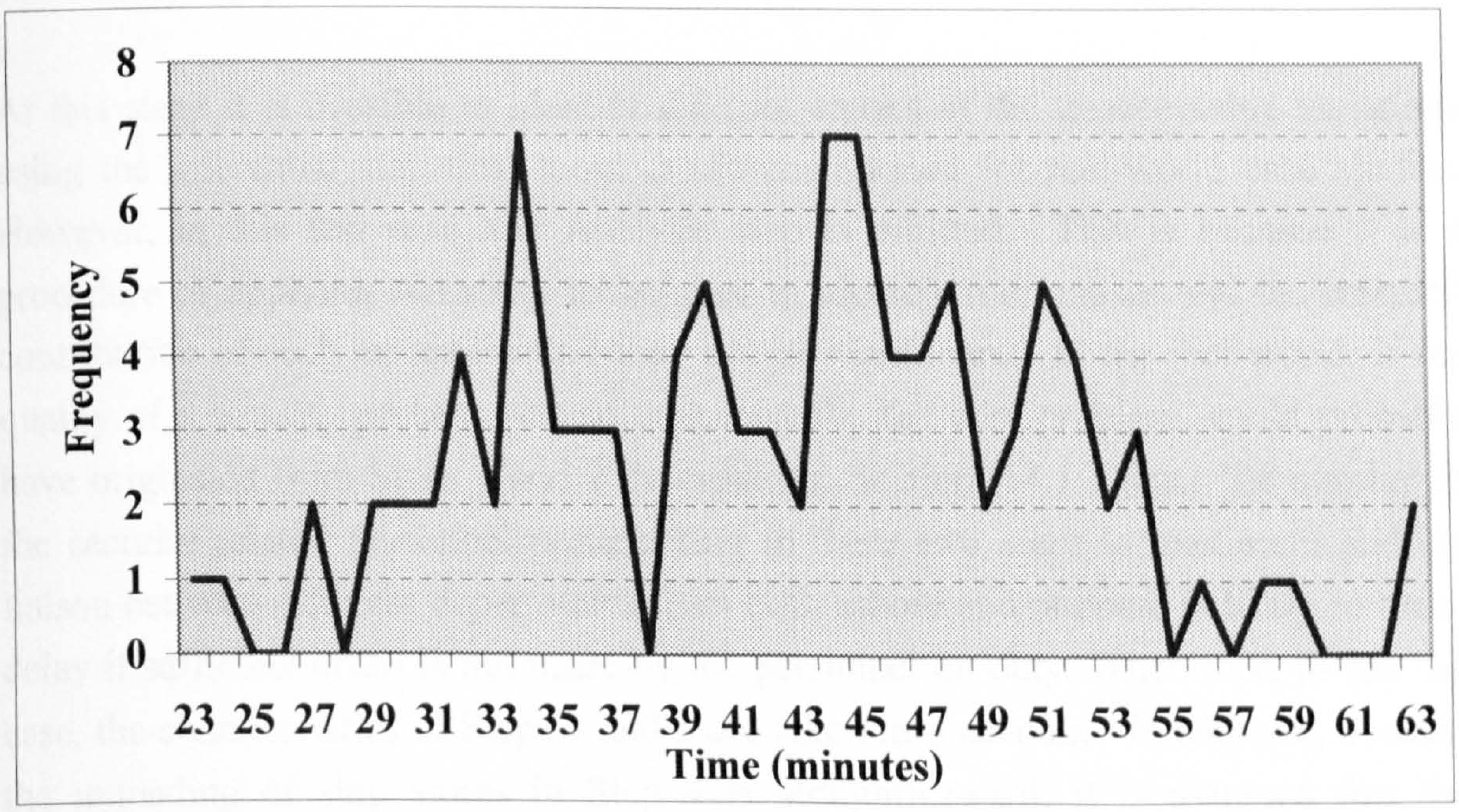

Figure 7.6. The time distribution of the current security process of the test case

Using Equation 7.4, the process sigma metric for short term is calculated as follows:

$$Z_{USL} = \frac{(USL - \overline{X}_{current})}{\sigma_{Current}} = \frac{(50 - 42.39)}{8.56} \cong 0.89$$

Since there is no LSL in this test case, the calculation of Z_{LSL} is omitted. The value of $P(Z_{USL})$ is obtained from the Standard Normal Probability Distribution Table in Appendix 12 and $P(Z_{satisfied})$ is calculated below using Equations 7.6, 7.7 and 7.8:

[1] The value (time) of the security process is the summation of the time estimated from Step 1 to Step 5 and the value generated in each step is the approximate random integer based on normal distribution.

$$P(Z_{satisfied}) = P(Z_{USL}) - P(Z_{LSL}) = 0.8133 - 0 = 0.8133$$

$$\therefore P(Z_{defect}) = 1 - P(Z_{satisfied}) = 1 - 0.8133 = 0.1867$$

$$DPMO_{current} = 1{,}000{,}000 \times P(Z_{defect}) = 186{,}700$$

$DPMO_{current} = 186{,}700$ means that if the same process was repeated one million opportunities, it is likely that the number of the frequency of failing to satisfy the customer needs would be 187,700. According to the DPMO-To-Process Sigma Conversion Table shown in Appendix 13, the process sigma metric for short term in this test case approximates to 2.4.

7.4.3 Analysis of the root causes and conduction of a sensitivity analysis to identify preferable solutions

At this stage it is possible to identify the root causes of the unacceptable variations using the inferential statistical tools as aforementioned for real-world case studies. However, in this test case, the Analysis step is omitted. This is because it is a procedure of applying statistical techniques to identify root causes and the research contribution of such an application may not be significant. In the real world, if the quality of a security process was so unacceptable, the core problem would probably have originated from Steps 1 and 2 described in Section 7.4.1.1 since the number of the security related personnel participating in these two steps is maximum and the liaison between different departments from both ashore and onboard is likely to cause delay if sufficient effort is not made by the personnel on duty. Therefore, in this test case, the characteristics of Steps 1 and 2 are taken into account. In addition, because the unloading of ship stores in Step 4 is straightforward, it is assumed that the Standard Deviation of this step remains constant. Accordingly, based on the sensitivity analysis by altering the values of Means in Steps 1 and 2 and Standard Deviations in Steps 1, 2, 3 and 5 individually or both simultaneously, the decision maker will realise how the distribution would be and compare such cases with the original one. The appropriate solutions will then be decided based on the quality improvement and resources available.

7.4.3.1 Sensitivity Analysis 1 - the alteration of the values of Mean (the average time spent in Steps 1 and 2)

Table 7.3. Sensitivity analysis 1

	Mean (μ)	Standard Deviation (σ)
Step 1	6	3.0

Step 2	12	6.5
Step 3	5	2.0
Step 4	10	2.0
Step5	5	1.5
The whole process	38.23	7.16

Unit: minutes

Altering the values of the Mean in Steps 1 and 2 from 8 and 14 to 6 and 12, i.e. changing the average time spent in Steps 1 and 2, while other parameters remain the same, it can be seen in Table 7.3 that the Mean of the whole process has been changed from 42.39 to 38.23 and that the Standard Deviation has been reduced from 8.56 to 7.16. The graph in Figure 7.7 is therefore thinner than in Figure 7.6. The extreme values have been changed from 63 and 23 to 53 and 21.

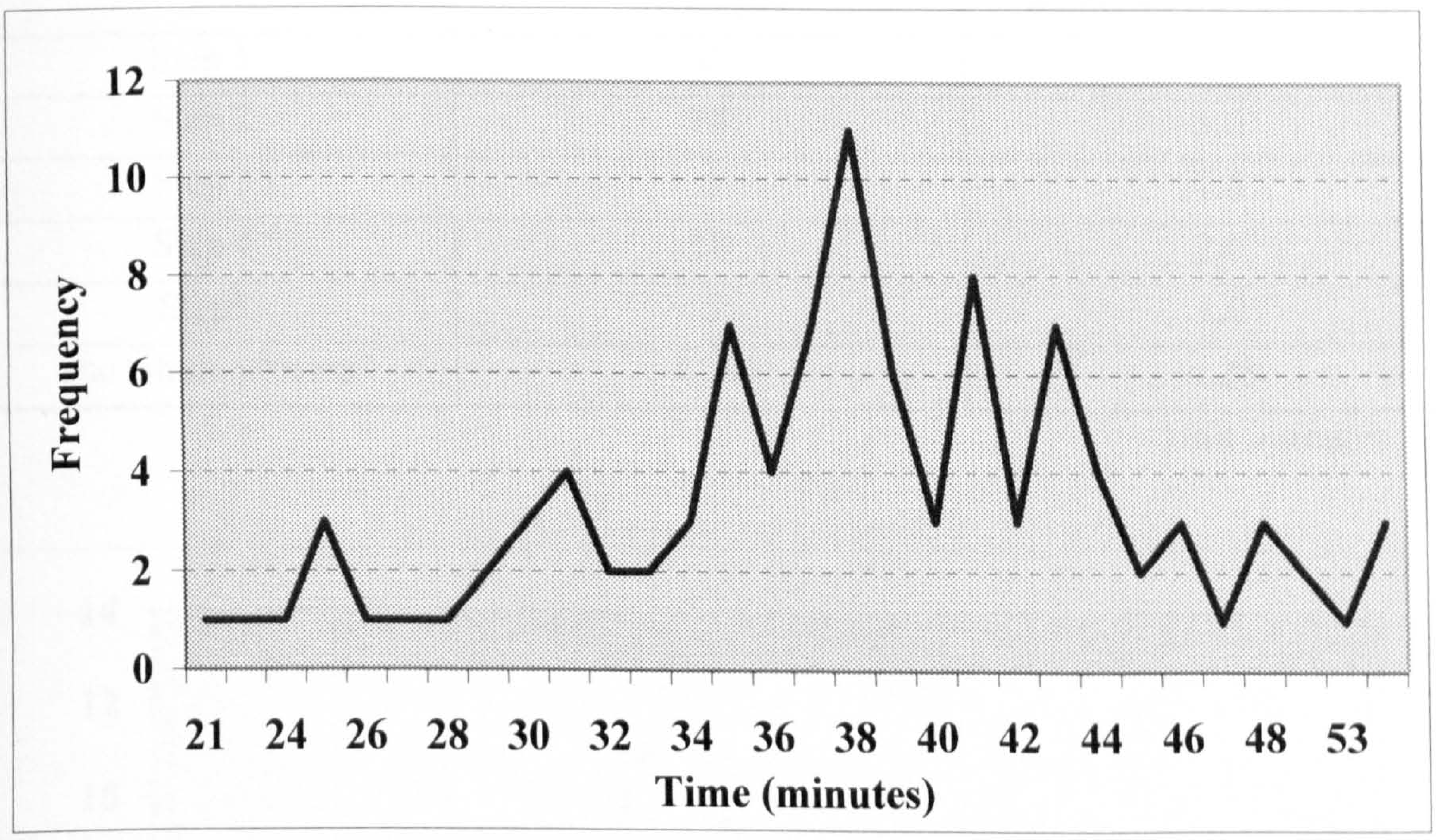

Figure 7.7. The time distribution of the improved security process of the test case by changing Mean

The quality improvement is subsequently calculated as follows:

$$Z_{iUSL} = \frac{(USL - \overline{X}_{improved})}{\sigma_{improved}} = \frac{(50 - 38.23)}{7.16} \cong 1.64$$

Since there is no LSL in this case study, the calculation of Z_{iLSL} is omitted. The value of $P(Z_{iUSL})$ is obtained from the Standard Normal Probability Distribution Table and $P(Z_{isatisfied})$ is calculated as follows:

$$P(Z_{isatisfied}) = P(Z_{iUSL}) - P(Z_{iLSL}) = 0.9495 - 0 = 0.9495$$

$$\therefore P(Z_{idefect}) = 1 - P(Z_{isatisfied}) = 1 - 0.9495 = 0.0505$$

$$DPMO_{improved} = 1{,}000{,}000 \times P(Z_{idefect}) = 50{,}500$$

According to the DPMO-To-Process Sigma Conversion Table, the estimated process sigma metric for short term approximates to 3.14. The quality improvement would then be:

$$PSM_i = PSM_{improved} - PSM_{original} = 3.14 - 2.4 = 0.74$$

7.4.3.2 Sensitivity Analysis 2 - the alternation of the values of Standard Deviation

Table 7.4. Sensitivity analysis 2

	Mean (μ)	Standard Deviation (σ)
Step 1	8	1.5
Step 2	14	3.0
Step 3	5	1.5
Step 4	10	2.0
Step5	5	1.0
The whole process	42.86	4.28

Unit: minutes

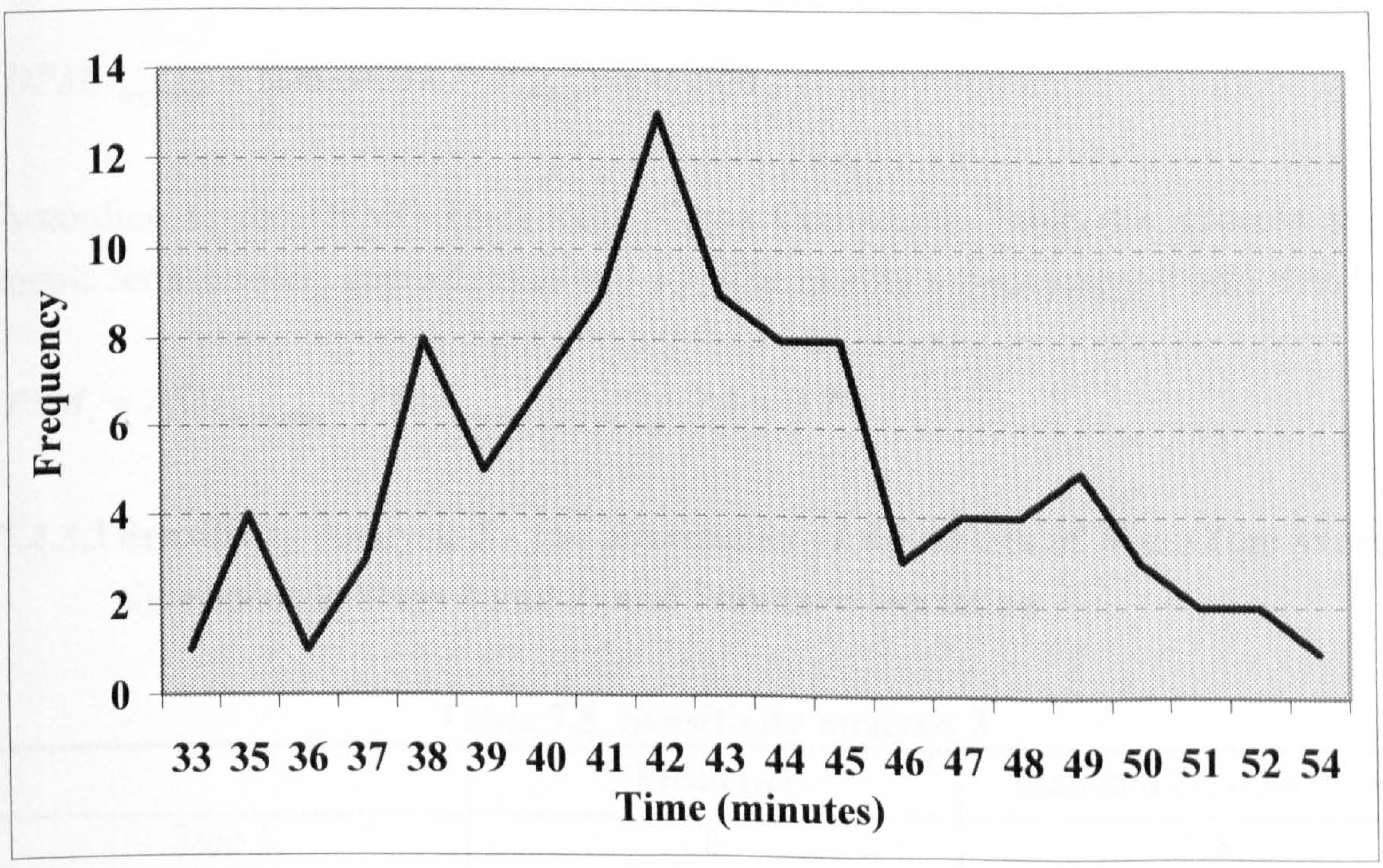

Figure 7.8. The time distribution of the improved security process of this test case by changing Standard Deviation

By decreasing the values of the Standard Deviation in Steps 1, 2, 3 and 5 from 3.0, 6.5, 2.0 and 1.5 to 1.5, 3.0, 1.5 and 1.0 respectively, and keeping the others unchanged, it shows that the Standard Deviation of the whole process is minimised by half, down to 4.28 and the value of the Mean almost remains the same as can be seen from Table 7.4. Figure 7.8 shows that the graph is more centred to the Mean than Figure 7.6 and the maximum and minimum values have been changed from 63 and 23 to 54 and 33.

The quality improvement is then calculated as follows:

$$Z_{iUSL} = \frac{(USL - \overline{X}_{improved})}{\sigma_{improved}} = \frac{(50 - 42.86)}{4.28} \cong 1.69$$

Since there is no LSL in this case study, the calculation of Z_{iLSL} is omitted. The value of $P(Z_{iUSL})$ is obtained from the Standard Normal Probability Distribution Table and $P(Z_{isatisfied})$ is then calculated as follows:

$$P(Z_{isatisfied}) = P(Z_{iUSL}) - P(Z_{iLSL}) = 0.9545 - 0 = 0.9545$$

$$\therefore P(Z_{idefect}) = 1 - P(Z_{isatisfied}) = 1 - 0.9545 = 0.0455$$

$$DPMO_{improved} = 1{,}000{,}000 \times P(Z_{idefect}) = 45{,}500$$

According to the DPMO-To-Process Sigma Conversion Table, the process sigma metric for short term approximates to 3.19. The quality improvement would then be:

$$PSM_i = PSM_{improved} - PSM_{original} = 3.19 - 2.4 = 0.79$$

7.4.3.3 Sensitivity Analysis 3 - the alternation of the values of Mean (the average time spent in Steps 1 and 2) and Standard Deviation

Table 7.5. Sensitivity analysis 3

	Mean (μ)	Standard Deviation (σ)
Step 1	6	1.5
Step 2	12	3.0
Step 3	5	1.5
Step 4	10	2.0

Step5	5	1.0
The Whole Process	38.07	4.31

Unit: minutes

Altering the values of the Mean in Step 1 and 2 as well as the Standard Deviation in Steps 1, 2, 3 and 5, while others remain constant, the Mean and Standard Deviation for the process performance decrease to 38.07 and 4.31 as shown in Table 7.5. Figure 7.9 is much more thinner and centred to the Mean than in Figure 7.6. The extreme values in Figure 7.9 therefore become smaller, shifting from 63 and 23 to 48 and 28.

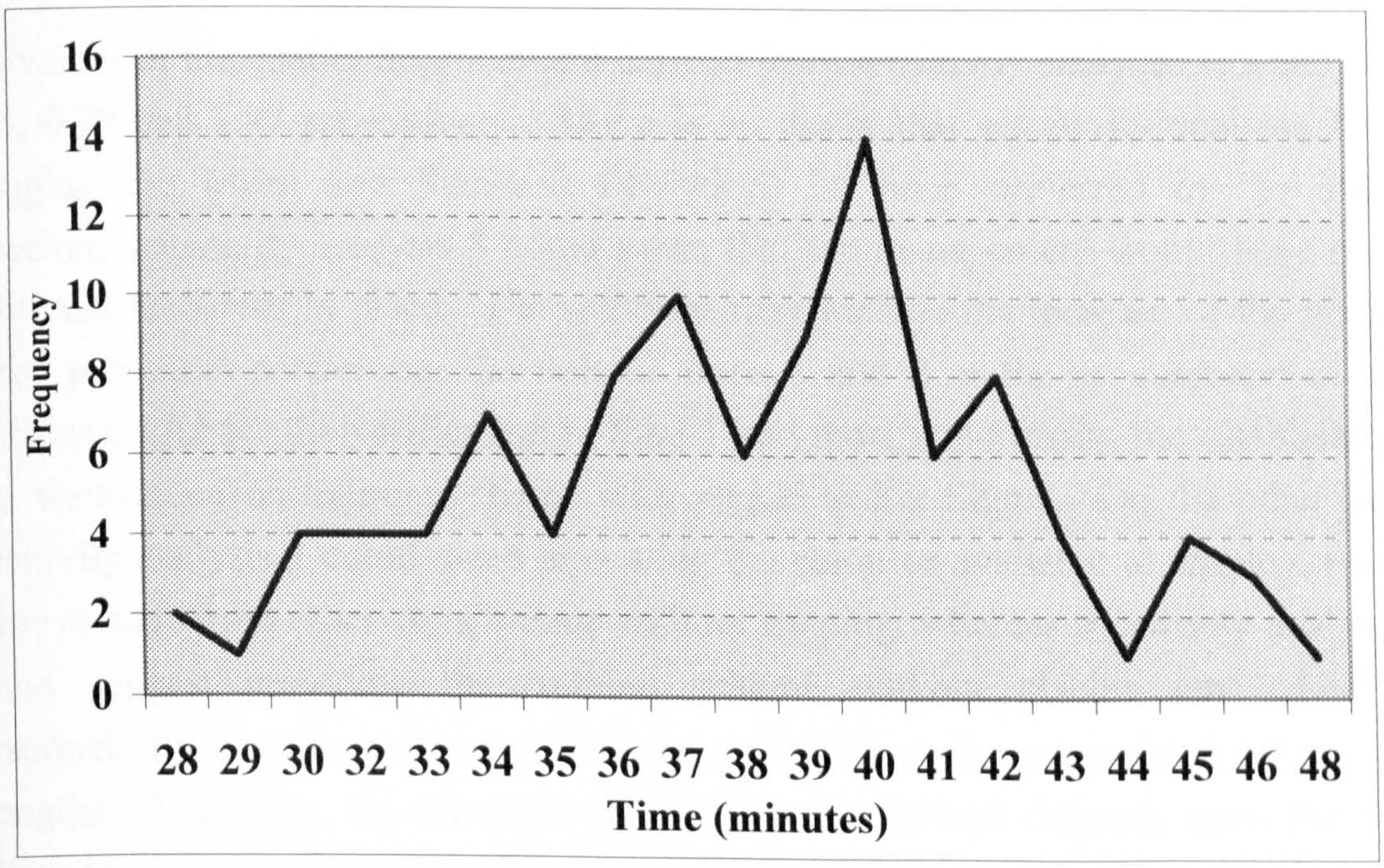

Figure 7.9. The time distribution of the improved security process of the test case by changing Mean and Standard Deviation

The quality improvement is therefore calculated as follows:

$$Z_{iUSL} = \frac{(USL - \overline{X}_{improved})}{\sigma_{improved}} = \frac{(50 - 38.07)}{4.31} \cong 2.77$$

Since there is no LSL in this case study, the calculation of Z_{iLSL} is omitted. The value of $P(Z_{iUSL})$ is obtained from the Standard Normal Probability Distribution Table and $P(Z_{isatisfied})$ is then calculated as follows:

$$P(Z_{isatisfied}) = P(Z_{iUSL}) - P(Z_{iLSL}) = 0.9972 - 0 = 0.9972$$

$$\therefore P(Z_{idefect}) = 1 - P(Z_{isatisfied}) = 1 - 0.9972 = 0.0028$$

$$DPMO_{improved} = 1{,}000{,}000 \times P(Z_{idefect}) = 2{,}800$$

According to the DPMO-To-Process Sigma Conversion Table, the assumed process sigma metric for short term approximates to 4.27. The quality improvement would then be:

$$PSM_{I} = PSM_{improved} - PSM_{original} = 4.27 - 2.4 = 1.87$$

The values of the quality improvement derived from sensitivity analyses 1, 2 and 3 are 0.74, 0.79 and 1.87 respectively. There is no doubt that sensitivity analysis 3 (i.e. changing the Mean and Standard Deviation) is much preferred to the others. However, sensitivity analysis 3 could mean that the management would have to put additional resources in place. The solutions may include the increase of the number of the personnel performing the task in Steps 1 and 2 or the procurement of new facilities useful for the verification in Step 1 and most importantly, the establishment of a well-organised training scheme with regard to Six Sigma. On the other hand, sensitivity analysis 1 could mean allocating the resource available to employ, recruit or move staff from other departments without training, whereas sensitivity analysis 2 would suggest providing the training scheme without placing any additional personnel. Each option originated from the sensitivity analyses has disadvantages and strengths. Therefore, the selection of appropriate solutions depends upon the ports willing to improve the quality of their security and safety measures.

7.4.4 Improvement of the quality of the process by employing the optimum solutions

The purposes of this step are to have the solution implemented in the security process and reduce the variation in order to provide customer satisfaction. In this test case, it is omitted. However, in the real world, having identified the root causes, it is possible to have more than one solution in hand simultaneously. The application of Cost-Benefit Assessment (CBA), Analytical Hierarchy Process (AHP) or some other appropriate decision-making techniques would be useful depending upon the circumstance encountered.

7.4.5 Calculation of the actual quality improvement and control and maintenance of the quality by reviewing each step periodically

The actual quality improvement in the process can be obtained by providing solutions such as procuring security checking sensors into the process or organising a periodical quality training scheme. This step is again omitted in this test case. However, it is important to note that none of the organisations or companies adopting the Six Sigma methodology was able to reach the perfect level i.e. the six sigma level in the first time. The way to achieve it is moving forward gradually and this will need the commitment from the management, the belts handling the quality control of security and safety measures and the employees.

7.5 Conclusion

Nowadays a number of conventions aimed at saving life and protecting the environment have been introduced to the port and shipping industries. The efficiency of port and vessel operations resulting from the introduction of port safety and security measures becomes an important issue for port customers. In this chapter an issue of introducing the quality concept to port was raised. A framework capable of improving the quality of port security and safety measures by applying Six Sigma using time as a measuring index is also proposed. Although the demonstration is through a test case based on expert judgement, the objective can be seen very explicitly that by introducing this approach, the customer satisfaction (i.e. the time saving in the test case) will be achieved thus improving the efficiency of port operations. In order to attain this positive result, it is crucial that in the outset each step of a security process should be identified clearly irrespective of the measuring index. A sensitivity analysis in the Analysis stage is also highly recommended since such a technique enables the management to identify the appropriate solutions for quality improvement based on the resources available. In addition, since Six Sigma is based on statistical analysis, the incorporation of this quality assurance tool into port security and safety studies may not be as easy as it is with the manufacturing industries where there is already a tradition of recording data on each stage of every single process. Therefore, if any port authority intends to apply Six Sigma to evaluate the quality of its operations, collecting the information and data from each stage carefully and quantitatively is required.

Chapter 8. Discussion

In this chapter, the integration of the research is discussed based on the safety principles arising from safety regulations, addressing how the findings of the previous chapters can be linked each other. This is followed by the verification of the research, explaining how the framework proposed can be tested and verified. Finally, the limitations of the research are addressed due to the nature of the design or the assumption made in the reasoning process.

8.1 Integration and verification of research

In the past, safety regulations were introduced following an accident or a series of accidents. Over years, however, after a number of defining incidents and accidents and the introduction of new safety regulations, the way in which safety is reviewed has been altered. The characteristics of maritime safety have evolved in a reactive manner towards a proactive attitude where a risk-based regime is required. The main objective of these safety regulations is to ensure that risks have been reduced to As Low As Reasonably Practicable (ALARP) and that Risk Control Options (RCOs) proposed are cost-effective. In general, the safety principles arising from these regulations with regard to the establishment of an effective risk assessment and safety management framework as discussed in sections 2.2-2.5 consist of five steps, namely, hazard identification, risk estimation, preparation of RCOs, cost-benefit assessment and decision making.

In this research, the areas in a port with higher potential to cause harm and damage to human beings and the environment were identified as discussed in Chapter 2. This is consistent with the first step of the aforementioned safety principles. In the chapter, the difficulties encountered when evaluating risks due to the nature of maritime operations were also revealed. These include the inadequacy or lack of data for new designs, processes and regulations for port and vessels, the difficulty of quantifying the information of safety-related parameters, the absence of effective techniques capable of handling human factors, the necessity of taking into account a variety of criteria other than safety for decision making and the absence of scientific-based quality assurance models for the port industry.

Chapters 3, 4 and 5 present three different risk assessment techniques that are independent of each other. In Chapter 3, a model incorporating fuzzy set theory and the rule base method was proposed. Such a model is particularly useful in circumstances where the lack of data exists or the level of uncertainty in data for use is high. It evaluates four parameters and is capable of taking into account different importance between such elements. In the model, the information with regard to the parameters for each scenario is fuzzified. Such fuzzified data are subsequently combined to obtain the fuzzy conclusions using the rule base method and min-max approach. The defuzzification process is then conducted to obtain the risk crisp-value for the scenario. Finally, a security risk ranking for all scenarios is established based on the crisp-values acquired. In the test case, it can be seen from Tables 3.8 and 3.13 that the scenarios with the parameters described by more negative linguistic terms have higher risks than those depicted by more positive terms. For instance, in Table 3.8 the parameters of criticality (C), probability of occurrence (P), severity (S) and vulnerability (V) of the Scenario 3 are Very High 0.4 and High 0.4; High 0.4 and Moderate 0.18; Moderate 0.5 and Very High 0.52 and High 0.29, respectively, whereas the C, P, S and V for Scenario 7 are Low 0.5 and Remote 0.14; Low 0.31 and Remote 0.31; Moderate 0.44 and Low 0.08 and Remote 1.0. In the common sense point of view, scenario 3 should have a higher risk than scenario 7. Such an issue can be verified by the risk ranking acquired based on the proposed framework using fuzzy set theory and the rule base method, i.e. the risk level of scenario 3 is the highest whereas scenario 7 ranks at the 9th position among all scenarios. Furthermore, the difference of the risk levels between these scenarios can be appreciated. That is, the difference of the risk levels between scenarios 3 and 7 in terms of the defuzzified value is 5.53 (6.53 for scenario 3 and 1.0 for scenario 7).

A risk prediction model based on fuzzy set theory and an Artificial Neural Network (ANN) was proposed in Chapter 4. The model was developed to resolve the difficulty encountered when applying fuzzy set theory and the rule base technique in circumstances where there are multiple parameters to be considered which are described by multiple linguistic terms. In the model, the parameters are first fuzzified using the membership functions developed. Fuzzy set theory enables safety analysts to evaluate risks under circumstances where the lack of data exists whereas an ANN has the strength of predicting reliable results based on the quantitative training data prepared. Therefore, for the purpose of incorporating the advantages of these two techniques and allowing for the fact that the data entered into an ANN must be quantitative, an interface between the fuzzy set theory and ANN must be provided. Accordingly, an algorithm capable of converting the risk-related parameters and the overall risk level from the fuzzy property to the crisp-valued attribute is developed. This is followed by the preparation of training and testing data. The training data prepared contains the potential circumstances that are likely encountered by the port industry hypothetically established by the author based on the experience from the supervisors and the experts specialising in ports. A neural network consisting of inputs and outputs is then established. The purpose of the testing data is to investigate whether the network achieves the acceptable criteria. The network is tested and modified by inputting the testing data until it meets the appropriate accuracy criteria. Consequently, the method based on fuzzy set theory and ANN can be utilised as a risk prediction tool to facilitate the process of decision making. In the test case, the scenarios in which the parameters described by more negative linguistic terms have higher risks than those depicted by more positive terms as can be seen from Table 4.7. The information with regard to the parameters of vessel traffic control (VTC) performance, navigational aids and facilities, pilotage performance and sealane maintenance from data no. 1 to 4, for instance, are identical. These are Very Poor 0.75 and Poor 0.25. The fuzzy data of the weather condition parameter from data no. 1 to 4 is Very Poor 0.75 and Poor 0.25; Poor 0.75 and Moderate 0.25; Moderate 0.75 and Good 0.25; and Good 0.75 and Excellent 0.25, respectively. The overall risks of data no. 1 to 4 acquired are 4.625, 4.425, 4.225 and 4.025. In other words, data no. 1 has the highest risk, followed by data no. 2 and 3 whereas data no. 4 relatively has the lowest risk. Furthermore, the difference of the overall risks between the data can also be identified based on the results obtained. In addition, Table 4.10 shows the detail of the testing data as well as the results predicted by the network in comparison to the target values conducted using the fuzzy combination algorithm developed. It can be seen that the lowest prediction rate is 92.88% in the set of data numbered 29, which is the only data below 95%. Inspiringly, the average prediction rate of the neural network is over 98% and therefore has achieved the acceptable criteria established by the author based on the experience gained from the ANN literature. Accordingly, it can be concluded that the neural network has been trained appropriately and is capable of predicting risks as long as the training data takes into account any potential circumstance that may be met by the port.

A human error assessment framework using fuzzy set theory and Analytical Hierarchy Process (AHP) was developed in Chapter 5 that is capable of conducting human error assessment with confidence and avoiding the difficulties encountered when employing traditional Human Reliability Assessment (HRA) methods. In the method proposed, an AHP structure is established based on the information available. In this structure, four hierarchies are required, namely, the operation hierarchy, risk factor (criteria), mission and step hierarchies. Since the study incorporates the fuzzy set theory into the AHP method to evaluate human error related risks, a set of linguistic priority terms along with the membership functions describing the relationship between the elements in each hierarchy of the AHP structure are adopted and developed. Therefore, the pairwise comparisons between the elements in each hierarchy using fuzzy set theory can be established. The fuzzy expressions are subsequently converted to the single crisp values using the defuzzification method. This is followed by a weighting vector calculation so as to obtain the relative importance of the elements. By repeating the steps aforementioned, the risk of the elements in the step hierarchy in terms of each criteria defined can be acquired based on the normalised weighting vectors calculated. The results obtained from these three criteria are then synthesised and an overall risk priority will finally be established based on the combined risks. In the test case, it can be seen from the Table 5.29 that steps 4.2 (continuous calculation and periodical verification of the volume of transfer), 5.1 (prior warning), 3.4 (all connections checked for leaks), 4.1 (gradual increase of flow to steady rate) and 5.2 (closing valves slowly by the initiating party) are the processes with higher risks in the oil cargo handling operation. This is because the relative importances of these steps are higher than the rest in terms of the human error likelihood, failure consequence probability and severity criteria as can be seen in Appendices 6, 7 and 8 and Tables 5.26, 5.27 and 5.28. In the appendices, such steps are either the most or second important elements of each mission in terms of the criteria. For instance, step 3.4 is the most important step of the start up mission in terms of the likelihood and failure consequence probability criteria. Because it is 0.9 moderately and 0.1 slightly, 0.9 moderately and 0.1 slightly, 0.6 strongly and 0.4 absolutely, 1.0 slightly and 0.4 moderately and 0.6 fairly important than steps 3.1, 3.2, 3.3, 3.5 and 3.6 in terms of the likelihood criterion as shown in Table A6.3. Also it is 0.9 moderately and 0.1 slightly, 0.3 moderately and 0.7 fairly, 0.1 fairly and 0.9 strongly, 0.5 slightly and 0.5 moderately and 0.5 moderately and 0.5 fairly important than steps 3.1, 3.2, 3.3, 3.5 and 3.6 in terms of the failure consequence probability criterion as indicated in Table A7.3. For the severity criterion, however, it is the second important element of the mission. The most important step in terms of the severity criterion is step 3.6, being 0.9 slightly and 0.1 moderately, 0.3 moderately and 0.7 fairly, 0.1 fairly and 0.9 strongly, 0.4 slightly and 0.6 moderately and 0.5 slightly and 0.5 moderately important than steps 3.1, 3.2, 3.3, 3.4 and 3.5 as shown in Table A8.3. Accordingly, step 3.4 is the third important element in the oil cargo handling test case in Table 5.29 since its values of the normalised weighting vector in terms the likelihood, failure consequence probability and severity criteria are 0.009, 0.0828 and 0.0046 as shown in Tables 5.26, 5.27 and 5.28 based on its fuzzy information obtained. In addition, since the proposed fuzzy AHP does not consider the Human Error Probability (HEP) database, it avoids the difficulties encountered when applying traditional HRA approaches as discussed in section 5.2.3.

The risk studies conducted in Chapters 3, 4 and 5 are in line with the risk estimation step in the safety principles and can be selectively applied depending upon circumstances encountered. In circumstances where there is no or extremely scarce data or information available, the risk studies in Chapters 3 and 4 may prove to be useful based on the test cases applied. When the data collected is sufficient to a certain level, the model proposed in Chapter 5 is recommended. This is because the risk assessment techniques in Chapters 3, 4 and 5 are based on a bottom-up approach. When the lack of data exists, the number of the levels of the bottom-up approach structure is often no more than two. The application of the rule base technique in Chapter 3 is capable of genuinely generating results with confidence. However, when the information is sufficient to a certain level, implying that such information can be presented in terms of a multiple-hierarchy structure such as the one in Chapter 5, the application of the rule base method will be inappropriate. This is due to the fact that the rule base method is applied to process the fuzzy information at the same level and the use of such a method cannot avoid the loss of useful information in a hierarchical synthesis process.

The safety management methods proposed in Chapters 6 and 7 are concerned with decision making and quality assurance. The parameters considered in the decision-making model in Chapter 6 are effectiveness, cost, time of deployment, resource availability and co-operation level, respectively. The AHP technique is subsequently employed to determine the relative weight of the criteria identified. The effects of each RCO in terms of the criteria identified are then evaluated by each expert. This result is then synthesised using the Evidential Reasoning (ER) approach to acquire the overall aggregating result. This, in turn, is followed by the development of a utility category-evaluation grade matrix for each expert to estimate the utility level of each evaluation grade using the belief degree method as discussed in section 6.4.4 and shown in Tables 6.11, A11.1, A11.2 and A11.3. The utility preference of each evaluation grade estimated by each expert is then combined using the ER algorithm and normalised. The synthesised utility level of each evaluation grade based on all experts is subsequently employed to the aggregating result of the effects of each RCO. An RCO priority is then established based on the results calculated. Finally, a sensitivity analysis is conducted to identify the best measures and so provide another way of considering the importance of the various risk and cost aspects. It can be seen from Table 6.15 of the test case that the first 5 RCOs are RCOs 10, 14, 12, 4 and 15. This is due to the fact that the belief degrees of the positive evaluation grades (Good and Excellent) of these RCOs are relatively higher than the others. For instance, the belief degrees of RCO 10 for the evaluation grades of Worst, Poor, Moderate, Good and Excellent are 0, 0, 0.0256, 0.1718, and 0.8027. Its belief degrees assigned for the negative evaluation grades of Worst and Poor are none whereas the degrees for the positive evaluation grades of Good and Excellent are very high. On the other hand, the RCOs ranked in the last 5 are ROCs 7, 13, 3, 5, and 9, and this is because their belief degrees assigned to negative grades are relatively higher compared to the rest of the alternatives. The belief degrees of RCO 9 for the evaluation grades of Worst, Poor, Moderate, Good and Excellent, for instance, are 0.8605, 0.1139, 0.0256, 0 and 0. Its belief degrees assigned for the negative evaluation grades of Worst and Poor are very high whereas none of the belief degrees for the positive evaluation grades of Good and Excellent is given. In addition, based on the sensitivity analysis conducted, it can be seen from Table 6.16 that the first 5 RCOs remain unchanged whereas the ranking order of the others has been rearranged as compared with Table 6.15. The positions of RCOs 7, 1 and 11 have been promoted, ranking at 6, 7 and 9, since the belief degrees of the RCOs assigned by the experts in the effectiveness criterion are relatively higher than in the cost criterion. Likewise, the first 3 RCOs in Table 6.17 remain the same in comparison to Table 6.15. However, RCOs 8, 2, 11, 13 and 5 have become more important since the belief degrees of the RCOs assigned in the cost criterion are relatively higher than in the effectiveness criterion. Thus, it can be concluded that the best RCOs in this study are RCOs 10, 14, 12 and 4, respectively based on Tables 6.15, 6.16 and 6.17. Through the above descriptions, it is reasonable to judge that the decision-making model is in line with the safety principles addressing cost-benefit assessment and decision making. It is also demonstrated from the above descriptions that the developed decision-making model is capable of evaluating multiple attributes with both a qualitative and quantitative nature such as cost and effectiveness in the test case and also selecting the best RCOs.

The introduction of more and more safety and security RCOs based on risk assessment and safety management implies an increased probability of inefficiency influencing port operations. The quality assurance model developed using Six Sigma in Chapter 7 introduces the quality concept to the port industry and is capable of evaluating, maintaining and improving the quality of the port new-designed regulations. When implementing a Six Sigma project to improve the quality of a port security process using time as the measuring unit in the test case, there are five steps which should be taken, namely, Define, Measure, Analyse, Improve and Control as discussed in sections 7.3 and 7.4. In the definition step, the unit of the measurement that is used to judge the performance of the quality of a process should first be decided. Secondly, the goal of the quality and the value of the Criticality to Quality (CTQ) must be identified. Thirdly, the term "defect" needs to be defined. The mission of the measurement step is to evaluate the current performance of the efficiency of a port process. At the analysis stage, the root causes of poor quality that may occur due to excessive variation contributing to the defects unacceptable for customers are identified and analysed. A sensitivity analysis is also conducted to identify appropriate solutions. In the improvement step, the solutions aimed at reducing the root causes identified in the analysis step can be generated. Accordingly, the quality of port security and safety measures can be improved. After the implementation of the solutions, the actual improvement of the quality of the process is realised and acquired in the final step. In the test case, the CTQ is 50 minutes. The short term sigma metric of the current performance of the port security process can be obtained by applying Equation 7.4, Standard Normal Probability Distribution Table and DPMO-to Process Sigma Conversion Table, being 2.4 as shown in section 7.4.2. The potential improvements can also be acquired based on sensitivity analyses 1 (the alteration of Mean), 2 (the alteration of Standard Deviation) and 3 (the alteration of Mean and Standard Deviation) using similar patterns aforementioned. The values of the quality improvement derived from sensitivity analyses 1, 2 and 3 are 0.74, 0.79 and 1.87 respectively. There is no doubt that sensitivity analysis 3 is much preferred to the others. However, sensitivity analysis 3 could mean that the management would have to put additional resources in place. The solutions may include the increase of the number of the personnel performing the task in Steps 1 and 2 or the procurement of new facilities useful for the verification in Step 1 and most importantly, the establishment of a well-organised training scheme with regard to Six Sigma. On the other hand, sensitivity analysis 1 could mean allocating the resource available to employ, recruit or move staff from other departments without training, whereas sensitivity analysis 2 would suggest providing the training scheme without placing any additional personnel. Each option originated from the sensitivity analyses has disadvantages and strengths. Therefore, the selection of appropriate solutions depends upon the ports willing to improve the quality of their security and safety measures.

The risk assessment and safety management techniques developed in this thesis ensure that risk results can be acquired with confidence and RCOs proposed are cost-effective meanwhile without jeopardising the quality of port operations. This meets the objective of the safety regulations discussed in sections 2.2-2.5 since such methods are consistent with the safety principles identified in such sections based on which each method can be linked each other and integrated together.

8.2 Limitation of research

When validating research, the benchmark based on previous research which are often used to compare to developed frameworks is essential. However, since the methods proposed in Chapters 3 to 7 are original, no such benchmarks are available for conducting a full validation. Lack of the industrial data has also made a full validation of the proposed methods challenging. Although there is a large potential of the proposed framework to be applied for risk modelling and decision making, the framework may be best utilised in circumstances where the lack of data exists or the level of uncertainty in data is unacceptably high since it effectively quantifies expert judgement which initially is expressed qualitatively.

As aforementioned that the risk assessment and safety management framework proposed is capable of effectively incorporating expert judgement to conduct safety analysis based on the verifications conducted in section 8.1. Therefore, the opinions from safety and port professional personnel are crucial once the developed framework is applied in the industry although it is not the case in this research due to the difficulty of acquiring real industry data. In other words, when the framework is applied in real-world case studies, if the experts consulted do not have sufficient knowledge with regard to the subject matter under consideration, the value of the framework in this research will not be foreseen. In addition, there are limitations with regard to the methods developed in the framework, which are described in the following paragraphs.

When the fuzzy set theory and the fuzzy rule base techniques are applied, a shortcoming occurs in circumstances where there are multiple parameters to be considered which are described by multiple linguistic terms. For instance, if there were five parameters described by five different linguistic terms, the number of fuzzy rules needed to be developed would be 3,125 as discussed in section 3.5. Accordingly, such an application would become impractical. Although the shortcoming can be resolved by the model incorporating fuzzy set theory and ANN, it is nevertheless a limitation of the design.

The reason for adopting ANN with fuzzy set theory to resolve the shortcoming aforementioned is that ANN has the strength of pattern recognition. However, such a technique can only recognise the inputs and generate the outputs that are similar to the ones it has met during the training process. Therefore, the limitation of the model developed in Chapter 4 is that if such a trained ANN encounters the inputs that it has never been trained to recognise, the outputs to be generated will be unreliable. This implies the importance of the training data preparation. The more potential situations that are likely to be encountered by the training data the less the limitation of the trained ANN.

The decision-making method proposed in Chapter 6 was developed based on the assumption that RCOs are mutually exclusive. In other words, the decision making was based only on the implementation of a single RCO. There would be a limitation occurring in circumstances where two or more RCOs were introduced simultaneously. The calculation of the overall effects predicted would not be simple since the RCOs may interact with each other. This implies the need to develop new techniques capable of addressing the issue of conditional probability between elements.

In summary, the literature review conducted in Chapter 2 and the risk assessment and safety management methods proposed from Chapters 3 to 7 were integrated based on the safety principles of hazard identification, risk estimation, cost-benefit assessment and decision making. The risk assessment and safety management framework consisting of such methods is capable of effectively incorporating expert judgement to conduct safety analysis in circumstances where the lack or incompleteness of data exists based on the verifications conducted in section 8.1. Therefore, expert judgement plays an important role in this research. In addition, there are some limitations with regard to the methods proposed. These imply the need to continuously develop novel risk assessment and safety management techniques.

Chapter 9. Conclusion and Implications

Following the peroration, the conclusions of the research questions and the research problem are drawn. The conclusions and recommendations for the port industry as well as the implications for further research are also given. In summary, it is concluded that these developed models can be integrated to formulate a platform to facilitate risk assessment and safety management of port operations without jeopardising the efficiency of port operations in a variety of situations where traditional techniques cannot be applied with confidence.

9.1 Peroration

Maritime safety has evolved in a reactive manner towards a risk-based and goal setting regime since the 1990s due to the public concern following several catastrophic disasters. Traditional risk assessment techniques are capable of handling risks with confidence on the premise that historical data is available. However, such techniques may not genuinely reflect risk results in circumstances where the lack of data exists or the information available consists of a high level of uncertainty. Accordingly, it is necessary for a study of safety and security in port to enable the areas with higher risks for which the data available is scarce to be addressed. Following the research needs, this PhD study has developed five analytical models capable of performing risk assessment and safety management with confidence under the aforementioned circumstances. Such frameworks have been demonstrated by five corresponding test cases with regard to the safety and security of port operations.

First, a risk assessment framework is proposed to evaluate port security using fuzzy set theory and the rule base technique. This is because of the lack of data resulting from the confidentiality of the intelligence with regard to terrorism and the difficulty of the information accession. Secondly, a shortcoming occurs when the fuzzy rule base technique is applied to circumstances where there are multiple parameters to be evaluated, which are described by multiple linguistic terms. Such a problem can be overcome by a proposed risk prediction model incorporating fuzzy set theory with an Artificial Neural Network (ANN). The framework is demonstrated by a test case focusing on port safety. Thirdly, human error accounts for significant contribution to port accidents. In this study, a new method of human error assessment using fuzzy set theory and Analytical Hierarchy Process (AHP) is proposed. It is demonstrated using a test case of an oil cargo handling process in port, and is capable of avoiding the criticism raised when traditional Human Error Assessment (HRA) techniques are applied. Fourthly, many real world decision analysis problems involve multiple attributes with both a quantitative and qualitative nature. A decision-making model using the Evidential Reasoning (ER) algorithm is proposed to demonstrate the selection of the best security, safety and human error reduction measures under such circumstances. Finally, more safety regulations and security measures may often paradoxically imply an increased probability of inefficiency influencing port operations. Thus, the quality of the port processes regulated by such measures is essential. A quality control model is proposed based on the Six Sigma technique and is demonstrated by a test case of a port security process.

On the basis of the verifications of the test cases as discussed in section 8.1, the scenarios or RCOs with the parameters described by more negative linguistic terms have higher risks or are less preferred than or to those depicted by more positive terms. Therefore, the frameworks do possess significant potential for use in improving safety and security of port operations. Thus, these developed models can be integrated to formulate a platform, based on the safety principles arising from safety regulations as discussed in section 8.1, to facilitate risk assessment and safety management of port operations without jeopardising the efficiency of port operations in a variety of situations where traditional techniques cannot be applied with confidence.

9.2 Conclusion about research questions

The research questions of this PhD study have been answered by the frameworks proposed and the test cases demonstrated from Chapters 3 to Chapter 7. These are summarised in the following subsections.

9.2.1 Research Question 1: How port security is modelled taking into account of the lack of data resulting from the confidentiality of the intelligence with regard to terrorism and the difficulty of the information accession.

Port security is evaluated based on the concept of risk assessment using fuzzy set theory along with the rule base technique. When developing a security model, the parameters of the criticality of each asset, the probability of occurrence of each threat against a specific asset or target, the severity of each adverse attack against that specific asset and the vulnerability of each asset or facility are considered. A scenario consisting of the aforementioned parameters is also established. Within the Failure

Mode, Effects and Criticality Analysis (FMECA) framework, the risk level of each scenario can be appreciated. Based on the risk results after the defuzification process, the scenarios with higher risks can be identified. The higher defuzzified values that the scenarios have, the more the attention should be paid to same. Thus, security measures aimed at reducing security risks can be identified based on the ranking acquired.

9.2.2 Research Question 2: How risks are modelled using the fuzzy rule base technique in circumstances where there are multiple parameters to be evaluated, which are described by multiple linguistic terms.

Although the fuzzy rule base technique applied in this study is capable of modelling and synthesising the fuzzy parameters under consideration in a consistent manner, it has drawbacks. A shortcoming occurs as the technique is applied to circumstances where there are multiple parameters to be evaluated which are described by multiple linguistic terms. If there were five parameters described by five different linguistic variables, for instance, the number of fuzzy rules needed to be developed would be 3,125. Accordingly, the applications of fuzzy set theory with the adoption of a fuzzy rule base would become impractical. The risk prediction approach incorporating fuzzy set theory and an ANN in this PhD study is capable of avoiding the awkward situations so encountered. The test case used to demonstrate the framework is the risk assessment of port marine safety. The crucial factors considered are Vessel Traffic Control (VTC) performance, navigation aids and facilities, pilotage performance, sealane maintenance and the weather conditions, respectively. It is noted that the successful application of this method depends upon the accuracy of the prediction rate. This implies the importance of the preparation of the training data. A thorough understanding of the parameters to be evaluated in the risk modelling is crucial since ANNs only recognise the patterns similar to the ones they previously met during the training process. Accordingly, if an ANN is trained using the data that covers more potential circumstances the port may usually confront, the predicting result generated is more reliable.

9.2.3 Research Question 3: How human error assessment is conducted without the difficulties imposed by traditional human error methods.

The human error assessment proposed in this PhD study is based on the fuzzy AHP method. It illustrates an alternative perspective for evaluating human error assessment. When assessing human error risks in the test case of an oil cargo handling process in this study, the steps in each mission are compared to each other in terms of the likelihood, failure consequence probability and severity criteria. The model proposed is capable of providing results with confidence. It also avoids the criticism raised from traditional HRA techniques where the human error data is transformed from the source that may not be relevant to the project in question or where human error related risks are purely estimated based on expert judgement due to the scarcity of such data. In addition, the fuzzy AHP method gives the practitioners a flexible and rational fashion upon which to model the relationships between the elements in the pairwise comparison process although such a method may require cumbersome computations if there are many criteria to be considered.

9.2.4 Research Question 4: How the best RCOs are selected by multi-experts in circumstances where the defined criteria are of a multi-attribute nature.

When evaluating RCOs, difficulties may be encountered due to the attribute nature of the defined criteria. In this study a decision-making model using the ER algorithm capable of resolving such difficulties is proposed provided that RCOs have been identified. Furthermore, the assignment of the evaluation grades and the associated belief degrees to RCOs is crucial for this decision-making framework. The more realistic is the RCO assessment, the more reliable is the decision-making result. Therefore, the identification of a threshold for each evaluation grade in terms of different criteria is recommended since it is capable of facilitating the RCO assessment process.

In addition, the ER approach has been applied in the engineering and management fields since the 1990s due to its capability of consistently modelling precise data and subjective judgement with uncertainty under a unified framework. However, a problem occurs in circumstances where a decision-making project is evaluated by multiple experts, and where various utility realisations arising from each expert exist when assessing each evaluation grade. This could result in an RCO or general attribute ranking order conflict between the experts. Such a conflict would become obvious if the evaluation grades and belief degrees obtained from each alternative or general attribute were close. Using the framework proposed and the test case demonstrated, such a difficulty can be resolved. This is accomplished by first, constructing a utility category-evaluation grade matrix for each expert using the belief degree method. Secondly, the utility levels contained in the matrices estimated by all experts are synthesised using the ER approach. Finally, after the normalisation process, the synthesised utility level is employed to acquire the aggregating result for each RCO. Therefore, the priority of the RCOs can be established based on the aggregating result calculated. The conduct of a sensitivity analysis is also recommended. In this study, such an analysis is applied to identify the best measures, providing another way of thinking in terms of the various importance in the risk and cost aspects. Consequently, the management is able to have the measures implemented based on the sensitivity analysis conducted.

9.2.5 Research Question 5: How the quality assurance concept is introduced to a port.

Nowadays a number of conventions aimed at saving life and protecting the environment have been introduced to the port and shipping industries. The efficiency of port operations resulting from the introduction for port security and safety measures is thus an important issue for port customers. A framework capable of improving and maintaining the quality of port security and safety measures by applying the Six Sigma technique using time as a measuring index is proposed. Although the demonstration is through a test case based on expert judgement, the objective can be seen very explicitly that by introducing this approach, the customer satisfaction (i.e. the time saving for the test case) will be achieved thus enhancing the efficiency of port operations. In order to attain this positive result, it is crucial that in the outset each step of any operation should be identified clearly irrespective of the unit of the measuring index. The conduct of a sensitivity analysis in the analysis stage is also highly recommended since it enables the management to identify the appropriate solutions for quality improvement based on the resources available.

9.3 Conclusion emanating from research problem

In risk assessment and safety management, the issue of, "How to manage uncertainty", is a main concern. However, the causes of uncertainty are diverse. Thus, regardless of what approach to be applied, it is always dependent upon human judgement to manage such negative effects. In other words, the deficiencies of risk modelling resulting from the lack of information or a high level of uncertainty must be made up by means of the general evaluation capacity of humans, who are able to grasp the essence of an object, even if it is vague and unclear. Thus, the experience of experts consulted is crucial, since the cornerstone of such uncertainty treatments is the professional judgement from such personnel.

The risk assessment and safety management frameworks proposed based on fuzzy set theory and the ER approach in this study are capable of handling imprecise, ambiguous and qualitative information from experts in a consistent manner. These can be regarded as decent reasoning processes with the capability of quantifying the judgement from experts who express their opinions qualitatively. In addition, the linguistic terms employed in the risk studies are developed in a consensus manner.

Such risk assessment frameworks can be facilitated by incorporating quantitative data available for the subject matter under consideration into the linguistic terms developed although it is not the case in this study. Furthermore, the utility levels of the linguistic terms used in safety management also play an important part. In this PhD study, a systematic method of acquiring a combined utility level of such terms is also presented. Such consensus assessments with regard to linguistic terms provide the consistence throughout the risk assessment and safety management process. Moreover, the identification of a quantitative threshold for each linguistic term applied to describe safety parameters may also facilitate the systematic process aforementioned if the data collected is sufficient to a certain level.

On the other hand, the risk assessment frameworks proposed are based on the bottom-up safety assessment approach. This is because such an approach can divide a system into subsystems that can be further broken down to system components in order to identify all possible hazards. Possible failure events at both the component and subsystem levels can then be combined. Consequently, the possible serious failure events can be identified with less or no omissions. Accordingly the frameworks are capable of providing risk results with a high level of confidence. Thus, when conducting risk assessment under circumstances where the lack of data or a high level of uncertainty exists, the bottom-up safety assessment process is recommended.

9.4 Conclusion and recommendations for the port industry

Security assessment is a difficult analysis to be conducted due to the lack of data stemming from the confidentiality of the intelligence with regard to terrorism and the difficulty of the information accession. Conventionally, such an analysis is performed using the risk index technique. When the security risk is evaluated, the parameters of the threat of an attack associated with the vulnerability of the object and the consequences caused by such attack are considered. Such an application results in some difficulties discussed in section 2.6.1. Such difficulties can be avoided by the generic methodology using fuzzy modelling proposed in this study. It illustrates an alternative way of evaluating security risks, taking into account an additional and crucial parameter, criticality of each port facility. This enables security analysts to have a holistic view when evaluating security risks and to provide risk results with confidence under the circumstances aforementioned.

The generic methodologies with regard to risk assessment for port marine safety and human error analysis in the oil cargo handling in this study have the potential for the port industry to improve the safety of its operations. It is noted that such frameworks are based on the bottom-up safety assessment approach as aforementioned, thus for the port industry dividing a specific operation into detailed components is a crucial task. In addition, more appropriate quantitative data can facilitate the risk assessment process in determining the level of the linguistic terms used to express the relationships between parameters. Accordingly, collecting data both qualitatively and quantitatively from each component based on daily operations is recommended. This can be accomplished by the adoption of the operations such as the daily records with regard to vessel traffic density, pilotage performance and weather conditions for port marine safety and near miss reports for human error assessment.

When evaluating RCOs for enhancing security and safety in ports, there are many parameters that need to be considered other than risk reduction and the ratio of cost and benefit such as time of deployment, current resources available, etc.. On the basis of the test case considering the elements of effectiveness, cost, time of deployment, resource availability and co-operation level and the verifications conducted, it is reasonable to judge that the decision-making model developed is capable of handling such multi-criteria decision problems. The framework proposed is particularly useful in obtaining the combined results in circumstances where multiple experts are involved in a decision-making process.

The introduction of the concept of quality assurance to security and safety measures can facilitate the efficiency of port operations. Its adoption will enable a port to be more competitive and attract more business. In addition, since Six Sigma is based on statistical analysis, the incorporation of this quality assurance tool into port security and safety studies may not be as easy as it is with the manufacturing industries where there is already a tradition of recording data on each stage of every single process. Therefore, if any port authority intends to apply Six Sigma to evaluate the quality of its operations, collecting the information and data from each stage carefully and quantitatively is required.

Since the test cases in this study provide reasonable results, the analytical models developed have the potential to improve the safety and security of port operations. Thus, such models can be applied individually by a port particularly in circumstances where the lack of data exists or such information is associated with a high level of uncertainty. More importantly, these frameworks can be integrated to formulate a platform to facilitate risk assessment and safety management of port operations without jeopardising the efficiency of port operations in a variety of situations where traditional techniques may not be applied with confidence.

9.5 Implications for further research

In maritime safety studies under circumstances where the lack of data or a high level of uncertainty exists, a large number of assumptions, judgements and opinions need to be involved subjectively in the reasoning process. Other than the approximate reasoning methods, new approaches capable of addressing uncertainty and combining expert judgement and empirical data should be further developed. Bayesian network, for instance, is a method that has the capability of incorporating expert judgement with historical data to evaluate risks. It provides intuitive visual representation with a sound mathematical basis in Bayesian probability that translates genuine cause and effect relationship. Moreover, the technique facilitates a meaningful communication of uncertainty, allowing decision to be made based on expected values. Such a technique is also capable of dealing with conditional probability problems. Accordingly, it may have the potential to resolve the limitation of the decision-making model developed as discussed in section 8.3.

Furthermore, when evaluating risks under circumstances of the scarcity of data due to a high level of costs of conducting a full-scale experimentation or some other reasons, the use of computer simulation may be potentially useful. It is worthwhile noting that some computer software facilitates the compilation process. Matlab, for instance, provides the Toolbox function, enabling safety analysts to perform the function needed by directly typing the command established.

It is also should be noted that safety management methods developed in the aviation and nuclear industries are more advanced than those in the maritime industry. Thus, the application of such techniques to the maritime field is required for the reinforcement of safety.

Within the security context, the establishment of security levels is required by the International Ship and Port Facility Security (ISPS) Code. Such security levels are defined qualitatively by the linguistic terms. In this study, however, the security risks of the scenarios are presented in terms of a ranking based on the defuzzified values acquired. Accordingly, it is implied that such security levels should be equipped with the quantitative meaning so that the risk level of a specific scenario acquired using the framework proposed can be assigned to the appropriate level. Thus, appropriate safeguards or measures according to the security level could be deployed without any hesitation.

The maritime industry is moving towards a goal-setting risk-based regime. This gives safety analysts more flexibility to employ novel and the latest risk modelling and decision-making techniques. Subjective modelling and approximate reasoning methods may be one of these useful approaches. It may be beneficial if these novel techniques developed in this research could be further applied to facilitate risk modelling and decision making. Thus, the practical application of such novel techniques to the port industry is emphasised. Furthermore, since the methodologies proposed in this study are generic, such frameworks can be further verified for the safety topics outside the port industry. This will provide an added value to the promotion of their use in different industries.

In addition, the introduction of a quality assurance concept is capable of facilitating the efficiency of port operations. Ports are encouraged to propose quality assurance projects using appropriate measuring units to improve and maintain the quality of the operations provided.

Finally, this PhD study formulates a platform for ports to improve the risk assessment and safety management of port operations. A main implication of this is that ports will have to collect data for each component with regard to safety and quality qualitatively and quantitatively based on daily operations for the objective of continuous improvement of safety and efficiency.

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Appendix 1. The Composition of the Fuzzy Rule Base

No.	Criticality	Probability of Occurrence	Severity	Vulnerability	Priority Level
1	Remote	Remote	Remote	Remote	Minor (1)
2	Remote	Remote	Remote	Low	Low (0.3)
3	Remote	Remote	Remote	Moderate	Low (0.6)
4	Remote	Remote	Remote	High	Low (0.9)
5	Remote	Remote	Remote	Very High	Moderate (0.2)
6	Remote	Remote	Low	Remote	Low (0.2)
7	Remote	Remote	Low	Low	Low (0.5)
8	Remote	Remote	Low	Moderate	Low (0.8)
9	Remote	Remote	Low	High	Moderate (0.1)
10	Remote	Remote	Low	Very High	Moderate (0.4)
11	Remote	Remote	Moderate	Remote	Low (0.4)
12	Remote	Remote	Moderate	Low	Low (0.7)
13	Remote	Remote	Moderate	Moderate	Low (1)
14	Remote	Remote	Moderate	High	Moderate (0.3)
15	Remote	Remote	Moderate	Very High	Moderate (0.6)
16	Remote	Remote	High	Remote	Low (0.6)
17	Remote	Remote	High	Low	Low (0.9)
18	Remote	Remote	High	Moderate	Moderate (0.2)
19	Remote	Remote	High	High	Moderate (0.5)
20	Remote	Remote	High	Very High	Moderate (0.8)
21	Remote	Remote	Very High	Remote	Low (0.8)
22	Remote	Remote	Very High	Low	Moderate (0.1)
23	Remote	Remote	Very High	Moderate	Moderate (0.4)
24	Remote	Remote	Very High	High	Moderate (0.7)
25	Remote	Remote	Very High	Very High	Moderate (1)
26	Remote	Low	Remote	Remote	Low (0.2)
27	Remote	Low	Remote	Low	Low (0.5)
28	Remote	Low	Remote	Moderate	Low (0.8)
29	Remote	Low	Remote	High	Moderate (0.1)
30	Remote	Low	Remote	Very High	Moderate (0.4)
31	Remote	Low	Low	Remote	Low (0.4)
32	Remote	Low	Low	Low	Low (0.7)
33	Remote	Low	Low	Moderate	Low (1)
34	Remote	Low	Low	High	Moderate (0.3)
35	Remote	Low	Low	Very High	Moderate (0.6)
36	Remote	Low	Moderate	Remote	Low (0.6)
37	Remote	Low	Moderate	Low	Low (0.9)
38	Remote	Low	Moderate	Moderate	Moderate (0.2)
39	Remote	Low	Moderate	High	Moderate (0.5)
40	Remote	Low	Moderate	Very High	Moderate (0.8)
41	Remote	Low	High	Remote	Low (0.8)
42	Remote	Low	High	Low	Moderate (0.1)
43	Remote	Low	High	Moderate	Moderate (0.4)
44	Remote	Low	High	High	Moderate (0.7)
45	Remote	Low	High	Very High	Moderate (1)
46	Remote	Low	Very High	Remote	Low (1)
47	Remote	Low	Very High	Low	Moderate (0.3)
48	Remote	Low	Very High	Moderate	Moderate (0.6)
49	Remote	Low	Very High	High	Moderate (0.9)
50	Remote	Low	Very High	Very High	Significant (0.2)
51	Remote	Moderate	Remote	Remote	Low (0.4)
52	Remote	Moderate	Remote	Low	Low (0.7)
53	Remote	Moderate	Remote	Moderate	Low (1)
54	Remote	Moderate	Remote	High	Moderate (0.3)

55	Remote	Moderate	Remote	Very High	Moderate (0.6)
56	Remote	Moderate	Low	Remote	Low (0.6)
57	Remote	Moderate	Low	Low	Low (0.9)
58	Remote	Moderate	Low	Moderate	Moderate (0.2)
59	Remote	Moderate	Low	High	Moderate (0.5)
60	Remote	Moderate	Low	Very High	Moderate (0.8)
61	Remote	Moderate	Moderate	Remote	Low (0.8)
62	Remote	Moderate	Moderate	Low	Moderate (0.1)
63	Remote	Moderate	Moderate	Moderate	Moderate (0.4)
64	Remote	Moderate	Moderate	High	Moderate (0.7)
65	Remote	Moderate	Moderate	Very High	Moderate (1)
66	Remote	Moderate	High	Remote	Low (1)
67	Remote	Moderate	High	Low	Moderate (0.3)
68	Remote	Moderate	High	Moderate	Moderate (0.6)
69	Remote	Moderate	High	High	Moderate (0.9)
70	Remote	Moderate	High	Very High	Significant (0.2)
71	Remote	Moderate	Very High	Remote	Moderate (0.2)
72	Remote	Moderate	Very High	Low	Moderate (0.5)
73	Remote	Moderate	Very High	Moderate	Moderate (0.8)
74	Remote	Moderate	Very High	High	Significant (0.1)
75	Remote	Moderate	Very High	Very High	Significant (0.4)
76	Remote	High	Remote	Remote	Low (0.6)
77	Remote	High	Remote	Low	Low (0.9)
78	Remote	High	Remote	Moderate	Moderate (0.2)
79	Remote	High	Remote	High	Moderate (0.5)
80	Remote	High	Remote	Very High	Moderate (0.8)
81	Remote	High	Low	Remote	Low (0.8)
82	Remote	High	Low	Low	Moderate (0.1)
83	Remote	High	Low	Moderate	Moderate (0.4)
84	Remote	High	Low	High	Moderate (0.7)
85	Remote	High	Low	Very High	Moderate (1)
86	Remote	High	Moderate	Remote	Low (1)
87	Remote	High	Moderate	Low	Moderate (0.3)
88	Remote	High	Moderate	Moderate	Moderate (0.6)
89	Remote	High	Moderate	High	Moderate (0.9)
90	Remote	High	Moderate	Very High	Significant (0.2)
91	Remote	High	High	Remote	Moderate (0.2)
92	Remote	High	High	Low	Moderate (0.5)
93	Remote	High	High	Moderate	Moderate (0.8)
94	Remote	High	High	High	Significant (0.1)
95	Remote	High	High	Very High	Significant (0.4)
96	Remote	High	Very High	Remote	Moderate (0.4)
97	Remote	High	Very High	Low	Moderate (0.7)
98	Remote	High	Very High	Moderate	Moderate (1)
99	Remote	High	Very High	High	Significant (0.3)
100	Remote	High	Very High	Very High	Significant (0.6)
101	Remote	Very High	Remote	Remote	Low (0.8)
102	Remote	Very High	Remote	Low	Moderate (0.1)
103	Remote	Very High	Remote	Moderate	Moderate (0.4)
104	Remote	Very High	Remote	High	Moderate (0.7)
105	Remote	Very High	Remote	Very High	Moderate (1)
106	Remote	Very High	Low	Remote	Low (1)
107	Remote	Very High	Low	Low	Moderate (0.3)
108	Remote	Very High	Low	Moderate	Moderate (0.6)
109	Remote	Very High	Low	High	Moderate (0.9)
110	Remote	Very High	Low	Very High	Significant (0.2)
111	Remote	Very High	Moderate	Remote	Moderate (0.2)
112	Remote	Very High	Moderate	Low	Moderate (0.5)
113	Remote	Very High	Moderate	Moderate	Moderate (0.8)
114	Remote	Very High	Moderate	High	Significant (0.1)

115	Remote	Very High	Moderate	Very High	Significant (0.4)
116	Remote	Very High	High	Remote	Moderate (0.4)
117	Remote	Very High	High	Low	Moderate (0.7)
118	Remote	Very High	High	Moderate	Moderate (1)
119	Remote	Very High	High	High	Significant (0.3)
120	Remote	Very High	High	Very High	Significant (0.6)
121	Remote	Very High	Very High	Remote	Moderate (0.6)
122	Remote	Very High	Very High	Low	Moderate (0.9)
123	Remote	Very High	Very High	Moderate	Significant (0.2)
124	Remote	Very High	Very High	High	Significant (0.5)
125	Remote	Very High	Very High	Very High	Significant (0.8)
126	Low	Remote	Remote	Remote	Low (0.3)
127	Low	Remote	Remote	Low	Low (0.6)
128	Low	Remote	Remote	Moderate	Low (0.9)
129	Low	Remote	Remote	High	Moderate (0.2)
130	Low	Remote	Remote	Very High	Moderate (0.5)
131	Low	Remote	Low	Remote	Low (0.5)
132	Low	Remote	Low	Low	Low (0.8)
133	Low	Remote	Low	Moderate	Moderate (0.1)
134	Low	Remote	Low	High	Moderate (0.4)
135	Low	Remote	Low	Very High	Moderate (0.7)
136	Low	Remote	Moderate	Remote	Low (0.7)
137	Low	Remote	Moderate	Low	Low (1)
138	Low	Remote	Moderate	Moderate	Moderate (0.3)
139	Low	Remote	Moderate	High	Moderate (0.6)
140	Low	Remote	Moderate	Very High	Moderate (0.9)
141	Low	Remote	High	Remote	Low (0.9)
142	Low	Remote	High	Low	Moderate (0.2)
143	Low	Remote	High	Moderate	Moderate (0.5)
144	Low	Remote	High	High	Moderate (0.8)
145	Low	Remote	High	Very High	Significant (0.1)
146	Low	Remote	Very High	Remote	Moderate (0.1)
147	Low	Remote	Very High	Low	Moderate (0.4)
148	Low	Remote	Very High	Moderate	Moderate (0.7)
149	Low	Remote	Very High	High	Moderate (1)
150	Low	Remote	Very High	Very High	Significant (0.3)
151	Low	Low	Remote	Remote	Low (0.5)
152	Low	Low	Remote	Low	Low (0.8)
153	Low	Low	Remote	Moderate	Moderate (0.1)
154	Low	Low	Remote	High	Moderate (0.4)
155	Low	Low	Remote	Very High	Moderate (0.7)
156	Low	Low	Low	Remote	Low (0.7)
157	Low	Low	Low	Low	Low (1)
158	Low	Low	Low	Moderate	Moderate (0.3)
159	Low	Low	Low	High	Moderate (0.6)
160	Low	Low	Low	Very High	Moderate (0.9)
161	Low	Low	Moderate	Remote	Low (0.9)
162	Low	Low	Moderate	Low	Moderate (0.2)
163	Low	Low	Moderate	Moderate	Moderate (0.5)
164	Low	Low	Moderate	High	Moderate (0.8)
165	Low	Low	Moderate	Very High	Significant (0.1)
166	Low	Low	High	Remote	Moderate (0.1)
167	Low	Low	High	Low	Moderate (0.4)
168	Low	Low	High	Moderate	Moderate (0.7)
169	Low	Low	High	High	Moderate (1)
170	Low	Low	High	Very High	Significant (0.3)
171	Low	Low	Very High	Remote	Moderate (0.3)
172	Low	Low	Very High	Low	Moderate (0.6)
173	Low	Low	Very High	Moderate	Moderate (0.9)
174	Low	Low	Very High	High	Significant (0.2)

175	Low	Low	Very High	Very High	Significant (0.5)
176	Low	Moderate	Remote	Remote	Low (0.7)
177	Low	Moderate	Remote	Low	Low (1)
178	Low	Moderate	Remote	Moderate	Moderate (0.3)
179	Low	Moderate	Remote	High	Moderate (0.6)
180	Low	Moderate	Remote	Very High	Moderate (0.9)
181	Low	Moderate	Low	Remote	Low (0.9)
182	Low	Moderate	Low	Low	Moderate (0.2)
183	Low	Moderate	Low	Moderate	Moderate (0.5)
184	Low	Moderate	Low	High	Moderate (0.8)
185	Low	Moderate	Low	Very High	Significant (0.1)
186	Low	Moderate	Moderate	Remote	Moderate (0.1)
187	Low	Moderate	Moderate	Low	Moderate (0.4)
188	Low	Moderate	Moderate	Moderate	Moderate (0.7)
189	Low	Moderate	Moderate	High	Moderate (1)
190	Low	Moderate	Moderate	Very High	Significant (0.3)
191	Low	Moderate	High	Remote	Moderate (0.3)
192	Low	Moderate	High	Low	Moderate (0.6)
193	Low	Moderate	High	Moderate	Moderate (0.9)
194	Low	Moderate	High	High	Significant (0.2)
195	Low	Moderate	High	Very High	Significant (0.5)
196	Low	Moderate	Very High	Remote	Moderate (0.5)
197	Low	Moderate	Very High	Low	Moderate (0.8)
198	Low	Moderate	Very High	Moderate	Significant (0.1)
199	Low	Moderate	Very High	High	Significant (0.4)
200	Low	Moderate	Very High	Very High	Significant (0.7)
201	Low	High	Remote	Remote	Low (0.9)
202	Low	High	Remote	Low	Moderate (0.2)
203	Low	High	Remote	Moderate	Moderate (0.5)
204	Low	High	Remote	High	Moderate (0.8)
205	Low	High	Remote	Very High	Significant (0.1)
206	Low	High	Low	Remote	Moderate (0.1)
207	Low	High	Low	Low	Moderate (0.4)
208	Low	High	Low	Moderate	Moderate (0.7)
209	Low	High	Low	High	Moderate (1)
210	Low	High	Low	Very High	Significant (0.3)
211	Low	High	Moderate	Remote	Moderate (0.3)
212	Low	High	Moderate	Low	Moderate (0.6)
213	Low	High	Moderate	Moderate	Moderate (0.9)
214	Low	High	Moderate	High	Significant (0.2)
215	Low	High	Moderate	Very High	Significant (0.5)
216	Low	High	High	Remote	Moderate (0.5)
217	Low	High	High	Low	Moderate (0.8)
218	Low	High	High	Moderate	Significant (0.1)
219	Low	High	High	High	Significant (0.4)
220	Low	High	High	Very High	Significant (0.7)
221	Low	High	Very High	Remote	Moderate (0.7)
222	Low	High	Very High	Low	Moderate (1)
223	Low	High	Very High	Moderate	Significant (0.3)
224	Low	High	Very High	High	Significant (0.6)
225	Low	High	Very High	Very High	Significant (0.9)
226	Low	Very High	Remote	Remote	Moderate (0.1)
227	Low	Very High	Remote	Low	Moderate (0.4)
228	Low	Very High	Remote	Moderate	Moderate (0.7)
229	Low	Very High	Remote	High	Moderate (1)
230	Low	Very High	Remote	Very High	Significant (0.3)
231	Low	Very High	Low	Remote	Moderate (0.3)
232	Low	Very High	Low	Low	Moderate (0.6)
233	Low	Very High	Low	Moderate	Moderate (0.9)
234	Low	Very High	Low	High	Significant (0.2)

235	Low	Very High	Low	Very High	Significant (0.5)
236	Low	Very High	Moderate	Remote	Moderate (0.5)
237	Low	Very High	Moderate	Low	Moderate (0.8)
238	Low	Very High	Moderate	Moderate	Significant (0.1)
239	Low	Very High	Moderate	High	Significant (0.4)
240	Low	Very High	Moderate	Very High	Significant (0.7)
241	Low	Very High	High	Remote	Moderate (0.7)
242	Low	Very High	High	Low	Moderate (1)
243	Low	Very High	High	Moderate	Significant (0.3)
244	Low	Very High	High	High	Significant (0.6)
245	Low	Very High	High	Very High	Significant (0.9)
246	Low	Very High	Very High	Remote	Moderate (0.9)
247	Low	Very High	Very High	Low	Significant (0.2)
248	Low	Very High	Very High	Moderate	Significant (0.5)
249	Low	Very High	Very High	High	Significant (0.8)
250	Low	Very High	Very High	Very High	High (0.1)
251	Moderate	Remote	Remote	Remote	Low (0.6)
252	Moderate	Remote	Remote	Low	Low (0.9)
253	Moderate	Remote	Remote	Moderate	Moderate (0.2)
254	Moderate	Remote	Remote	High	Moderate (0.5)
255	Moderate	Remote	Remote	Very High	Moderate (0.8)
256	Moderate	Remote	Low	Remote	Low (0.8)
257	Moderate	Remote	Low	Low	Moderate (0.1)
258	Moderate	Remote	Low	Moderate	Moderate (0.4)
259	Moderate	Remote	Low	High	Moderate (0.7)
260	Moderate	Remote	Low	Very High	Moderate (1)
261	Moderate	Remote	Moderate	Remote	Low (1)
262	Moderate	Remote	Moderate	Low	Moderate (0.3)
263	Moderate	Remote	Moderate	Moderate	Moderate (0.6)
264	Moderate	Remote	Moderate	High	Moderate (0.9)
265	Moderate	Remote	Moderate	Very High	Significant (0.2)
266	Moderate	Remote	High	Remote	Moderate (0.2)
267	Moderate	Remote	High	Low	Moderate (0.5)
268	Moderate	Remote	High	Moderate	Moderate (0.8)
269	Moderate	Remote	High	High	Significant (0.1)
270	Moderate	Remote	High	Very High	Significant (0.4)
271	Moderate	Remote	Very High	Remote	Moderate (0.4)
272	Moderate	Remote	Very High	Low	Moderate (0.7)
273	Moderate	Remote	Very High	Moderate	Moderate (1)
274	Moderate	Remote	Very High	High	Significant (0.3)
275	Moderate	Remote	Very High	Very High	Significant (0.6)
276	Moderate	Low	Remote	Remote	Low (0.8)
277	Moderate	Low	Remote	Low	Moderate (0.1)
278	Moderate	Low	Remote	Moderate	Moderate (0.4)
279	Moderate	Low	Remote	High	Moderate (0.7)
280	Moderate	Low	Remote	Very High	Moderate (1)
281	Moderate	Low	Low	Remote	Low (1)
282	Moderate	Low	Low	Low	Moderate (0.3)
283	Moderate	Low	Low	Moderate	Moderate (0.6)
284	Moderate	Low	Low	High	Moderate (0.9)
285	Moderate	Low	Low	Very High	Significant (0.2)
286	Moderate	Low	Moderate	Remote	Moderate (0.2)
287	Moderate	Low	Moderate	Low	Moderate (0.5)
288	Moderate	Low	Moderate	Moderate	Moderate (0.8)
289	Moderate	Low	Moderate	High	Significant (0.1)
290	Moderate	Low	Moderate	Very High	Significant (0.4)
291	Moderate	Low	High	Remote	Moderate (0.4)
292	Moderate	Low	High	Low	Moderate (0.7)
293	Moderate	Low	High	Moderate	Moderate (1)
294	Moderate	Low	High	High	Significant (0.3)

295	Moderate	Low	High	Very High	Significant (0.6)
296	Moderate	Low	Very High	Remote	Moderate (0.6)
297	Moderate	Low	Very High	Low	Moderate (0.9)
298	Moderate	Low	Very High	Moderate	Significant (0.2)
299	Moderate	Low	Very High	High	Significant (0.5)
300	Moderate	Low	Very High	Very High	Significant (0.8)
301	Moderate	Moderate	Remote	Remote	Low (1)
302	Moderate	Moderate	Remote	Low	Moderate (0.3)
303	Moderate	Moderate	Remote	Moderate	Moderate (0.6)
304	Moderate	Moderate	Remote	High	Moderate (0.9)
305	Moderate	Moderate	Remote	Very High	Significant (0.2)
306	Moderate	Moderate	Low	Remote	Moderate (0.2)
307	Moderate	Moderate	Low	Low	Moderate (0.5)
308	Moderate	Moderate	Low	Moderate	Moderate (0.8)
309	Moderate	Moderate	Low	High	Significant (0.1)
310	Moderate	Moderate	Low	Very High	Significant (0.4)
311	Moderate	Moderate	Moderate	Remote	Moderate (0.4)
312	Moderate	Moderate	Moderate	Low	Moderate (0.7)
313	Moderate	Moderate	Moderate	Moderate	Moderate (1)
314	Moderate	Moderate	Moderate	High	Significant (0.3)
315	Moderate	Moderate	Moderate	Very High	Significant (0.6)
316	Moderate	Moderate	High	Remote	Moderate (0.6)
317	Moderate	Moderate	High	Low	Moderate (0.9)
318	Moderate	Moderate	High	Moderate	Significant (0.2)
319	Moderate	Moderate	High	High	Significant (0.5)
320	Moderate	Moderate	High	Very High	Significant (0.8)
321	Moderate	Moderate	Very High	Remote	Moderate (0.8)
322	Moderate	Moderate	Very High	Low	Significant (0.1)
323	Moderate	Moderate	Very High	Moderate	Significant (0.4)
324	Moderate	Moderate	Very High	High	Significant (0.7)
325	Moderate	Moderate	Very High	Very High	Significant (1)
326	Moderate	High	Remote	Remote	Moderate (0.2)
327	Moderate	High	Remote	Low	Moderate (0.5)
328	Moderate	High	Remote	Moderate	Moderate (0.8)
329	Moderate	High	Remote	High	Significant (0.1)
330	Moderate	High	Remote	Very High	Significant (0.4)
331	Moderate	High	Low	Remote	Moderate (0.4)
332	Moderate	High	Low	Low	Moderate (0.7)
333	Moderate	High	Low	Moderate	Moderate (1)
334	Moderate	High	Low	High	Significant (0.3)
335	Moderate	High	Low	Very High	Significant (0.6)
336	Moderate	High	Moderate	Remote	Moderate (0.6)
337	Moderate	High	Moderate	Low	Moderate (0.9)
338	Moderate	High	Moderate	Moderate	Significant (0.2)
339	Moderate	High	Moderate	High	Significant (0.5)
340	Moderate	High	Moderate	Very High	Significant (0.8)
341	Moderate	High	High	Remote	Moderate (0.8)
342	Moderate	High	High	Low	Significant (0.1)
343	Moderate	High	High	Moderate	Significant (0.4)
344	Moderate	High	High	High	Significant (0.7)
345	Moderate	High	High	Very High	Significant (1)
346	Moderate	High	Very High	Remote	Moderate (1)
347	Moderate	High	Very High	Low	Significant (0.3)
348	Moderate	High	Very High	Moderate	Significant (0.6)
349	Moderate	High	Very High	High	Significant (0.9)
350	Moderate	High	Very High	Very High	Very Significant (0.2)
351	Moderate	Very High	Remote	Remote	Moderate (0.4)
352	Moderate	Very High	Remote	Low	Moderate (0.7)
353	Moderate	Very High	Remote	Moderate	Moderate (1)

354	Moderate	Very High	Remote	High	Significant (0.3)
355	Moderate	Very High	Remote	Very High	Significant (0.6)
356	Moderate	Very High	Low	Remote	Moderate (0.6)
357	Moderate	Very High	Low	Low	Moderate (0.9)
358	Moderate	Very High	Low	Moderate	Significant (0.2)
359	Moderate	Very High	Low	High	Significant (0.5)
360	Moderate	Very High	Low	Very High	Significant (0.8)
361	Moderate	Very High	Moderate	Remote	Moderate (0.8)
362	Moderate	Very High	Moderate	Low	Significant (0.1)
363	Moderate	Very High	Moderate	Moderate	Significant (0.4)
364	Moderate	Very High	Moderate	High	Significant (0.7)
365	Moderate	Very High	Moderate	Very High	Significant (1)
366	Moderate	Very High	High	Remote	Moderate (1)
367	Moderate	Very High	High	Low	Significant (0.3)
368	Moderate	Very High	High	Moderate	Significant (0.6)
369	Moderate	Very High	High	High	Significant (0.9)
370	Moderate	Very High	High	Very High	Very Significant (0.2)
371	Moderate	Very High	Very High	Remote	Significant (0.2)
372	Moderate	Very High	Very High	Low	Significant (0.5)
373	Moderate	Very High	Very High	Moderate	Significant (0.8)
374	Moderate	Very High	Very High	High	Very Significant (0.1)
375	Moderate	Very High	Very High	Very High	Very Significant (0.4)
376	High	Remote	Remote	Remote	Low (0.9)
377	High	Remote	Remote	Low	Moderate (0.2)
378	High	Remote	Remote	Moderate	Moderate (0.5)
379	High	Remote	Remote	High	Moderate (0.8)
380	High	Remote	Remote	Very High	Significant (0.1)
381	High	Remote	Low	Remote	Moderate (0.1)
382	High	Remote	Low	Low	Moderate (0.4)
383	High	Remote	Low	Moderate	Moderate (0.7)
384	High	Remote	Low	High	Moderate (1)
385	High	Remote	Low	Very High	Significant (0.3)
386	High	Remote	Moderate	Remote	Moderate (0.3)
387	High	Remote	Moderate	Low	Moderate (0.6)
388	High	Remote	Moderate	Moderate	Moderate (0.9)
389	High	Remote	Moderate	High	Significant (0.2)
390	High	Remote	Moderate	Very High	Significant (0.5)
391	High	Remote	High	Remote	Moderate (0.5)
392	High	Remote	High	Low	Moderate (0.8)
393	High	Remote	High	Moderate	Significant (0.1)
394	High	Remote	High	High	Significant (0.4)
395	High	Remote	High	Very High	Significant (0.7)
396	High	Remote	Very High	Remote	Moderate (0.7)
397	High	Remote	Very High	Low	Moderate (1)
398	High	Remote	Very High	Moderate	Significant (0.3)
399	High	Remote	Very High	High	Significant (0.6)
400	High	Remote	Very High	Very High	Significant (0.9)
401	High	Low	Remote	Remote	Moderate (0.1)
402	High	Low	Remote	Low	Moderate (0.4)
403	High	Low	Remote	Moderate	Moderate (0.7)
404	High	Low	Remote	High	Moderate (1)
405	High	Low	Remote	Very High	Significant (0.3)
406	High	Low	Low	Remote	Moderate (0.3)
407	High	Low	Low	Low	Moderate (0.6)
408	High	Low	Low	Moderate	Moderate (0.9)
409	High	Low	Low	High	Significant (0.2)
410	High	Low	Low	Very High	Significant (0.5)

411	High	Low	Moderate	Remote	Moderate (0.5)
412	High	Low	Moderate	Low	Moderate (0.8)
413	High	Low	Moderate	Moderate	Significant (0.1)
414	High	Low	Moderate	High	Significant (0.4)
415	High	Low	Moderate	Very High	Significant (0.7)
416	High	Low	High	Remote	Moderate (0.7)
417	High	Low	High	Low	Moderate (1)
418	High	Low	High	Moderate	Significant (0.3)
419	High	Low	High	High	Significant (0.6)
420	High	Low	High	Very High	Significant (0.9)
421	High	Low	Very High	Remote	Moderate (0.9)
422	High	Low	Very High	Low	Significant (0.2)
423	High	Low	Very High	Moderate	Significant (0.5)
424	High	Low	Very High	High	Significant (0.8)
425	High	Low	Very High	Very High	Very Significant (0.1)
426	High	Moderate	Remote	Remote	Moderate (0.3)
427	High	Moderate	Remote	Low	Moderate (0.6)
428	High	Moderate	Remote	Moderate	Moderate (0.9)
429	High	Moderate	Remote	High	Significant (0.2)
430	High	Moderate	Remote	Very High	Significant (0.5)
431	High	Moderate	Low	Remote	Moderate (0.5)
432	High	Moderate	Low	Low	Moderate (0.8)
433	High	Moderate	Low	Moderate	Significant (0.1)
434	High	Moderate	Low	High	Significant (0.4)
435	High	Moderate	Low	Very High	Significant (0.7)
436	High	Moderate	Moderate	Remote	Moderate (0.7)
437	High	Moderate	Moderate	Low	Moderate (1)
438	High	Moderate	Moderate	Moderate	Significant (0.3)
439	High	Moderate	Moderate	High	Significant (0.6)
440	High	Moderate	Moderate	Very High	Significant (0.9)
441	High	Moderate	High	Remote	Moderate (0.9)
442	High	Moderate	High	Low	Significant (0.2)
443	High	Moderate	High	Moderate	Significant (0.5)
444	High	Moderate	High	High	Significant (0.8)
445	High	Moderate	High	Very High	Very Significant (0.1)
446	High	Moderate	Very High	Remote	Significant (0.1)
447	High	Moderate	Very High	Low	Significant (0.4)
448	High	Moderate	Very High	Moderate	Significant (0.7)
449	High	Moderate	Very High	High	Significant (1)
450	High	Moderate	Very High	Very High	Very Significant (0.3)
451	High	High	Remote	Remote	Moderate (0.5)
452	High	High	Remote	Low	Moderate (0.8)
453	High	High	Remote	Moderate	Significant (0.1)
454	High	High	Remote	High	Significant (0.4)
455	High	High	Remote	Very High	Significant (0.7)
456	High	High	Low	Remote	Moderate (0.7)
457	High	High	Low	Low	Moderate (1)
458	High	High	Low	Moderate	Significant (0.3)
459	High	High	Low	High	Significant (0.6)
460	High	High	Low	Very High	Significant (0.9)
461	High	High	Moderate	Remote	Moderate (0.9)
462	High	High	Moderate	Low	Significant (0.2)
463	High	High	Moderate	Moderate	Significant (0.5)
464	High	High	Moderate	High	Significant (0.8)
465	High	High	Moderate	Very High	Very Significant (0.1)
466	High	High	High	Remote	Significant (0.1)

467	High	High	High	Low	Significant (0.4)
468	High	High	High	Moderate	Significant (0.7)
469	High	High	High	High	Significant (1)
470	High	High	High	Very High	Very Significant (0.3)
471	High	High	Very High	Remote	Significant (0.3)
472	High	High	Very High	Low	Significant (0.6)
473	High	High	Very High	Moderate	Significant (0.9)
474	High	High	Very High	High	Very Significant (0.2)
475	High	High	Very High	Very High	Very Significant (0.5)
476	High	Very High	Remote	Remote	Moderate (0.7)
477	High	Very High	Remote	Low	Moderate (1)
478	High	Very High	Remote	Moderate	Significant (0.3)
479	High	Very High	Remote	High	Significant (0.6)
480	High	Very High	Remote	Very High	Significant (0.9)
481	High	Very High	Low	Remote	Moderate (0.9)
482	High	Very High	Low	Low	Significant (0.2)
483	High	Very High	Low	Moderate	Significant (0.5)
484	High	Very High	Low	High	Significant (0.8)
485	High	Very High	Low	Very High	Very Significant (0.1)
486	High	Very High	Moderate	Remote	Significant (0.1)
487	High	Very High	Moderate	Low	Significant (0.4)
488	High	Very High	Moderate	Moderate	Significant (0.7)
489	High	Very High	Moderate	High	Significant (1)
490	High	Very High	Moderate	Very High	Very Significant (0.3)
491	High	Very High	High	Remote	Significant (0.3)
492	High	Very High	High	Low	Significant (0.6)
493	High	Very High	High	Moderate	Significant (0.9)
494	High	Very High	High	High	Very Significant (0.2)
495	High	Very High	High	Very High	Very Significant (0.5)
496	High	Very High	Very High	Remote	Significant (0.5)
497	High	Very High	Very High	Low	Significant (0.8)
498	High	Very High	Very High	Moderate	Very Significant (0.1)
499	High	Very High	Very High	High	Very Significant (0.4)
500	High	Very High	Very High	Very High	Very Significant (0.7)
501	Very High	Remote	Remote	Remote	Moderate (0.2)
502	Very High	Remote	Remote	Low	Moderate (0.5)
503	Very High	Remote	Remote	Moderate	Moderate (0.8)
504	Very High	Remote	Remote	High	Significant (0.1)
505	Very High	Remote	Remote	Very High	Significant (0.4)
506	Very High	Remote	Low	Remote	Moderate (0.4)
507	Very High	Remote	Low	Low	Moderate (0.7)
508	Very High	Remote	Low	Moderate	Moderate (1)
509	Very High	Remote	Low	High	Significant (0.3)
510	Very High	Remote	Low	Very High	Significant (0.6)
511	Very High	Remote	Moderate	Remote	Moderate (0.6)
512	Very High	Remote	Moderate	Low	Moderate (0.9)
513	Very High	Remote	Moderate	Moderate	Significant (0.2)
514	Very High	Remote	Moderate	High	Significant (0.5)
515	Very High	Remote	Moderate	Very High	Significant (0.8)
516	Very High	Remote	High	Remote	Moderate (0.8)

517	Very High	Remote	High	Low	Significant (0.1)
518	Very High	Remote	High	Moderate	Significant (0.4)
519	Very High	Remote	High	High	Significant (0.7)
520	Very High	Remote	High	Very High	Significant (1)
521	Very High	Remote	Very High	Remote	Moderate (1)
522	Very High	Remote	Very High	Low	Significant (0.3)
523	Very High	Remote	Very High	Moderate	Significant (0.6)
524	Very High	Remote	Very High	High	Significant (0.9)
525	Very High	Remote	Very High	Very High	Very Significant (0.2)
526	Very High	Low	Remote	Remote	Moderate (0.4)
527	Very High	Low	Remote	Low	Moderate (0.7)
528	Very High	Low	Remote	Moderate	Moderate (1)
529	Very High	Low	Remote	High	Significant (0.3)
530	Very High	Low	Remote	Very High	Significant (0.6)
531	Very High	Low	Low	Remote	Moderate (0.6)
532	Very High	Low	Low	Low	Moderate (0.9)
533	Very High	Low	Low	Moderate	Significant (0.2)
534	Very High	Low	Low	High	Significant (0.5)
535	Very High	Low	Low	Very High	Significant (0.8)
536	Very High	Low	Moderate	Remote	Moderate (0.8)
537	Very High	Low	Moderate	Low	Significant (0.1)
538	Very High	Low	Moderate	Moderate	Significant (0.4)
539	Very High	Low	Moderate	High	Significant (0.7)
540	Very High	Low	Moderate	Very High	Significant (1)
541	Very High	Low	High	Remote	Moderate (1)
542	Very High	Low	High	Low	Significant (0.3)
543	Very High	Low	High	Moderate	Significant (0.6)
544	Very High	Low	High	High	Significant (0.9)
545	Very High	Low	High	Very High	Very Significant (0.2)
546	Very High	Low	Very High	Remote	Significant (0.2)
547	Very High	Low	Very High	Low	Significant (0.5)
548	Very High	Low	Very High	Moderate	Significant (0.8)
549	Very High	Low	Very High	High	Very Significant (0.1)
550	Very High	Low	Very High	Very High	Very Significant (0.4)
551	Very High	Moderate	Remote	Remote	Moderate (0.6)
552	Very High	Moderate	Remote	Low	Moderate (0.9)
553	Very High	Moderate	Remote	Moderate	Significant (0.2)
554	Very High	Moderate	Remote	High	Significant (0.5)
555	Very High	Moderate	Remote	Very High	Significant (0.8)
556	Very High	Moderate	Low	Remote	Moderate (0.8)
557	Very High	Moderate	Low	Low	Significant (0.1)
558	Very High	Moderate	Low	Moderate	Significant (0.4)
559	Very High	Moderate	Low	High	Significant (0.7)
560	Very High	Moderate	Low	Very High	Significant (1)
561	Very High	Moderate	Moderate	Remote	Moderate (1)
562	Very High	Moderate	Moderate	Low	Significant (0.3)
563	Very High	Moderate	Moderate	Moderate	Significant (0.6)
564	Very High	Moderate	Moderate	High	Significant (0.9)
565	Very High	Moderate	Moderate	Very High	Very Significant (0.2)
566	Very High	Moderate	High	Remote	Significant (0.2)
567	Very High	Moderate	High	Low	Significant (0.5)
568	Very High	Moderate	High	Moderate	Significant (0.8)
569	Very High	Moderate	High	High	Very Significant (0.1)

570	Very High	Moderate	High	Very High	Very Significant (0.4)
571	Very High	Moderate	Very High	Remote	Significant (0.4)
572	Very High	Moderate	Very High	Low	Significant (0.7)
573	Very High	Moderate	Very High	Moderate	Significant (1)
574	Very High	Moderate	Very High	High	Very Significant (0.3)
575	Very High	Moderate	Very High	Very High	Very Significant (0.6)
576	Very High	High	Remote	Remote	Moderate (0.8)
577	Very High	High	Remote	Low	Significant (0.1)
578	Very High	High	Remote	Moderate	Significant (0.4)
579	Very High	High	Remote	High	Significant (0.7)
580	Very High	High	Remote	Very High	Significant (1)
581	Very High	High	Low	Remote	Moderate (1)
582	Very High	High	Low	Low	Significant (0.3)
583	Very High	High	Low	Moderate	Significant (0.6)
584	Very High	High	Low	High	Significant (0.9)
585	Very High	High	Low	Very High	Very Significant (0.2)
586	Very High	High	Moderate	Remote	Significant (0.2)
587	Very High	High	Moderate	Low	Significant (0.5)
588	Very High	High	Moderate	Moderate	Significant (0.8)
589	Very High	High	Moderate	High	Very Significant (0.1)
590	Very High	High	Moderate	Very High	Very Significant (0.4)
591	Very High	High	High	Remote	Significant (0.4)
592	Very High	High	High	Low	Significant (0.7)
593	Very High	High	High	Moderate	Significant (1)
594	Very High	High	High	High	Very Significant (0.3)
595	Very High	High	High	Very High	Very Significant (0.6)
596	Very High	High	Very High	Remote	Significant (0.6)
597	Very High	High	Very High	Low	Significant (0.9)
598	Very High	High	Very High	Moderate	Very Significant (0.2)
599	Very High	High	Very High	High	Very Significant (0.5)
600	Very High	High	Very High	Very High	Very Significant (0.8)
601	Very High	Very High	Remote	Remote	Moderate (1)
602	Very High	Very High	Remote	Low	Significant (0.3)
603	Very High	Very High	Remote	Moderate	Significant (0.6)
604	Very High	Very High	Remote	High	Significant (0.9)
605	Very High	Very High	Remote	Very High	Very Significant (0.2)
606	Very High	Very High	Low	Remote	Significant (0.2)
607	Very High	Very High	Low	Low	Significant (0.5)
608	Very High	Very High	Low	Moderate	Significant (0.8)
609	Very High	Very High	Low	High	Very Significant (0.1)
610	Very High	Very High	Low	Very High	Very Significant (0.4)
611	Very High	Very High	Moderate	Remote	Significant (0.4)
612	Very High	Very High	Moderate	Low	Significant (0.7)
613	Very High	Very High	Moderate	Moderate	Significant (1)
614	Very High	Very High	Moderate	High	Very Significant (0.3)

615	Very High	Very High	Moderate	Very High	Very Significant (0.6)
616	Very High	Very High	High	Remote	Significant (0.6)
617	Very High	Very High	High	Low	Significant (0.9)
618	Very High	Very High	High	Moderate	Very Significant (0.2)
619	Very High	Very High	High	High	Very Significant (0.5)
620	Very High	Very High	High	Very High	Very Significant (0.8)
621	Very High	Very High	Very High	Remote	Significant (0.8)
622	Very High	Very High	Very High	Low	Very Significant (0.1)
623	Very High	Very High	Very High	Moderate	Very Significant (0.4)
624	Very High	Very High	Very High	High	Very Significant (0.7)
625	Very High	Very High	Very High	Very High	Very Significant (1)

Appendix 2. The Training Data for the Neural Network

No.	VTC Performance	Navigation Aids & Facilities	Pilot Performance	Sealane Maintenance	Weather Condition	Overall Risk
1	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	4.625
2	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	4.425
3	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Moderate 0.75, Good 0.25	4.225
4	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Good 0.75, Excellent 0.25	4.025
5	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	3.825
6	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	3.625
7	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	3.425
8	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	3.225
9	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	3.025
10	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	2.825
11	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	2.625
12	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	2.425
13	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	V.Poor 0.75, Poor 0.25	2.225
14	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Poor 0.75, Moderate 0.25	2.025
15	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	1.825
16	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	1.625
17	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	4.425
18	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	4.225
19	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Moderate 0.75, Good 0.25	4.025
20	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Good 0.75, Excellent 0.25	3.825
21	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	4.425
22	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	4.225
23	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Moderate 0.75, Good 0.25	4.025
24	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Good 0.75, Excellent 0.25	3.825
25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	4.425
26	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	4.225
27	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Moderate 0.75, Good 0.25	4.025
28	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Good 0.75, Excellent 0.25	3.825
29	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	4.425

30	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	4.225
31	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	4.025
32	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	3.825
33	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	4.225
34	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	4.025
35	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Moderate 0.75, Good 0.25	3.825
36	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Good 0.75, Excellent 0.25	3.625
37	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	4.225
38	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	4.025
39	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Moderate 0.75, Good 0.25	3.825
40	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Good 0.75, Excellent 0.25	3.625
41	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	4.225
42	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	4.025
43	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	3.825
44	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	3.625
45	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	4.225
46	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	4.025
47	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Moderate 0.75, Good 0.25	3.825
48	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Good 0.75, Excellent 0.25	3.625
49	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	4.225
50	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	4.025
51	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	3.825
52	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	3.625
53	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	4.225
54	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	4.025
55	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	3.825
56	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	3.625
57	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	V.Poor 0.75, Poor 0.25	4.025
58	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	3.825
59	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Moderate 0.75, Good 0.25	3.625
60	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Good 0.75, Excellent 0.25	3.425
61	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	4.025

62	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	3.825
63	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	3.625
64	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	3.425
65	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	4.025
66	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	3.825
67	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	3.625
68	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	3.425
69	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	4.025
70	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	3.825
71	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	3.625
72	V.Poor 0.75, Poor 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	3.425
73	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	3.625
74	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	3.425
75	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	3.225
76	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	3.025
77	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	3.625
78	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	3.425
79	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	3.225
80	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	3.025
81	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	3.625
82	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	3.425
83	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	3.225
84	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	3.025
85	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	3.625
86	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	3.425
87	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	3.225
88	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	3.025
89	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	3.425
90	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	3.225
91	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	3.025
92	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	2.825
93	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	3.425

94	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	3.225
95	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	3.025
96	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	2.825
97	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	3.425
98	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	3.225
99	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	3.025
100	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	2.825
101	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	3.425
102	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	3.225
103	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	3.025
104	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	2.825
105	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	3.425
106	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	3.225
107	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	3.025
108	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	2.825
109	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	3.425
110	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	3.225
111	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	3.025
112	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	2.825
113	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	V.Poor 0.75, Poor 0.25	3.225
114	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Poor 0.75, Moderate 0.25	3.025
115	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	2.825
116	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Good 0.75, Excellent 0.25	2.625
117	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	3.225
118	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	3.025
119	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	2.825
120	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	2.625
121	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	3.225
122	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	3.025
123	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	2.825
124	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	2.625
125	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	3.225

126	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	3.025
127	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	2.825
128	Poor 0.75, Moderate 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	2.625
129	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	2.825
130	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	2.625
131	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	2.425
132	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	2.225
133	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	2.825
134	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	2.625
135	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	2.425
136	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	2.225
137	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	2.825
138	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	2.625
139	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	2.425
140	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	2.225
141	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	V.Poor 0.75, Poor 0.25	2.825
142	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Poor 0.75, Moderate 0.25	2.625
143	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	2.425
144	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	2.225
145	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	2.625
146	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	2.425
147	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	2.225
148	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	2.025
149	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	2.625
150	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	2.425
151	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	2.225
152	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	2.025
153	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	V.Poor 0.75, Poor 0.25	2.625
154	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Poor 0.75, Moderate 0.25	2.425
155	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	2.225
156	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	2.025
157	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	2.625

158	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	2.425
159	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	2.225
160	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	2.025
161	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	V.Poor 0.75, Poor 0.25	2.625
162	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Poor 0.75, Moderate 0.25	2.425
163	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	2.225
164	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	2.025
165	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	V.Poor 0.75, Poor 0.25	2.625
166	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Poor 0.75, Moderate 0.25	2.425
167	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	2.225
168	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	2.025
169	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	V.Poor 0.75, Poor 0.25	2.425
170	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Poor 0.75, Moderate 0.25	2.225
171	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Moderate 0.75, Good 0.25	2.025
172	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	1.825
173	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	V.Poor 0.75, Poor 0.25	2.425
174	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Poor 0.75, Moderate 0.25	2.225
175	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	2.025
176	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	1.825
177	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	V.Poor 0.75, Poor 0.25	2.425
178	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Poor 0.75, Moderate 0.25	2.225
179	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	2.025
180	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	1.825
181	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	V.Poor 0.75, Poor 0.25	2.425
182	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Poor 0.75, Moderate 0.25	2.225
183	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Moderate 0.75, Good 0.25	2.025
184	Moderate 0.75, Good 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	Good 0.75, Excellent 0.25	1.825
185	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	4.375
186	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	4.175
187	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Moderate 0.25, Good 0.75	3.975
188	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Good 0.25, Excellent 0.75	3.775
189	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	3.575

190	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	3.375
191	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	3.175
192	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	2.975
193	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	2.775
194	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	2.575
195	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	2.375
196	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	2.175
197	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	V.Poor 0.25, Poor 0.75	1.975
198	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Poor 0.25, Moderate 0.75	1.775
199	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	1.575
200	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	1.375
201	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	4.175
202	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	3.975
203	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Moderate 0.25, Good 0.75	3.775
204	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Good 0.25, Excellent 0.75	3.575
205	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	4.175
206	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	3.975
207	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Moderate 0.25, Good 0.75	3.775
208	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Good 0.25, Excellent 0.75	3.575
209	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	4.175
210	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	3.975
211	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Moderate 0.25, Good 0.75	3.775
212	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Good 0.25, Excellent 0.75	3.575
213	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	4.175
214	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	3.975
215	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	3.775
216	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	3.575
217	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	3.975
218	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	3.775
219	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Moderate 0.25, Good 0.75	3.575
220	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Good 0.25, Excellent 0.75	3.375
221	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	3.975

222	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	3.775
223	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Moderate 0.25, Good 0.75	3.575
224	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Good 0.25, Excellent 0.75	3.375
225	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	3.975
226	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	3.775
227	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	3.575
228	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	3.375
229	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	3.975
230	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	3.775
231	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Moderate 0.25, Good 0.75	3.575
232	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Good 0.25, Excellent 0.75	3.375
233	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	3.975
234	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	3.775
235	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	3.575
236	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	3.375
237	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	3.975
238	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	3.775
239	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	3.575
240	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	3.375
241	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	V.Poor 0.25, Poor 0.75	3.775
242	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	3.575
243	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Moderate 0.25, Good 0.75	3.375
244	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Good 0.25, Excellent 0.75	3.175
245	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	3.775
246	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	3.575
247	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	3.375
248	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	3.175
249	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	3.775
250	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	3.575
251	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	3.375
252	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	3.175
253	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	3.775

254	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	3.575
255	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	3.375
256	V.Poor 0.25, Poor 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	3.175
257	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	3.375
258	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	3.175
259	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	2.975
260	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	2.775
261	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	3.375
262	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	3.175
263	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	2.975
264	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	2.775
265	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	3.375
266	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	3.175
267	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	2.975
268	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	2.775
269	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	3.375
270	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	3.175
271	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	2.975
272	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	2.775
273	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	3.175
274	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	2.975
275	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	2.775
276	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	2.575
277	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	3.175
278	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	2.975
279	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	2.775
280	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	2.575
281	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	3.175
282	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	2.975
283	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	2.775
284	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	2.575
285	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	3.175

286	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	2.975
287	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	2.775
288	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	2.575
289	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	3.175
290	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	2.975
291	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	2.775
292	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	2.575
293	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	3.175
294	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	2.975
295	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	2.775
296	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	2.575
297	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	V.Poor 0.25, Poor 0.75	2.975
298	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Poor 0.25, Moderate 0.75	2.775
299	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	2.575
300	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Good 0.25, Excellent 0.75	2.375
301	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	2.975
302	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	2.775
303	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	2.575
304	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	2.375
305	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	2.975
306	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	2.775
307	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	2.575
308	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	2.375
309	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	2.975
310	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	2.775
311	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	2.575
312	Poor 0.25, Moderate 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	2.375
313	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	2.575
314	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	2.375
315	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	2.175
316	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	1.975
317	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	2.575

318	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	2.375
319	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	2.175
320	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	1.975
321	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	2.575
322	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	2.375
323	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	2.175
324	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	1.975
325	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	V.Poor 0.25, Poor 0.75	2.575
326	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Poor 0.25, Moderate 0.75	2.375
327	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	2.175
328	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	1.975
329	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	2.375
330	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	2.175
331	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	1.975
332	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	1.775
333	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	2.375
334	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	2.175
335	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	1.975
336	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	1.775
337	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	V.Poor 0.25, Poor 0.75	2.375
338	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Poor 0.25, Moderate 0.75	2.175
339	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	1.975
340	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	1.775
341	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	2.375
342	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	2.175
343	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	1.975
344	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	1.775
345	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	V.Poor 0.25, Poor 0.75	2.375
346	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Poor 0.25, Moderate 0.75	2.175
347	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	1.975
348	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	1.775
349	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	V.Poor 0.25, Poor 0.75	2.375

350	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Poor 0.25, Moderate 0.75	2.175
351	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	1.975
352	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	1.775
353	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	V.Poor 0.25, Poor 0.75	2.175
354	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Poor 0.25, Moderate 0.75	1.975
355	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Moderate 0.25, Good 0.75	1.775
356	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	1.575
357	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	V.Poor 0.25, Poor 0.75	2.175
358	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Poor 0.25, Moderate 0.75	1.975
359	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	1.775
360	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	1.575
361	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	V.Poor 0.25, Poor 0.75	2.175
362	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Poor 0.25, Moderate 0.75	1.975
363	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	1.775
364	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	1.575
365	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	V.Poor 0.25, Poor 0.75	2.175
366	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Poor 0.25, Moderate 0.75	1.975
367	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Moderate 0.25, Good 0.75	1.775
368	Moderate 0.25, Good 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	Good 0.25, Excellent 0.75	1.575
369	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	4.5
370	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	4.3
371	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Moderate 0.5, Good 0.5	4.1
372	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Good 0.5, Excellent 0.5	3.9
373	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	3.7
374	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	3.5
375	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	3.3
376	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	3.1
377	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	2.9
378	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	2.7
379	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	2.5
380	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	2.3
381	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	V.Poor 0.5, Poor 0.5	2.1

382	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Poor 0.5, Moderate 0.5	1.9
383	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	1.7
384	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	1.5
385	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	4.3
386	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	4.1
387	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Moderate 0.5, Good 0.5	3.9
388	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Good 0.5, Excellent 0.5	3.7
389	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	4.3
390	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	4.1
391	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Moderate 0.5, Good 0.5	3.9
392	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Good 0.5, Excellent 0.5	3.7
393	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	4.3
394	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	4.1
395	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Moderate 0.5, Good 0.5	3.9
396	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Good 0.5, Excellent 0.5	3.7
397	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	4.3
398	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	4.1
399	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	3.9
400	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	3.7
401	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	4.1
402	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	3.9
403	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Moderate 0.5, Good 0.5	3.7
404	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Good 0.5, Excellent 0.5	3.5
405	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	4.1
406	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	3.9
407	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Moderate 0.5, Good 0.5	3.7
408	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Good 0.5, Excellent 0.5	3.5
409	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	4.1
410	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	3.9
411	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	3.7
412	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	3.5
413	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	4.1

414	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	3.9
415	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Moderate 0.5, Good 0.5	3.7
416	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Good 0.5, Excellent 0.5	3.5
417	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	4.1
418	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	3.9
419	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	3.7
420	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	3.5
421	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	4.1
422	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	3.9
423	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	3.7
424	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	3.5
425	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	V.Poor 0.5, Poor 0.5	3.9
426	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	3.7
427	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Moderate 0.5, Good 0.5	3.5
428	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Good 0.5, Excellent 0.5	3.3
429	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	3.9
430	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	3.7
431	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	3.5
432	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	3.3
433	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	3.9
434	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	3.7
435	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	3.5
436	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	3.3
437	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	3.9
438	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	3.7
439	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	3.5
440	V.Poor 0.5, Poor 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	3.3
441	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	3.5
442	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	3.3
443	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	3.1
444	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	2.9
445	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	3.5

446	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	3.3
447	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	3.1
448	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	2.9
449	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	3.5
450	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	3.3
451	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	3.1
452	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	2.9
453	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	3.5
454	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	3.3
455	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	3.1
456	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	2.9
457	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	3.3
458	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	3.1
459	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	2.9
460	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	2.7
461	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	3.3
462	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	3.1
463	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	2.9
464	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	2.7
465	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	3.3
466	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	3.1
467	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	2.9
468	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	2.7
469	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	3.3
470	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	3.1
471	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	2.9
472	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	2.7
473	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	3.3
474	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	3.1
475	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	2.9
476	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	2.7
477	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	3.3

478	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	3.1
479	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	2.9
480	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	2.7
481	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	V.Poor 0.5, Poor 0.5	3.1
482	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Poor 0.5, Moderate 0.5	2.9
483	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	2.7
484	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Good 0.5, Excellent 0.5	2.5
485	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	3.1
486	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	2.9
487	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	2.7
488	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	2.5
489	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	3.1
490	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	2.9
491	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	2.7
492	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	2.5
493	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	3.1
494	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	2.9
495	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	2.7
496	Poor 0.5, Moderate 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	2.5
497	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	2.7
498	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	2.5
499	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	2.3
500	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	2.1
501	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	2.7
502	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	2.5
503	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	2.3
504	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	2.1
505	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	2.7
506	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	2.5
507	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	2.3
508	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	2.1
509	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	V.Poor 0.5, Poor 0.5	2.7

510	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Poor 0.5, Moderate 0.5	2.5
511	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	2.3
512	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	2.1
513	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	2.5
514	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	2.3
515	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	2.1
516	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	1.9
517	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	2.5
518	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	2.3
519	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	2.1
520	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	1.9
521	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	V.Poor 0.5, Poor 0.5	2.5
522	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Poor 0.5, Moderate 0.5	2.3
523	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	2.1
524	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	1.9
525	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	2.5
526	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	2.3
527	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	2.1
528	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	1.9
529	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	V.Poor 0.5, Poor 0.5	2.5
530	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Poor 0.5, Moderate 0.5	2.3
531	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	2.1
532	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	1.9
533	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	V.Poor 0.5, Poor 0.5	2.5
534	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Poor 0.5, Moderate 0.5	2.3
535	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	2.1
536	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	1.9
537	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	V.Poor 0.5, Poor 0.5	2.3
538	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Poor 0.5, Moderate 0.5	2.1
539	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Moderate 0.5, Good 0.5	1.9
540	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	1.7
541	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	V.Poor 0.5, Poor 0.5	2.3

542	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Poor 0.5, Moderate 0.5	2.1
543	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	1.9
544	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	1.7
545	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	V.Poor 0.5, Poor 0.5	2.3
546	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Poor 0.5, Moderate 0.5	2.1
547	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	1.9
548	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	1.7
549	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	V.Poor 0.5, Poor 0.5	2.3
550	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Poor 0.5, Moderate 0.5	2.1
551	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Moderate 0.5, Good 0.5	1.9
552	Moderate 0.5, Good 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	Good 0.5, Excellent 0.5	1.7
553	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	5
554	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	Poor 1.0	4.8
555	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	Moderate 1.0	4.6
556	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	Good 1.0	4.4
557	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	Excellent 1.0	4.2
558	Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	4.2
559	Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	4
560	Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	3.8
561	Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	Good 1.0	3.6
562	Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	Excellent 1.0	3.4
563	Moderate 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	V.Poor 1.0	3.4
564	Moderate 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	3.2
565	Moderate 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	3
566	Moderate 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	2.8
567	Moderate 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	Excellent 1.0	2.6
568	Good 1.0	Good 1.0	Good 1.0	Good 1.0	V.Poor 1.0	2.6
569	Good 1.0	Good 1.0	Good 1.0	Good 1.0	Poor 1.0	2.4
570	Good 1.0	Good 1.0	Good 1.0	Good 1.0	Moderate 1.0	2.2
571	Good 1.0	Good 1.0	Good 1.0	Good 1.0	Good 1.0	2
572	Good 1.0	Good 1.0	Good 1.0	Good 1.0	Excellent 1.0	1.8
573	Excellent 1.0	Excellent 1.0	Excellent 1.0	Excellent 1.0	V.Poor 1.0	1.8
574	Excellent 1.0	Excellent 1.0	Excellent 1.0	Excellent 1.0	Poor 1.0	1.6
575	Excellent 1.0	Excellent 1.0	Excellent 1.0	Excellent 1.0	Moderate 1.0	1.4
576	Excellent 1.0	Excellent 1.0	Excellent 1.0	Excellent 1.0	Good 1.0	1.2
577	Excellent 1.0	Excellent 1.0	Excellent 1.0	Excellent 1.0	Excellent 1.0	1
578	Poor 1.0	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	4.8
579	Poor 1.0	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	Poor 1.0	4.6
580	Poor 1.0	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	Moderate 1.0	4.4
581	Poor 1.0	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	Good 1.0	4.2
582	Poor 1.0	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	Excellent 1.0	4
583	V.Poor 1.0	Poor 1.0	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	4.8
584	V.Poor 1.0	Poor 1.0	V.Poor 1.0	V.Poor 1.0	Poor 1.0	4.6
585	V.Poor 1.0	Poor 1.0	V.Poor 1.0	V.Poor 1.0	Moderate 1.0	4.4
586	V.Poor 1.0	Poor 1.0	V.Poor 1.0	V.Poor 1.0	Good 1.0	4.2
587	V.Poor 1.0	Poor 1.0	V.Poor 1.0	V.Poor 1.0	Excellent 1.0	4
588	V.Poor 1.0	V.Poor 1.0	Poor 1.0	V.Poor 1.0	V.Poor 1.0	4.8
589	V.Poor 1.0	V.Poor 1.0	Poor 1.0	V.Poor 1.0	Poor 1.0	4.6
590	V.Poor 1.0	V.Poor 1.0	Poor 1.0	V.Poor 1.0	Moderate 1.0	4.4
591	V.Poor 1.0	V.Poor 1.0	Poor 1.0	V.Poor 1.0	Good 1.0	4.2
592	V.Poor 1.0	V.Poor 1.0	Poor 1.0	V.Poor 1.0	Excellent 1.0	4
593	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	Poor 1.0	V.Poor 1.0	4.8

594	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	Poor 1.0	Poor 1.0	4.6
595	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	Poor 1.0	Moderate 1.0	4.4
596	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	Poor 1.0	Good 1.0	4.2
597	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	Poor 1.0	Excellent 1.0	4
598	Poor 1.0	Poor 1.0	V.Poor 1.0	V.Poor 1.0	V.Poor 1.0	4.6
599	Poor 1.0	Poor 1.0	V.Poor 1.0	V.Poor 1.0	Poor 1.0	4.4
600	Poor 1.0	Poor 1.0	V.Poor 1.0	V.Poor 1.0	Moderate 1.0	4.2
601	Poor 1.0	Poor 1.0	V.Poor 1.0	V.Poor 1.0	Good 1.0	4
602	Poor 1.0	Poor 1.0	V.Poor 1.0	V.Poor 1.0	Excellent 1.0	3.8
603	Poor 1.0	V.Poor 1.0	Poor 1.0	V.Poor 1.0	V.Poor 1.0	4.6
604	Poor 1.0	V.Poor 1.0	Poor 1.0	V.Poor 1.0	Poor 1.0	4.4
605	Poor 1.0	V.Poor 1.0	Poor 1.0	V.Poor 1.0	Moderate 1.0	4.2
606	Poor 1.0	V.Poor 1.0	Poor 1.0	V.Poor 1.0	Good 1.0	4
607	Poor 1.0	V.Poor 1.0	Poor 1.0	V.Poor 1.0	Excellent 1.0	3.8
608	Poor 1.0	V.Poor 1.0	V.Poor 1.0	Poor 1.0	V.Poor 1.0	4.6
609	Poor 1.0	V.Poor 1.0	V.Poor 1.0	Poor 1.0	Poor 1.0	4.4
610	Poor 1.0	V.Poor 1.0	V.Poor 1.0	Poor 1.0	Moderate 1.0	4.2
611	Poor 1.0	V.Poor 1.0	V.Poor 1.0	Poor 1.0	Good 1.0	4
612	Poor 1.0	V.Poor 1.0	V.Poor 1.0	Poor 1.0	Excellent 1.0	3.8
613	V.Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	V.Poor 1.0	4.6
614	V.Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	Poor 1.0	4.4
615	V.Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	Moderate 1.0	4.2
616	V.Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	Good 1.0	4
617	V.Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	Excellent 1.0	3.8
618	V.Poor 1.0	Poor 1.0	V.Poor 1.0	Poor 1.0	V.Poor 1.0	4.6
619	V.Poor 1.0	Poor 1.0	V.Poor 1.0	Poor 1.0	Poor 1.0	4.4
620	V.Poor 1.0	Poor 1.0	V.Poor 1.0	Poor 1.0	Moderate 1.0	4.2
621	V.Poor 1.0	Poor 1.0	V.Poor 1.0	Poor 1.0	Good 1.0	4
622	V.Poor 1.0	Poor 1.0	V.Poor 1.0	Poor 1.0	Excellent 1.0	3.8
623	V.Poor 1.0	V.Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	4.6
624	V.Poor 1.0	V.Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	4.4
625	V.Poor 1.0	V.Poor 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	4.2
626	V.Poor 1.0	V.Poor 1.0	Poor 1.0	Poor 1.0	Good 1.0	4
627	V.Poor 1.0	V.Poor 1.0	Poor 1.0	Poor 1.0	Excellent 1.0	3.8
628	Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	V.Poor 1.0	4.4
629	Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	Poor 1.0	4.2
630	Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	Moderate 1.0	4
631	Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	Good 1.0	3.8
632	Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	Excellent 1.0	3.6
633	Poor 1.0	Poor 1.0	V.Poor 1.0	Poor 1.0	V.Poor 1.0	4.4
634	Poor 1.0	Poor 1.0	V.Poor 1.0	Poor 1.0	Poor 1.0	4.2
635	Poor 1.0	Poor 1.0	V.Poor 1.0	Poor 1.0	Moderate 1.0	4
636	Poor 1.0	Poor 1.0	V.Poor 1.0	Poor 1.0	Good 1.0	3.8
637	Poor 1.0	Poor 1.0	V.Poor 1.0	Poor 1.0	Excellent 1.0	3.6
638	Poor 1.0	V.Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	4.4
639	Poor 1.0	V.Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	4.2
640	Poor 1.0	V.Poor 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	4
641	Poor 1.0	V.Poor 1.0	Poor 1.0	Poor 1.0	Good 1.0	3.8
642	Poor 1.0	V.Poor 1.0	Poor 1.0	Poor 1.0	Excellent 1.0	3.6
643	V.Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	4.4
644	V.Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	4.2
645	V.Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	4
646	V.Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	Good 1.0	3.8
647	V.Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	Excellent 1.0	3.6
648	Moderate 1.0	Poor 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	4
649	Moderate 1.0	Poor 1.0	Poor 1.0	Poor 1.0	Poor 1.0	3.8
650	Moderate 1.0	Poor 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	3.6
651	Moderate 1.0	Poor 1.0	Poor 1.0	Poor 1.0	Good 1.0	3.4
652	Moderate 1.0	Poor 1.0	Poor 1.0	Poor 1.0	Excellent 1.0	3.2
653	Poor 1.0	Moderate 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	4
654	Poor 1.0	Moderate 1.0	Poor 1.0	Poor 1.0	Poor 1.0	3.8
655	Poor 1.0	Moderate 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	3.6

656	Poor 1.0	Moderate 1.0	Poor 1.0	Poor 1.0	Good 1.0	3.4
657	Poor 1.0	Moderate 1.0	Poor 1.0	Poor 1.0	Excellent 1.0	3.2
658	Poor 1.0	Poor 1.0	Moderate 1.0	Poor 1.0	V.Poor 1.0	4
659	Poor 1.0	Poor 1.0	Moderate 1.0	Poor 1.0	Poor 1.0	3.8
660	Poor 1.0	Poor 1.0	Moderate 1.0	Poor 1.0	Moderate 1.0	3.6
661	Poor 1.0	Poor 1.0	Moderate 1.0	Poor 1.0	Good 1.0	3.4
662	Poor 1.0	Poor 1.0	Moderate 1.0	Poor 1.0	Excellent 1.0	3.2
663	Poor 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	V.Poor 1.0	4
664	Poor 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	Poor 1.0	3.8
665	Poor 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	Moderate 1.0	3.6
666	Poor 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	Good 1.0	3.4
667	Poor 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	Excellent 1.0	3.2
668	Moderate 1.0	Moderate 1.0	Poor 1.0	Poor 1.0	V.Poor 1.0	3.8
669	Moderate 1.0	Moderate 1.0	Poor 1.0	Poor 1.0	Poor 1.0	3.6
670	Moderate 1.0	Moderate 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	3.4
671	Moderate 1.0	Moderate 1.0	Poor 1.0	Poor 1.0	Good 1.0	3.2
672	Moderate 1.0	Moderate 1.0	Poor 1.0	Poor 1.0	Excellent 1.0	3
673	Moderate 1.0	Poor 1.0	Moderate 1.0	Poor 1.0	V.Poor 1.0	3.8
674	Moderate 1.0	Poor 1.0	Moderate 1.0	Poor 1.0	Poor 1.0	3.6
675	Moderate 1.0	Poor 1.0	Moderate 1.0	Poor 1.0	Moderate 1.0	3.4
676	Moderate 1.0	Poor 1.0	Moderate 1.0	Poor 1.0	Good 1.0	3.2
677	Moderate 1.0	Poor 1.0	Moderate 1.0	Poor 1.0	Excellent 1.0	3
678	Moderate 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	V.Poor 1.0	3.8
679	Moderate 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	Poor 1.0	3.6
680	Moderate 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	Moderate 1.0	3.4
681	Moderate 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	Good 1.0	3.2
682	Moderate 1.0	Poor 1.0	Poor 1.0	Moderate 1.0	Excellent 1.0	3
683	Poor 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	V.Poor 1.0	3.8
684	Poor 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	Poor 1.0	3.6
685	Poor 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	Moderate 1.0	3.4
686	Poor 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	Good 1.0	3.2
687	Poor 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	Excellent 1.0	3
688	Poor 1.0	Moderate 1.0	Poor 1.0	Moderate 1.0	V.Poor 1.0	3.8
689	Poor 1.0	Moderate 1.0	Poor 1.0	Moderate 1.0	Poor 1.0	3.6
690	Poor 1.0	Moderate 1.0	Poor 1.0	Moderate 1.0	Moderate 1.0	3.4
691	Poor 1.0	Moderate 1.0	Poor 1.0	Moderate 1.0	Good 1.0	3.2
692	Poor 1.0	Moderate 1.0	Poor 1.0	Moderate 1.0	Excellent 1.0	3
693	Poor 1.0	Poor 1.0	Moderate 1.0	Moderate 1.0	V.Poor 1.0	3.8
694	Poor 1.0	Poor 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	3.6
695	Poor 1.0	Poor 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	3.4
696	Poor 1.0	Poor 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	3.2
697	Poor 1.0	Poor 1.0	Moderate 1.0	Moderate 1.0	Excellent 1.0	3
698	Moderate 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	V.Poor 1.0	3.6
699	Moderate 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	Poor 1.0	3.4
700	Moderate 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	Moderate 1.0	3.2
701	Moderate 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	Good 1.0	3
702	Moderate 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	Excellent 1.0	2.8
703	Moderate 1.0	Moderate 1.0	Poor 1.0	Moderate 1.0	V.Poor 1.0	3.6
704	Moderate 1.0	Moderate 1.0	Poor 1.0	Moderate 1.0	Poor 1.0	3.4
705	Moderate 1.0	Moderate 1.0	Poor 1.0	Moderate 1.0	Moderate 1.0	3.2
706	Moderate 1.0	Moderate 1.0	Poor 1.0	Moderate 1.0	Good 1.0	3
707	Moderate 1.0	Moderate 1.0	Poor 1.0	Moderate 1.0	Excellent 1.0	2.8
708	Moderate 1.0	Poor 1.0	Moderate 1.0	Moderate 1.0	V.Poor 1.0	3.6
709	Moderate 1.0	Poor 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	3.4
710	Moderate 1.0	Poor 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	3.2
711	Moderate 1.0	Poor 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	3
712	Moderate 1.0	Poor 1.0	Moderate 1.0	Moderate 1.0	Excellent 1.0	2.8
713	Poor 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	V.Poor 1.0	3.6
714	Poor 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	3.4
715	Poor 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	3.2
716	Poor 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	3
717	Poor 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	Excellent 1.0	2.8

718	Good 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	V.Poor 1.0	3.2
719	Good 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	3
720	Good 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	2.8
721	Good 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	2.6
722	Good 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	Excellent 1.0	2.4
723	Moderate 1.0	Good 1.0	Moderate 1.0	Moderate 1.0	V.Poor 1.0	3.2
724	Moderate 1.0	Good 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	3
725	Moderate 1.0	Good 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	2.8
726	Moderate 1.0	Good 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	2.6
727	Moderate 1.0	Good 1.0	Moderate 1.0	Moderate 1.0	Excellent 1.0	2.4
728	Moderate 1.0	Moderate 1.0	Good 1.0	Moderate 1.0	V.Poor 1.0	3.2
729	Moderate 1.0	Moderate 1.0	Good 1.0	Moderate 1.0	Poor 1.0	3
730	Moderate 1.0	Moderate 1.0	Good 1.0	Moderate 1.0	Moderate 1.0	2.8
731	Moderate 1.0	Moderate 1.0	Good 1.0	Moderate 1.0	Good 1.0	2.6
732	Moderate 1.0	Moderate 1.0	Good 1.0	Moderate 1.0	Excellent 1.0	2.4
733	Moderate 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	V.Poor 1.0	3.2
734	Moderate 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	Poor 1.0	3
735	Moderate 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	Moderate 1.0	2.8
736	Moderate 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	Good 1.0	2.6
737	Moderate 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	Excellent 1.0	2.4
738	Good 1.0	Good 1.0	Moderate 1.0	Moderate 1.0	V.Poor 1.0	3
739	Good 1.0	Good 1.0	Moderate 1.0	Moderate 1.0	Poor 1.0	2.8
740	Good 1.0	Good 1.0	Moderate 1.0	Moderate 1.0	Moderate 1.0	2.6
741	Good 1.0	Good 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	2.4
742	Good 1.0	Good 1.0	Moderate 1.0	Moderate 1.0	Excellent 1.0	2.2
743	Good 1.0	Moderate 1.0	Good 1.0	Moderate 1.0	V.Poor 1.0	3
744	Good 1.0	Moderate 1.0	Good 1.0	Moderate 1.0	Poor 1.0	2.8
745	Good 1.0	Moderate 1.0	Good 1.0	Moderate 1.0	Moderate 1.0	2.6
746	Good 1.0	Moderate 1.0	Good 1.0	Moderate 1.0	Good 1.0	2.4
747	Good 1.0	Moderate 1.0	Good 1.0	Moderate 1.0	Excellent 1.0	2.2
748	Good 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	V.Poor 1.0	3
749	Good 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	Poor 1.0	2.8
750	Good 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	Moderate 1.0	2.6
751	Good 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	Good 1.0	2.4
752	Good 1.0	Moderate 1.0	Moderate 1.0	Good 1.0	Excellent 1.0	2.2
753	Moderate 1.0	Good 1.0	Good 1.0	Moderate 1.0	V.Poor 1.0	3
754	Moderate 1.0	Good 1.0	Good 1.0	Moderate 1.0	Poor 1.0	2.8
755	Moderate 1.0	Good 1.0	Good 1.0	Moderate 1.0	Moderate 1.0	2.6
756	Moderate 1.0	Good 1.0	Good 1.0	Moderate 1.0	Good 1.0	2.4
757	Moderate 1.0	Good 1.0	Good 1.0	Moderate 1.0	Excellent 1.0	2.2
758	Moderate 1.0	Good 1.0	Moderate 1.0	Good 1.0	V.Poor 1.0	3
759	Moderate 1.0	Good 1.0	Moderate 1.0	Good 1.0	Poor 1.0	2.8
760	Moderate 1.0	Good 1.0	Moderate 1.0	Good 1.0	Moderate 1.0	2.6
761	Moderate 1.0	Good 1.0	Moderate 1.0	Good 1.0	Good 1.0	2.4
762	Moderate 1.0	Good 1.0	Moderate 1.0	Good 1.0	Excellent 1.0	2.2
763	Moderate 1.0	Moderate 1.0	Good 1.0	Good 1.0	V.Poor 1.0	3
764	Moderate 1.0	Moderate 1.0	Good 1.0	Good 1.0	Poor 1.0	2.8
765	Moderate 1.0	Moderate 1.0	Good 1.0	Good 1.0	Moderate 1.0	2.6
766	Moderate 1.0	Moderate 1.0	Good 1.0	Good 1.0	Good 1.0	2.4
767	Moderate 1.0	Moderate 1.0	Good 1.0	Good 1.0	Excellent 1.0	2.2
768	Good 1.0	Good 1.0	Good 1.0	Moderate 1.0	V.Poor 1.0	2.8
769	Good 1.0	Good 1.0	Good 1.0	Moderate 1.0	Poor 1.0	2.6
770	Good 1.0	Good 1.0	Good 1.0	Moderate 1.0	Moderate 1.0	2.4
771	Good 1.0	Good 1.0	Good 1.0	Moderate 1.0	Good 1.0	2.2
772	Good 1.0	Good 1.0	Good 1.0	Moderate 1.0	Excellent 1.0	2
773	Good 1.0	Good 1.0	Moderate 1.0	Good 1.0	V.Poor 1.0	2.8
774	Good 1.0	Good 1.0	Moderate 1.0	Good 1.0	Poor 1.0	2.6
775	Good 1.0	Good 1.0	Moderate 1.0	Good 1.0	Moderate 1.0	2.4
776	Good 1.0	Good 1.0	Moderate 1.0	Good 1.0	Good 1.0	2.2
777	Good 1.0	Good 1.0	Moderate 1.0	Good 1.0	Excellent 1.0	2
778	Good 1.0	Moderate 1.0	Good 1.0	Good 1.0	V.Poor 1.0	2.8
779	Good 1.0	Moderate 1.0	Good 1.0	Good 1.0	Poor 1.0	2.6

780	Good 1.0	Moderate 1.0	Good 1.0	Good 1.0	Moderate 1.0	2.4
781	Good 1.0	Moderate 1.0	Good 1.0	Good 1.0	Good 1.0	2.2
782	Good 1.0	Moderate 1.0	Good 1.0	Good 1.0	Excellent 1.0	2
783	Moderate 1.0	Good 1.0	Good 1.0	Good 1.0	V.Poor 1.0	2.8
784	Moderate 1.0	Good 1.0	Good 1.0	Good 1.0	Poor 1.0	2.6
785	Moderate 1.0	Good 1.0	Good 1.0	Good 1.0	Moderate 1.0	2.4
786	Moderate 1.0	Good 1.0	Good 1.0	Good 1.0	Good 1.0	2.2
787	Moderate 1.0	Good 1.0	Good 1.0	Good 1.0	Excellent 1.0	2
788	Excellent 1.0	Good 1.0	Good 1.0	Good 1.0	V.Poor 1.0	2.4
789	Excellent 1.0	Good 1.0	Good 1.0	Good 1.0	Poor 1.0	2.2
790	Excellent 1.0	Good 1.0	Good 1.0	Good 1.0	Moderate 1.0	2
791	Excellent 1.0	Good 1.0	Good 1.0	Good 1.0	Good 1.0	1.8
792	Excellent 1.0	Good 1.0	Good 1.0	Good 1.0	Excellent 1.0	1.6
793	Good 1.0	Excellent 1.0	Good 1.0	Good 1.0	V.Poor 1.0	2.4
794	Good 1.0	Excellent 1.0	Good 1.0	Good 1.0	Poor 1.0	2.2
795	Good 1.0	Excellent 1.0	Good 1.0	Good 1.0	Moderate 1.0	2
796	Good 1.0	Excellent 1.0	Good 1.0	Good 1.0	Good 1.0	1.8
797	Good 1.0	Excellent 1.0	Good 1.0	Good 1.0	Excellent 1.0	1.6
798	Good 1.0	Good 1.0	Excellent 1.0	Good 1.0	V.Poor 1.0	2.4
799	Good 1.0	Good 1.0	Excellent 1.0	Good 1.0	Poor 1.0	2.2
800	Good 1.0	Good 1.0	Excellent 1.0	Good 1.0	Moderate 1.0	2
801	Good 1.0	Good 1.0	Excellent 1.0	Good 1.0	Good 1.0	1.8
802	Good 1.0	Good 1.0	Excellent 1.0	Good 1.0	Excellent 1.0	1.6
803	Good 1.0	Good 1.0	Good 1.0	Excellent 1.0	V.Poor 1.0	2.4
804	Good 1.0	Good 1.0	Good 1.0	Excellent 1.0	Poor 1.0	2.2
805	Good 1.0	Good 1.0	Good 1.0	Excellent 1.0	Moderate 1.0	2
806	Good 1.0	Good 1.0	Good 1.0	Excellent 1.0	Good 1.0	1.8
807	Good 1.0	Good 1.0	Good 1.0	Excellent 1.0	Excellent 1.0	1.6
808	Excellent 1.0	Excellent 1.0	Good 1.0	Good 1.0	V.Poor 1.0	2.2
809	Excellent 1.0	Excellent 1.0	Good 1.0	Good 1.0	Poor 1.0	2
810	Excellent 1.0	Excellent 1.0	Good 1.0	Good 1.0	Moderate 1.0	1.8
811	Excellent 1.0	Excellent 1.0	Good 1.0	Good 1.0	Good 1.0	1.6
812	Excellent 1.0	Excellent 1.0	Good 1.0	Good 1.0	Excellent 1.0	1.4
813	Excellent 1.0	Good 1.0	Excellent 1.0	Good 1.0	V.Poor 1.0	2.2
814	Excellent 1.0	Good 1.0	Excellent 1.0	Good 1.0	Poor 1.0	2
815	Excellent 1.0	Good 1.0	Excellent 1.0	Good 1.0	Moderate 1.0	1.8
816	Excellent 1.0	Good 1.0	Excellent 1.0	Good 1.0	Good 1.0	1.6
817	Excellent 1.0	Good 1.0	Excellent 1.0	Good 1.0	Excellent 1.0	1.4
818	Excellent 1.0	Good 1.0	Good 1.0	Excellent 1.0	V.Poor 1.0	2.2
819	Excellent 1.0	Good 1.0	Good 1.0	Excellent 1.0	Poor 1.0	2
820	Excellent 1.0	Good 1.0	Good 1.0	Excellent 1.0	Moderate 1.0	1.8
821	Excellent 1.0	Good 1.0	Good 1.0	Excellent 1.0	Good 1.0	1.6
822	Excellent 1.0	Good 1.0	Good 1.0	Excellent 1.0	Excellent 1.0	1.4
823	Good 1.0	Excellent 1.0	Excellent 1.0	Good 1.0	V.Poor 1.0	2.2
824	Good 1.0	Excellent 1.0	Excellent 1.0	Good 1.0	Poor 1.0	2
825	Good 1.0	Excellent 1.0	Excellent 1.0	Good 1.0	Moderate 1.0	1.8
826	Good 1.0	Excellent 1.0	Excellent 1.0	Good 1.0	Good 1.0	1.6
827	Good 1.0	Excellent 1.0	Excellent 1.0	Good 1.0	Excellent 1.0	1.4
828	Good 1.0	Excellent 1.0	Good 1.0	Excellent 1.0	V.Poor 1.0	2.2
829	Good 1.0	Excellent 1.0	Good 1.0	Excellent 1.0	Poor 1.0	2
830	Good 1.0	Excellent 1.0	Good 1.0	Excellent 1.0	Moderate 1.0	1.8
831	Good 1.0	Excellent 1.0	Good 1.0	Excellent 1.0	Good 1.0	1.6
832	Good 1.0	Excellent 1.0	Good 1.0	Excellent 1.0	Excellent 1.0	1.4
833	Good 1.0	Good 1.0	Excellent 1.0	Excellent 1.0	V.Poor 1.0	2.2
834	Good 1.0	Good 1.0	Excellent 1.0	Excellent 1.0	Poor 1.0	2
835	Good 1.0	Good 1.0	Excellent 1.0	Excellent 1.0	Moderate 1.0	1.8
836	Good 1.0	Good 1.0	Excellent 1.0	Excellent 1.0	Good 1.0	1.6
837	Good 1.0	Good 1.0	Excellent 1.0	Excellent 1.0	Excellent 1.0	1.4
838	Excellent 1.0	Excellent 1.0	Excellent 1.0	Good 1.0	V.Poor 1.0	2
839	Excellent 1.0	Excellent 1.0	Excellent 1.0	Good 1.0	Poor 1.0	1.8
840	Excellent 1.0	Excellent 1.0	Excellent 1.0	Good 1.0	Moderate 1.0	1.6
841	Excellent 1.0	Excellent 1.0	Excellent 1.0	Good 1.0	Good 1.0	1.4

842	Excellent 1.0	Excellent 1.0	Excellent 1.0	Good 1.0	Excellent 1.0	1.2
843	Excellent 1.0	Excellent 1.0	Good 1.0	Excellent 1.0	V.Poor 1.0	2
844	Excellent 1.0	Excellent 1.0	Good 1.0	Excellent 1.0	Poor 1.0	1.8
845	Excellent 1.0	Excellent 1.0	Good 1.0	Excellent 1.0	Moderate 1.0	1.6
846	Excellent 1.0	Excellent 1.0	Good 1.0	Excellent 1.0	Good 1.0	1.4
847	Excellent 1.0	Excellent 1.0	Good 1.0	Excellent 1.0	Excellent 1.0	1.2
848	Excellent 1.0	Good 1.0	Excellent 1.0	Excellent 1.0	V.Poor 1.0	2
849	Excellent 1.0	Good 1.0	Excellent 1.0	Excellent 1.0	Poor 1.0	1.8
850	Excellent 1.0	Good 1.0	Excellent 1.0	Excellent 1.0	Moderate 1.0	1.6
851	Excellent 1.0	Good 1.0	Excellent 1.0	Excellent 1.0	Good 1.0	1.4
852	Excellent 1.0	Good 1.0	Excellent 1.0	Excellent 1.0	Excellent 1.0	1.2
853	Good 1.0	Excellent 1.0	Excellent 1.0	Excellent 1.0	V.Poor 1.0	2
854	Good 1.0	Excellent 1.0	Excellent 1.0	Excellent 1.0	Poor 1.0	1.8
855	Good 1.0	Excellent 1.0	Excellent 1.0	Excellent 1.0	Moderate 1.0	1.6
856	Good 1.0	Excellent 1.0	Excellent 1.0	Excellent 1.0	Good 1.0	1.4
857	Good 1.0	Excellent 1.0	Excellent 1.0	Excellent 1.0	Excellent 1.0	1.2

Appendix 3. The Crisp-Value Training Data for the Neural Network

No.	VTC Performance	Navigation Aids & Facilities	Pilot Performance	Sealane Maintenance	Weather Condition	Overall Risk
1	4.75	4.75	4.75	4.75	4.75	4.625
2	4.75	4.75	4.75	4.75	3.75	4.425
3	4.75	4.75	4.75	4.75	2.75	4.225
4	4.75	4.75	4.75	4.75	1.75	4.025
5	3.75	3.75	3.75	3.75	4.75	3.825
6	3.75	3.75	3.75	3.75	3.75	3.625
7	3.75	3.75	3.75	3.75	2.75	3.425
8	3.75	3.75	3.75	3.75	1.75	3.225
9	2.75	2.75	2.75	2.75	4.75	3.025
10	2.75	2.75	2.75	2.75	3.75	2.825
11	2.75	2.75	2.75	2.75	2.75	2.625
12	2.75	2.75	2.75	2.75	1.75	2.425
13	1.75	1.75	1.75	1.75	4.75	2.225
14	1.75	1.75	1.75	1.75	3.75	2.025
15	1.75	1.75	1.75	1.75	2.75	1.825
16	1.75	1.75	1.75	1.75	1.75	1.625
17	3.75	4.75	4.75	4.75	4.75	4.425
18	3.75	4.75	4.75	4.75	3.75	4.225
19	3.75	4.75	4.75	4.75	2.75	4.025
20	3.75	4.75	4.75	4.75	1.75	3.825
21	4.75	3.75	4.75	4.75	4.75	4.425
22	4.75	3.75	4.75	4.75	3.75	4.225
23	4.75	3.75	4.75	4.75	2.75	4.025
24	4.75	3.75	4.75	4.75	1.75	3.825
25	4.75	4.75	3.75	4.75	4.75	4.425
26	4.75	4.75	3.75	4.75	3.75	4.225
27	4.75	4.75	3.75	4.75	2.75	4.025
28	4.75	4.75	3.75	4.75	1.75	3.825
29	4.75	4.75	4.75	3.75	4.75	4.425
30	4.75	4.75	4.75	3.75	3.75	4.225
31	4.75	4.75	4.75	3.75	2.75	4.025
32	4.75	4.75	4.75	3.75	1.75	3.825
33	3.75	3.75	4.75	4.75	4.75	4.225
34	3.75	3.75	4.75	4.75	3.75	4.025
35	3.75	3.75	4.75	4.75	2.75	3.825
36	3.75	3.75	4.75	4.75	1.75	3.625
37	3.75	4.75	3.75	4.75	4.75	4.225
38	3.75	4.75	3.75	4.75	3.75	4.025
39	3.75	4.75	3.75	4.75	2.75	3.825
40	3.75	4.75	3.75	4.75	1.75	3.625
41	3.75	4.75	4.75	3.75	4.75	4.225
42	3.75	4.75	4.75	3.75	3.75	4.025
43	3.75	4.75	4.75	3.75	2.75	3.825
44	3.75	4.75	4.75	3.75	1.75	3.625
45	4.75	3.75	3.75	4.75	4.75	4.225
46	4.75	3.75	3.75	4.75	3.75	4.025
47	4.75	3.75	3.75	4.75	2.75	3.825
48	4.75	3.75	3.75	4.75	1.75	3.625

49	4.75	3.75	4.75	3.75	4.75	4.225
50	4.75	3.75	4.75	3.75	3.75	4.025
51	4.75	3.75	4.75	3.75	2.75	3.825
52	4.75	3.75	4.75	3.75	1.75	3.625
53	4.75	4.75	3.75	3.75	4.75	4.225
54	4.75	4.75	3.75	3.75	3.75	4.025
55	4.75	4.75	3.75	3.75	2.75	3.825
56	4.75	4.75	3.75	3.75	1.75	3.625
57	3.75	3.75	3.75	4.75	4.75	4.025
58	3.75	3.75	3.75	4.75	3.75	3.825
59	3.75	3.75	3.75	4.75	2.75	3.625
60	3.75	3.75	3.75	4.75	1.75	3.425
61	3.75	3.75	4.75	3.75	4.75	4.025
62	3.75	3.75	4.75	3.75	3.75	3.825
63	3.75	3.75	4.75	3.75	2.75	3.625
64	3.75	3.75	4.75	3.75	1.75	3.425
65	3.75	4.75	3.75	3.75	4.75	4.025
66	3.75	4.75	3.75	3.75	3.75	3.825
67	3.75	4.75	3.75	3.75	2.75	3.625
68	3.75	4.75	3.75	3.75	1.75	3.425
69	4.75	3.75	3.75	3.75	4.75	4.025
70	4.75	3.75	3.75	3.75	3.75	3.825
71	4.75	3.75	3.75	3.75	2.75	3.625
72	4.75	3.75	3.75	3.75	1.75	3.425
73	2.75	3.75	3.75	3.75	4.75	3.625
74	2.75	3.75	3.75	3.75	3.75	3.425
75	2.75	3.75	3.75	3.75	2.75	3.225
76	2.75	3.75	3.75	3.75	1.75	3.025
77	3.75	2.75	3.75	3.75	4.75	3.625
78	3.75	2.75	3.75	3.75	3.75	3.425
79	3.75	2.75	3.75	3.75	2.75	3.225
80	3.75	2.75	3.75	3.75	1.75	3.025
81	3.75	3.75	2.75	3.75	4.75	3.625
82	3.75	3.75	2.75	3.75	3.75	3.425
83	3.75	3.75	2.75	3.75	2.75	3.225
84	3.75	3.75	2.75	3.75	1.75	3.025
85	3.75	3.75	3.75	2.75	4.75	3.625
86	3.75	3.75	3.75	2.75	3.75	3.425
87	3.75	3.75	3.75	2.75	2.75	3.225
88	3.75	3.75	3.75	2.75	1.75	3.025
89	2.75	2.75	3.75	3.75	4.75	3.425
90	2.75	2.75	3.75	3.75	3.75	3.225
91	2.75	2.75	3.75	3.75	2.75	3.025
92	2.75	2.75	3.75	3.75	1.75	2.825
93	2.75	3.75	2.75	3.75	4.75	3.425
94	2.75	3.75	2.75	3.75	3.75	3.225
95	2.75	3.75	2.75	3.75	2.75	3.025
96	2.75	3.75	2.75	3.75	1.75	2.825
97	2.75	3.75	3.75	2.75	4.75	3.425
98	2.75	3.75	3.75	2.75	3.75	3.225
99	2.75	3.75	3.75	2.75	2.75	3.025
100	2.75	3.75	3.75	2.75	1.75	2.825
101	3.75	2.75	2.75	3.75	4.75	3.425
102	3.75	2.75	2.75	3.75	3.75	3.225
103	3.75	2.75	2.75	3.75	2.75	3.025
104	3.75	2.75	2.75	3.75	1.75	2.825

105	3.75	2.75	3.75	2.75	4.75	3.425
106	3.75	2.75	3.75	2.75	3.75	3.225
107	3.75	2.75	3.75	2.75	2.75	3.025
108	3.75	2.75	3.75	2.75	1.75	2.825
109	3.75	3.75	2.75	2.75	4.75	3.425
110	3.75	3.75	2.75	2.75	3.75	3.225
111	3.75	3.75	2.75	2.75	2.75	3.025
112	3.75	3.75	2.75	2.75	1.75	2.825
113	2.75	2.75	2.75	3.75	4.75	3.225
114	2.75	2.75	2.75	3.75	3.75	3.025
115	2.75	2.75	2.75	3.75	2.75	2.825
116	2.75	2.75	2.75	3.75	1.75	2.625
117	2.75	2.75	3.75	2.75	4.75	3.225
118	2.75	2.75	3.75	2.75	3.75	3.025
119	2.75	2.75	3.75	2.75	2.75	2.825
120	2.75	2.75	3.75	2.75	1.75	2.625
121	2.75	3.75	2.75	2.75	4.75	3.225
122	2.75	3.75	2.75	2.75	3.75	3.025
123	2.75	3.75	2.75	2.75	2.75	2.825
124	2.75	3.75	2.75	2.75	1.75	2.625
125	3.75	2.75	2.75	2.75	4.75	3.225
126	3.75	2.75	2.75	2.75	3.75	3.025
127	3.75	2.75	2.75	2.75	2.75	2.825
128	3.75	2.75	2.75	2.75	1.75	2.625
129	1.75	2.75	2.75	2.75	4.75	2.825
130	1.75	2.75	2.75	2.75	3.75	2.625
131	1.75	2.75	2.75	2.75	2.75	2.425
132	1.75	2.75	2.75	2.75	1.75	2.225
133	2.75	1.75	2.75	2.75	4.75	2.825
134	2.75	1.75	2.75	2.75	3.75	2.625
135	2.75	1.75	2.75	2.75	2.75	2.425
136	2.75	1.75	2.75	2.75	1.75	2.225
137	2.75	2.75	1.75	2.75	4.75	2.825
138	2.75	2.75	1.75	2.75	3.75	2.625
139	2.75	2.75	1.75	2.75	2.75	2.425
140	2.75	2.75	1.75	2.75	1.75	2.225
141	2.75	2.75	2.75	1.75	4.75	2.825
142	2.75	2.75	2.75	1.75	3.75	2.625
143	2.75	2.75	2.75	1.75	2.75	2.425
144	2.75	2.75	2.75	1.75	1.75	2.225
145	1.75	1.75	2.75	2.75	4.75	2.625
146	1.75	1.75	2.75	2.75	3.75	2.425
147	1.75	1.75	2.75	2.75	2.75	2.225
148	1.75	1.75	2.75	2.75	1.75	2.025
149	1.75	2.75	1.75	2.75	4.75	2.625
150	1.75	2.75	1.75	2.75	3.75	2.425
151	1.75	2.75	1.75	2.75	2.75	2.225
152	1.75	2.75	1.75	2.75	1.75	2.025
153	1.75	2.75	2.75	1.75	4.75	2.625
154	1.75	2.75	2.75	1.75	3.75	2.425
155	1.75	2.75	2.75	1.75	2.75	2.225
156	1.75	2.75	2.75	1.75	1.75	2.025
157	2.75	1.75	1.75	2.75	4.75	2.625
158	2.75	1.75	1.75	2.75	3.75	2.425
159	2.75	1.75	1.75	2.75	2.75	2.225
160	2.75	1.75	1.75	2.75	1.75	2.025

161	2.75	1.75	2.75	1.75	4.75	2.625
162	2.75	1.75	2.75	1.75	3.75	2.425
163	2.75	1.75	2.75	1.75	2.75	2.225
164	2.75	1.75	2.75	1.75	1.75	2.025
165	2.75	2.75	1.75	1.75	4.75	2.625
166	2.75	2.75	1.75	1.75	3.75	2.425
167	2.75	2.75	1.75	1.75	2.75	2.225
168	2.75	2.75	1.75	1.75	1.75	2.025
169	1.75	1.75	1.75	2.75	4.75	2.425
170	1.75	1.75	1.75	2.75	3.75	2.225
171	1.75	1.75	1.75	2.75	2.75	2.025
172	1.75	1.75	1.75	2.75	1.75	1.825
173	1.75	1.75	2.75	1.75	4.75	2.425
174	1.75	1.75	2.75	1.75	3.75	2.225
175	1.75	1.75	2.75	1.75	2.75	2.025
176	1.75	1.75	2.75	1.75	1.75	1.825
177	1.75	2.75	1.75	1.75	4.75	2.425
178	1.75	2.75	1.75	1.75	3.75	2.225
179	1.75	2.75	1.75	1.75	2.75	2.025
180	1.75	2.75	1.75	1.75	1.75	1.825
181	2.75	1.75	1.75	1.75	4.75	2.425
182	2.75	1.75	1.75	1.75	3.75	2.225
183	2.75	1.75	1.75	1.75	2.75	2.025
184	2.75	1.75	1.75	1.75	1.75	1.825
185	4.25	4.25	4.25	4.25	4.25	4.375
186	4.25	4.25	4.25	4.25	3.25	4.175
187	4.25	4.25	4.25	4.25	2.25	3.975
188	4.25	4.25	4.25	4.25	1.25	3.775
189	3.25	3.25	3.25	3.25	4.25	3.575
190	3.25	3.25	3.25	3.25	3.25	3.375
191	3.25	3.25	3.25	3.25	2.25	3.175
192	3.25	3.25	3.25	3.25	1.25	2.975
193	2.25	2.25	2.25	2.25	4.25	2.775
194	2.25	2.25	2.25	2.25	3.25	2.575
195	2.25	2.25	2.25	2.25	2.25	2.375
196	2.25	2.25	2.25	2.25	1.25	2.175
197	1.25	1.25	1.25	1.25	4.25	1.975
198	1.25	1.25	1.25	1.25	3.25	1.775
199	1.25	1.25	1.25	1.25	2.25	1.575
200	1.25	1.25	1.25	1.25	1.25	1.375
201	3.25	4.25	4.25	4.25	4.25	4.175
202	3.25	4.25	4.25	4.25	3.25	3.975
203	3.25	4.25	4.25	4.25	2.25	3.775
204	3.25	4.25	4.25	4.25	1.25	3.575
205	4.25	3.25	4.25	4.25	4.25	4.175
206	4.25	3.25	4.25	4.25	3.25	3.975
207	4.25	3.25	4.25	4.25	2.25	3.775
208	4.25	3.25	4.25	4.25	1.25	3.575
209	4.25	4.25	3.25	4.25	4.25	4.175
210	4.25	4.25	3.25	4.25	3.25	3.975
211	4.25	4.25	3.25	4.25	2.25	3.775
212	4.25	4.25	3.25	4.25	1.25	3.575
213	4.25	4.25	4.25	3.25	4.25	4.175
214	4.25	4.25	4.25	3.25	3.25	3.975
215	4.25	4.25	4.25	3.25	2.25	3.775
216	4.25	4.25	4.25	3.25	1.25	3.575

217	3.25	3.25	4.25	4.25	4.25	3.975
218	3.25	3.25	4.25	4.25	3.25	3.775
219	3.25	3.25	4.25	4.25	2.25	3.575
220	3.25	3.25	4.25	4.25	1.25	3.375
221	3.25	4.25	3.25	4.25	4.25	3.975
222	3.25	4.25	3.25	4.25	3.25	3.775
223	3.25	4.25	3.25	4.25	2.25	3.575
224	3.25	4.25	3.25	4.25	1.25	3.375
225	3.25	4.25	4.25	3.25	4.25	3.975
226	3.25	4.25	4.25	3.25	3.25	3.775
227	3.25	4.25	4.25	3.25	2.25	3.575
228	3.25	4.25	4.25	3.25	1.25	3.375
229	4.25	3.25	3.25	4.25	4.25	3.975
230	4.25	3.25	3.25	4.25	3.25	3.775
231	4.25	3.25	3.25	4.25	2.25	3.575
232	4.25	3.25	3.25	4.25	1.25	3.375
233	4.25	3.25	4.25	3.25	4.25	3.975
234	4.25	3.25	4.25	3.25	3.25	3.775
235	4.25	3.25	4.25	3.25	2.25	3.575
236	4.25	3.25	4.25	3.25	1.25	3.375
237	4.25	4.25	3.25	3.25	4.25	3.975
238	4.25	4.25	3.25	3.25	3.25	3.775
239	4.25	4.25	3.25	3.25	2.25	3.575
240	4.25	4.25	3.25	3.25	1.25	3.375
241	3.25	3.25	3.25	4.25	4.25	3.775
242	3.25	3.25	3.25	4.25	3.25	3.575
243	3.25	3.25	3.25	4.25	2.25	3.375
244	3.25	3.25	3.25	4.25	1.25	3.175
245	3.25	3.25	4.25	3.25	4.25	3.775
246	3.25	3.25	4.25	3.25	3.25	3.575
247	3.25	3.25	4.25	3.25	2.25	3.375
248	3.25	3.25	4.25	3.25	1.25	3.175
249	3.25	4.25	3.25	3.25	4.25	3.775
250	3.25	4.25	3.25	3.25	3.25	3.575
251	3.25	4.25	3.25	3.25	2.25	3.375
252	3.25	4.25	3.25	3.25	1.25	3.175
253	4.25	3.25	3.25	3.25	4.25	3.775
254	4.25	3.25	3.25	3.25	3.25	3.575
255	4.25	3.25	3.25	3.25	2.25	3.375
256	4.25	3.25	3.25	3.25	1.25	3.175
257	2.25	3.25	3.25	3.25	4.25	3.375
258	2.25	3.25	3.25	3.25	3.25	3.175
259	2.25	3.25	3.25	3.25	2.25	2.975
260	2.25	3.25	3.25	3.25	1.25	2.775
261	3.25	2.25	3.25	3.25	4.25	3.375
262	3.25	2.25	3.25	3.25	3.25	3.175
263	3.25	2.25	3.25	3.25	2.25	2.975
264	3.25	2.25	3.25	3.25	1.25	2.775
265	3.25	3.25	2.25	3.25	4.25	3.375
266	3.25	3.25	2.25	3.25	3.25	3.175
267	3.25	3.25	2.25	3.25	2.25	2.975
268	3.25	3.25	2.25	3.25	1.25	2.775
269	3.25	3.25	3.25	2.25	4.25	3.375
270	3.25	3.25	3.25	2.25	3.25	3.175
271	3.25	3.25	3.25	2.25	2.25	2.975
272	3.25	3.25	3.25	2.25	1.25	2.775

273	2.25	2.25	3.25	3.25	4.25	3.175
274	2.25	2.25	3.25	3.25	3.25	2.975
275	2.25	2.25	3.25	3.25	2.25	2.775
276	2.25	2.25	3.25	3.25	1.25	2.575
277	2.25	3.25	2.25	3.25	4.25	3.175
278	2.25	3.25	2.25	3.25	3.25	2.975
279	2.25	3.25	2.25	3.25	2.25	2.775
280	2.25	3.25	2.25	3.25	1.25	2.575
281	2.25	3.25	3.25	2.25	4.25	3.175
282	2.25	3.25	3.25	2.25	3.25	2.975
283	2.25	3.25	3.25	2.25	2.25	2.775
284	2.25	3.25	3.25	2.25	1.25	2.575
285	3.25	2.25	2.25	3.25	4.25	3.175
286	3.25	2.25	2.25	3.25	3.25	2.975
287	3.25	2.25	2.25	3.25	2.25	2.775
288	3.25	2.25	2.25	3.25	1.25	2.575
289	3.25	2.25	3.25	2.25	4.25	3.175
290	3.25	2.25	3.25	2.25	3.25	2.975
291	3.25	2.25	3.25	2.25	2.25	2.775
292	3.25	2.25	3.25	2.25	1.25	2.575
293	3.25	3.25	2.25	2.25	4.25	3.175
294	3.25	3.25	2.25	2.25	3.25	2.975
295	3.25	3.25	2.25	2.25	2.25	2.775
296	3.25	3.25	2.25	2.25	1.25	2.575
297	2.25	2.25	2.25	3.25	4.25	2.975
298	2.25	2.25	2.25	3.25	3.25	2.775
299	2.25	2.25	2.25	3.25	2.25	2.575
300	2.25	2.25	2.25	3.25	1.25	2.375
301	2.25	2.25	3.25	2.25	4.25	2.975
302	2.25	2.25	3.25	2.25	3.25	2.775
303	2.25	2.25	3.25	2.25	2.25	2.575
304	2.25	2.25	3.25	2.25	1.25	2.375
305	2.25	3.25	2.25	2.25	4.25	2.975
306	2.25	3.25	2.25	2.25	3.25	2.775
307	2.25	3.25	2.25	2.25	2.25	2.575
308	2.25	3.25	2.25	2.25	1.25	2.375
309	3.25	2.25	2.25	2.25	4.25	2.975
310	3.25	2.25	2.25	2.25	3.25	2.775
311	3.25	2.25	2.25	2.25	2.25	2.575
312	3.25	2.25	2.25	2.25	1.25	2.375
313	1.25	2.25	2.25	2.25	4.25	2.575
314	1.25	2.25	2.25	2.25	3.25	2.375
315	1.25	2.25	2.25	2.25	2.25	2.175
316	1.25	2.25	2.25	2.25	1.25	1.975
317	2.25	1.25	2.25	2.25	4.25	2.575
318	2.25	1.25	2.25	2.25	3.25	2.375
319	2.25	1.25	2.25	2.25	2.25	2.175
320	2.25	1.25	2.25	2.25	1.25	1.975
321	2.25	2.25	1.25	2.25	4.25	2.575
322	2.25	2.25	1.25	2.25	3.25	2.375
323	2.25	2.25	1.25	2.25	2.25	2.175
324	2.25	2.25	1.25	2.25	1.25	1.975
325	2.25	2.25	2.25	1.25	4.25	2.575
326	2.25	2.25	2.25	1.25	3.25	2.375
327	2.25	2.25	2.25	1.25	2.25	2.175
328	2.25	2.25	2.25	1.25	1.25	1.975

329	1.25	1.25	2.25	2.25	4.25	2.375
330	1.25	1.25	2.25	2.25	3.25	2.175
331	1.25	1.25	2.25	2.25	2.25	1.975
332	1.25	1.25	2.25	2.25	1.25	1.775
333	1.25	2.25	1.25	2.25	4.25	2.375
334	1.25	2.25	1.25	2.25	3.25	2.175
335	1.25	2.25	1.25	2.25	2.25	1.975
336	1.25	2.25	1.25	2.25	1.25	1.775
337	1.25	2.25	2.25	1.25	4.25	2.375
338	1.25	2.25	2.25	1.25	3.25	2.175
339	1.25	2.25	2.25	1.25	2.25	1.975
340	1.25	2.25	2.25	1.25	1.25	1.775
341	2.25	1.25	1.25	2.25	4.25	2.375
342	2.25	1.25	1.25	2.25	3.25	2.175
343	2.25	1.25	1.25	2.25	2.25	1.975
344	2.25	1.25	1.25	2.25	1.25	1.775
345	2.25	1.25	2.25	1.25	4.25	2.375
346	2.25	1.25	2.25	1.25	3.25	2.175
347	2.25	1.25	2.25	1.25	2.25	1.975
348	2.25	1.25	2.25	1.25	1.25	1.775
349	2.25	2.25	1.25	1.25	4.25	2.375
350	2.25	2.25	1.25	1.25	3.25	2.175
351	2.25	2.25	1.25	1.25	2.25	1.975
352	2.25	2.25	1.25	1.25	1.25	1.775
353	1.25	1.25	1.25	2.25	4.25	2.175
354	1.25	1.25	1.25	2.25	3.25	1.975
355	1.25	1.25	1.25	2.25	2.25	1.775
356	1.25	1.25	1.25	2.25	1.25	1.575
357	1.25	1.25	2.25	1.25	4.25	2.175
358	1.25	1.25	2.25	1.25	3.25	1.975
359	1.25	1.25	2.25	1.25	2.25	1.775
360	1.25	1.25	2.25	1.25	1.25	1.575
361	1.25	2.25	1.25	1.25	4.25	2.175
362	1.25	2.25	1.25	1.25	3.25	1.975
363	1.25	2.25	1.25	1.25	2.25	1.775
364	1.25	2.25	1.25	1.25	1.25	1.575
365	2.25	1.25	1.25	1.25	4.25	2.175
366	2.25	1.25	1.25	1.25	3.25	1.975
367	2.25	1.25	1.25	1.25	2.25	1.775
368	2.25	1.25	1.25	1.25	1.25	1.575
369	4.5	4.5	4.5	4.5	4.5	4.5
370	4.5	4.5	4.5	4.5	3.5	4.3
371	4.5	4.5	4.5	4.5	2.5	4.1
372	4.5	4.5	4.5	4.5	1.5	3.9
373	3.5	3.5	3.5	3.5	4.5	3.7
374	3.5	3.5	3.5	3.5	3.5	3.5
375	3.5	3.5	3.5	3.5	2.5	3.3
376	3.5	3.5	3.5	3.5	1.5	3.1
377	2.5	2.5	2.5	2.5	4.5	2.9
378	2.5	2.5	2.5	2.5	3.5	2.7
379	2.5	2.5	2.5	2.5	2.5	2.5
380	2.5	2.5	2.5	2.5	1.5	2.3
381	1.5	1.5	1.5	1.5	4.5	2.1
382	1.5	1.5	1.5	1.5	3.5	1.9
383	1.5	1.5	1.5	1.5	2.5	1.7
384	1.5	1.5	1.5	1.5	1.5	1.5

385	3.5	4.5	4.5	4.5	4.5	4.3
386	3.5	4.5	4.5	4.5	3.5	4.1
387	3.5	4.5	4.5	4.5	2.5	3.9
388	3.5	4.5	4.5	4.5	1.5	3.7
389	4.5	3.5	4.5	4.5	4.5	4.3
390	4.5	3.5	4.5	4.5	3.5	4.1
391	4.5	3.5	4.5	4.5	2.5	3.9
392	4.5	3.5	4.5	4.5	1.5	3.7
393	4.5	4.5	3.5	4.5	4.5	4.3
394	4.5	4.5	3.5	4.5	3.5	4.1
395	4.5	4.5	3.5	4.5	2.5	3.9
396	4.5	4.5	3.5	4.5	1.5	3.7
397	4.5	4.5	4.5	3.5	4.5	4.3
398	4.5	4.5	4.5	3.5	3.5	4.1
399	4.5	4.5	4.5	3.5	2.5	3.9
400	4.5	4.5	4.5	3.5	1.5	3.7
401	3.5	3.5	4.5	4.5	4.5	4.1
402	3.5	3.5	4.5	4.5	3.5	3.9
403	3.5	3.5	4.5	4.5	2.5	3.7
404	3.5	3.5	4.5	4.5	1.5	3.5
405	3.5	4.5	3.5	4.5	4.5	4.1
406	3.5	4.5	3.5	4.5	3.5	3.9
407	3.5	4.5	3.5	4.5	2.5	3.7
408	3.5	4.5	3.5	4.5	1.5	3.5
409	3.5	4.5	4.5	3.5	4.5	4.1
410	3.5	4.5	4.5	3.5	3.5	3.9
411	3.5	4.5	4.5	3.5	2.5	3.7
412	3.5	4.5	4.5	3.5	1.5	3.5
413	4.5	3.5	3.5	4.5	4.5	4.1
414	4.5	3.5	3.5	4.5	3.5	3.9
415	4.5	3.5	3.5	4.5	2.5	3.7
416	4.5	3.5	3.5	4.5	1.5	3.5
417	4.5	3.5	4.5	3.5	4.5	4.1
418	4.5	3.5	4.5	3.5	3.5	3.9
419	4.5	3.5	4.5	3.5	2.5	3.7
420	4.5	3.5	4.5	3.5	1.5	3.5
421	4.5	4.5	3.5	3.5	4.5	4.1
422	4.5	4.5	3.5	3.5	3.5	3.9
423	4.5	4.5	3.5	3.5	2.5	3.7
424	4.5	4.5	3.5	3.5	1.5	3.5
425	3.5	3.5	3.5	4.5	4.5	3.9
426	3.5	3.5	3.5	4.5	3.5	3.7
427	3.5	3.5	3.5	4.5	2.5	3.5
428	3.5	3.5	3.5	4.5	1.5	3.3
429	3.5	3.5	4.5	3.5	4.5	3.9
430	3.5	3.5	4.5	3.5	3.5	3.7
431	3.5	3.5	4.5	3.5	2.5	3.5
432	3.5	3.5	4.5	3.5	1.5	3.3
433	3.5	4.5	3.5	3.5	4.5	3.9
434	3.5	4.5	3.5	3.5	3.5	3.7
435	3.5	4.5	3.5	3.5	2.5	3.5
436	3.5	4.5	3.5	3.5	1.5	3.3
437	4.5	3.5	3.5	3.5	4.5	3.9
438	4.5	3.5	3.5	3.5	3.5	3.7
439	4.5	3.5	3.5	3.5	2.5	3.5
440	4.5	3.5	3.5	3.5	1.5	3.3

441	2.5	3.5	3.5	3.5	4.5	3.5
442	2.5	3.5	3.5	3.5	3.5	3.3
443	2.5	3.5	3.5	3.5	2.5	3.1
444	2.5	3.5	3.5	3.5	1.5	2.9
445	3.5	2.5	3.5	3.5	4.5	3.5
446	3.5	2.5	3.5	3.5	3.5	3.3
447	3.5	2.5	3.5	3.5	2.5	3.1
448	3.5	2.5	3.5	3.5	1.5	2.9
449	3.5	3.5	2.5	3.5	4.5	3.5
450	3.5	3.5	2.5	3.5	3.5	3.3
451	3.5	3.5	2.5	3.5	2.5	3.1
452	3.5	3.5	2.5	3.5	1.5	2.9
453	3.5	3.5	3.5	2.5	4.5	3.5
454	3.5	3.5	3.5	2.5	3.5	3.3
455	3.5	3.5	3.5	2.5	2.5	3.1
456	3.5	3.5	3.5	2.5	1.5	2.9
457	2.5	2.5	3.5	3.5	4.5	3.3
458	2.5	2.5	3.5	3.5	3.5	3.1
459	2.5	2.5	3.5	3.5	2.5	2.9
460	2.5	2.5	3.5	3.5	1.5	2.7
461	2.5	3.5	2.5	3.5	4.5	3.3
462	2.5	3.5	2.5	3.5	3.5	3.1
463	2.5	3.5	2.5	3.5	2.5	2.9
464	2.5	3.5	2.5	3.5	1.5	2.7
465	2.5	3.5	3.5	2.5	4.5	3.3
466	2.5	3.5	3.5	2.5	3.5	3.1
467	2.5	3.5	3.5	2.5	2.5	2.9
468	2.5	3.5	3.5	2.5	1.5	2.7
469	3.5	2.5	2.5	3.5	4.5	3.3
470	3.5	2.5	2.5	3.5	3.5	3.1
471	3.5	2.5	2.5	3.5	2.5	2.9
472	3.5	2.5	2.5	3.5	1.5	2.7
473	3.5	2.5	3.5	2.5	4.5	3.3
474	3.5	2.5	3.5	2.5	3.5	3.1
475	3.5	2.5	3.5	2.5	2.5	2.9
476	3.5	2.5	3.5	2.5	1.5	2.7
477	3.5	3.5	2.5	2.5	4.5	3.3
478	3.5	3.5	2.5	2.5	3.5	3.1
479	3.5	3.5	2.5	2.5	2.5	2.9
480	3.5	3.5	2.5	2.5	1.5	2.7
481	2.5	2.5	2.5	3.5	4.5	3.1
482	2.5	2.5	2.5	3.5	3.5	2.9
483	2.5	2.5	2.5	3.5	2.5	2.7
484	2.5	2.5	2.5	3.5	1.5	2.5
485	2.5	2.5	3.5	2.5	4.5	3.1
486	2.5	2.5	3.5	2.5	3.5	2.9
487	2.5	2.5	3.5	2.5	2.5	2.7
488	2.5	2.5	3.5	2.5	1.5	2.5
489	2.5	3.5	2.5	2.5	4.5	3.1
490	2.5	3.5	2.5	2.5	3.5	2.9
491	2.5	3.5	2.5	2.5	2.5	2.7
492	2.5	3.5	2.5	2.5	1.5	2.5
493	3.5	2.5	2.5	2.5	4.5	3.1
494	3.5	2.5	2.5	2.5	3.5	2.9
495	3.5	2.5	2.5	2.5	2.5	2.7
496	3.5	2.5	2.5	2.5	1.5	2.5

497	1.5	2.5	2.5	2.5	4.5	2.7
498	1.5	2.5	2.5	2.5	3.5	2.5
499	1.5	2.5	2.5	2.5	2.5	2.3
500	1.5	2.5	2.5	2.5	1.5	2.1
501	2.5	1.5	2.5	2.5	4.5	2.7
502	2.5	1.5	2.5	2.5	3.5	2.5
503	2.5	1.5	2.5	2.5	2.5	2.3
504	2.5	1.5	2.5	2.5	1.5	2.1
505	2.5	2.5	1.5	2.5	4.5	2.7
506	2.5	2.5	1.5	2.5	3.5	2.5
507	2.5	2.5	1.5	2.5	2.5	2.3
508	2.5	2.5	1.5	2.5	1.5	2.1
509	2.5	2.5	2.5	1.5	4.5	2.7
510	2.5	2.5	2.5	1.5	3.5	2.5
511	2.5	2.5	2.5	1.5	2.5	2.3
512	2.5	2.5	2.5	1.5	1.5	2.1
513	1.5	1.5	2.5	2.5	4.5	2.5
514	1.5	1.5	2.5	2.5	3.5	2.3
515	1.5	1.5	2.5	2.5	2.5	2.1
516	1.5	1.5	2.5	2.5	1.5	1.9
517	1.5	2.5	1.5	2.5	4.5	2.5
518	1.5	2.5	1.5	2.5	3.5	2.3
519	1.5	2.5	1.5	2.5	2.5	2.1
520	1.5	2.5	1.5	2.5	1.5	1.9
521	1.5	2.5	2.5	1.5	4.5	2.5
522	1.5	2.5	2.5	1.5	3.5	2.3
523	1.5	2.5	2.5	1.5	2.5	2.1
524	1.5	2.5	2.5	1.5	1.5	1.9
525	2.5	1.5	1.5	2.5	4.5	2.5
526	2.5	1.5	1.5	2.5	3.5	2.3
527	2.5	1.5	1.5	2.5	2.5	2.1
528	2.5	1.5	1.5	2.5	1.5	1.9
529	2.5	1.5	2.5	1.5	4.5	2.5
530	2.5	1.5	2.5	1.5	3.5	2.3
531	2.5	1.5	2.5	1.5	2.5	2.1
532	2.5	1.5	2.5	1.5	1.5	1.9
533	2.5	2.5	1.5	1.5	4.5	2.5
534	2.5	2.5	1.5	1.5	3.5	2.3
535	2.5	2.5	1.5	1.5	2.5	2.1
536	2.5	2.5	1.5	1.5	1.5	1.9
537	1.5	1.5	1.5	2.5	4.5	2.3
538	1.5	1.5	1.5	2.5	3.5	2.1
539	1.5	1.5	1.5	2.5	2.5	1.9
540	1.5	1.5	1.5	2.5	1.5	1.7
541	1.5	1.5	2.5	1.5	4.5	2.3
542	1.5	1.5	2.5	1.5	3.5	2.1
543	1.5	1.5	2.5	1.5	2.5	1.9
544	1.5	1.5	2.5	1.5	1.5	1.7
545	1.5	2.5	1.5	1.5	4.5	2.3
546	1.5	2.5	1.5	1.5	3.5	2.1
547	1.5	2.5	1.5	1.5	2.5	1.9
548	1.5	2.5	1.5	1.5	1.5	1.7
549	2.5	1.5	1.5	1.5	4.5	2.3
550	2.5	1.5	1.5	1.5	3.5	2.1
551	2.5	1.5	1.5	1.5	2.5	1.9
552	2.5	1.5	1.5	1.5	1.5	1.7

553	5	5	5	5	5	5
554	5	5	5	5	4	4.8
555	5	5	5	5	3	4.6
556	5	5	5	5	2	4.4
557	5	5	5	5	1	4.2
558	4	4	4	4	5	4.2
559	4	4	4	4	4	4
560	4	4	4	4	3	3.8
561	4	4	4	4	2	3.6
562	4	4	4	4	1	3.4
563	3	3	3	3	5	3.4
564	3	3	3	3	4	3.2
565	3	3	3	3	3	3
566	3	3	3	3	2	2.8
567	3	3	3	3	1	2.6
568	2	2	2	2	5	2.6
569	2	2	2	2	4	2.4
570	2	2	2	2	3	2.2
571	2	2	2	2	2	2
572	2	2	2	2	1	1.8
573	1	1	1	1	5	1.8
574	1	1	1	1	4	1.6
575	1	1	1	1	3	1.4
576	1	1	1	1	2	1.2
577	1	1	1	1	1	1
578	4	5	5	5	5	4.8
579	4	5	5	5	4	4.6
580	4	5	5	5	3	4.4
581	4	5	5	5	2	4.2
582	4	5	5	5	1	4
583	5	4	5	5	5	4.8
584	5	4	5	5	4	4.6
585	5	4	5	5	3	4.4
586	5	4	5	5	2	4.2
587	5	4	5	5	1	4
588	5	5	4	5	5	4.8
589	5	5	4	5	4	4.6
590	5	5	4	5	3	4.4
591	5	5	4	5	2	4.2
592	5	5	4	5	1	4
593	5	5	5	4	5	4.8
594	5	5	5	4	4	4.6
595	5	5	5	4	3	4.4
596	5	5	5	4	2	4.2
597	5	5	5	4	1	4
598	4	4	5	5	5	4.6
599	4	4	5	5	4	4.4
600	4	4	5	5	3	4.2
601	4	4	5	5	2	4
602	4	4	5	5	1	3.8
603	4	5	4	5	5	4.6
604	4	5	4	5	4	4.4
605	4	5	4	5	3	4.2
606	4	5	4	5	2	4
607	4	5	4	5	1	3.8
608	4	5	5	4	5	4.6

609	4	5	5	4	4	4.4
610	4	5	5	4	3	4.2
611	4	5	5	4	2	4
612	4	5	5	4	1	3.8
613	5	4	4	5	5	4.6
614	5	4	4	5	4	4.4
615	5	4	4	5	3	4.2
616	5	4	4	5	2	4
617	5	4	4	5	1	3.8
618	5	4	5	4	5	4.6
619	5	4	5	4	4	4.4
620	5	4	5	4	3	4.2
621	5	4	5	4	2	4
622	5	4	5	4	1	3.8
623	5	5	4	4	5	4.6
624	5	5	4	4	4	4.4
625	5	5	4	4	3	4.2
626	5	5	4	4	2	4
627	5	5	4	4	1	3.8
628	4	4	4	5	5	4.4
629	4	4	4	5	4	4.2
630	4	4	4	5	3	4
631	4	4	4	5	2	3.8
632	4	4	4	5	1	3.6
633	4	4	5	4	5	4.4
634	4	4	5	4	4	4.2
635	4	4	5	4	3	4
636	4	4	5	4	2	3.8
637	4	4	5	4	1	3.6
638	4	5	4	4	5	4.4
639	4	5	4	4	4	4.2
640	4	5	4	4	3	4
641	4	5	4	4	2	3.8
642	4	5	4	4	1	3.6
643	5	4	4	4	5	4.4
644	5	4	4	4	4	4.2
645	5	4	4	4	3	4
646	5	4	4	4	2	3.8
647	5	4	4	4	1	3.6
648	3	4	4	4	5	4
649	3	4	4	4	4	3.8
650	3	4	4	4	3	3.6
651	3	4	4	4	2	3.4
652	3	4	4	4	1	3.2
653	4	3	4	4	5	4
654	4	3	4	4	4	3.8
655	4	3	4	4	3	3.6
656	4	3	4	4	2	3.4
657	4	3	4	4	1	3.2
658	4	4	3	4	5	4
659	4	4	3	4	4	3.8
660	4	4	3	4	3	3.6
661	4	4	3	4	2	3.4
662	4	4	3	4	1	3.2
663	4	4	4	3	5	4
664	4	4	4	3	4	3.8

665	4	4	4	3	3	3.6
666	4	4	4	3	2	3.4
667	4	4	4	3	1	3.2
668	3	3	4	4	5	3.8
669	3	3	4	4	4	3.6
670	3	3	4	4	3	3.4
671	3	3	4	4	2	3.2
672	3	3	4	4	1	3
673	3	4	3	4	5	3.8
674	3	4	3	4	4	3.6
675	3	4	3	4	3	3.4
676	3	4	3	4	2	3.2
677	3	4	3	4	1	3
678	3	4	4	3	5	3.8
679	3	4	4	3	4	3.6
680	3	4	4	3	3	3.4
681	3	4	4	3	2	3.2
682	3	4	4	3	1	3
683	4	3	3	4	5	3.8
684	4	3	3	4	4	3.6
685	4	3	3	4	3	3.4
686	4	3	3	4	2	3.2
687	4	3	3	4	1	3
688	4	3	4	3	5	3.8
689	4	3	4	3	4	3.6
690	4	3	4	3	3	3.4
691	4	3	4	3	2	3.2
692	4	3	4	3	1	3
693	4	4	3	3	5	3.8
694	4	4	3	3	4	3.6
695	4	4	3	3	3	3.4
696	4	4	3	3	2	3.2
697	4	4	3	3	1	3
698	3	3	3	4	5	3.6
699	3	3	3	4	4	3.4
700	3	3	3	4	3	3.2
701	3	3	3	4	2	3
702	3	3	3	4	1	2.8
703	3	3	4	3	5	3.6
704	3	3	4	3	4	3.4
705	3	3	4	3	3	3.2
706	3	3	4	3	2	3
707	3	3	4	3	1	2.8
708	3	4	3	3	5	3.6
709	3	4	3	3	4	3.4
710	3	4	3	3	3	3.2
711	3	4	3	3	2	3
712	3	4	3	3	1	2.8
713	4	3	3	3	5	3.6
714	4	3	3	3	4	3.4
715	4	3	3	3	3	3.2
716	4	3	3	3	2	3
717	4	3	3	3	1	2.8
718	2	3	3	3	5	3.2
719	2	3	3	3	4	3
720	2	3	3	3	3	2.8

721	2	3	3	3	2	2.6
722	2	3	3	3	1	2.4
723	3	2	3	3	5	3.2
724	3	2	3	3	4	3
725	3	2	3	3	3	2.8
726	3	2	3	3	2	2.6
727	3	2	3	3	1	2.4
728	3	3	2	3	5	3.2
729	3	3	2	3	4	3
730	3	3	2	3	3	2.8
731	3	3	2	3	2	2.6
732	3	3	2	3	1	2.4
733	3	3	3	2	5	3.2
734	3	3	3	2	4	3
735	3	3	3	2	3	2.8
736	3	3	3	2	2	2.6
737	3	3	3	2	1	2.4
738	2	2	3	3	5	3
739	2	2	3	3	4	2.8
740	2	2	3	3	3	2.6
741	2	2	3	3	2	2.4
742	2	2	3	3	1	2.2
743	2	3	2	3	5	3
744	2	3	2	3	4	2.8
745	2	3	2	3	3	2.6
746	2	3	2	3	2	2.4
747	2	3	2	3	1	2.2
748	2	3	3	2	5	3
749	2	3	3	2	4	2.8
750	2	3	3	2	3	2.6
751	2	3	3	2	2	2.4
752	2	3	3	2	1	2.2
753	3	2	2	3	5	3
754	3	2	2	3	4	2.8
755	3	2	2	3	3	2.6
756	3	2	2	3	2	2.4
757	3	2	2	3	1	2.2
758	3	2	3	2	5	3
759	3	2	3	2	4	2.8
760	3	2	3	2	3	2.6
761	3	2	3	2	2	2.4
762	3	2	3	2	1	2.2
763	3	3	2	2	5	3
764	3	3	2	2	4	2.8
765	3	3	2	2	3	2.6
766	3	3	2	2	2	2.4
767	3	3	2	2	1	2.2
768	2	2	2	3	5	2.8
769	2	2	2	3	4	2.6
770	2	2	2	3	3	2.4
771	2	2	2	3	2	2.2
772	2	2	2	3	1	2
773	2	2	3	2	5	2.8
774	2	2	3	2	4	2.6
775	2	2	3	2	3	2.4
776	2	2	3	2	2	2.2

777	2	2	3	2	1	2
778	2	3	2	2	5	2.8
779	2	3	2	2	4	2.6
780	2	3	2	2	3	2.4
781	2	3	2	2	2	2.2
782	2	3	2	2	1	2
783	3	2	2	2	5	2.8
784	3	2	2	2	4	2.6
785	3	2	2	2	3	2.4
786	3	2	2	2	2	2.2
787	3	2	2	2	1	2
788	1	2	2	2	5	2.4
789	1	2	2	2	4	2.2
790	1	2	2	2	3	2
791	1	2	2	2	2	1.8
792	1	2	2	2	1	1.6
793	2	1	2	2	5	2.4
794	2	1	2	2	4	2.2
795	2	1	2	2	3	2
796	2	1	2	2	2	1.8
797	2	1	2	2	1	1.6
798	2	2	1	2	5	2.4
799	2	2	1	2	4	2.2
800	2	2	1	2	3	2
801	2	2	1	2	2	1.8
802	2	2	1	2	1	1.6
803	2	2	2	1	5	2.4
804	2	2	2	1	4	2.2
805	2	2	2	1	3	2
806	2	2	2	1	2	1.8
807	2	2	2	1	1	1.6
808	1	1	2	2	5	2.2
809	1	1	2	2	4	2
810	1	1	2	2	3	1.8
811	1	1	2	2	2	1.6
812	1	1	2	2	1	1.4
813	1	2	1	2	5	2.2
814	1	2	1	2	4	2
815	1	2	1	2	3	1.8
816	1	2	1	2	2	1.6
817	1	2	1	2	1	1.4
818	1	2	2	1	5	2.2
819	1	2	2	1	4	2
820	1	2	2	1	3	1.8
821	1	2	2	1	2	1.6
822	1	2	2	1	1	1.4
823	2	1	1	2	5	2.2
824	2	1	1	2	4	2
825	2	1	1	2	3	1.8
826	2	1	1	2	2	1.6
827	2	1	1	2	1	1.4
828	2	1	2	1	5	2.2
829	2	1	2	1	4	2
830	2	1	2	1	3	1.8
831	2	1	2	1	2	1.6
832	2	1	2	1	1	1.4

833	2	2	1	1	5	2.2
834	2	2	1	1	4	2
835	2	2	1	1	3	1.8
836	2	2	1	1	2	1.6
837	2	2	1	1	1	1.4
838	1	1	1	2	5	2
839	1	1	1	2	4	1.8
840	1	1	1	2	3	1.6
841	1	1	1	2	2	1.4
842	1	1	1	2	1	1.2
843	1	1	2	1	5	2
844	1	1	2	1	4	1.8
845	1	1	2	1	3	1.6
846	1	1	2	1	2	1.4
847	1	1	2	1	1	1.2
848	1	2	1	1	5	2
849	1	2	1	1	4	1.8
850	1	2	1	1	3	1.6
851	1	2	1	1	2	1.4
852	1	2	1	1	1	1.2
853	2	1	1	1	5	2
854	2	1	1	1	4	1.8
855	2	1	1	1	3	1.6
856	2	1	1	1	2	1.4
857	2	1	1	1	1	1.2

Appendix 4. The Normalised Training Data for the Neural Network

No.	VTC Performance	Navigation Aids & Facilities	Pilot Performance	Sealane Maintenance	Weather Condition	Overall Risk
1	0.9375	0.9375	0.9375	0.9375	0.9375	0.90625
2	0.9375	0.9375	0.9375	0.9375	0.6875	0.85625
3	0.9375	0.9375	0.9375	0.9375	0.4375	0.80625
4	0.9375	0.9375	0.9375	0.9375	0.1875	0.75625
5	0.6875	0.6875	0.6875	0.6875	0.9375	0.70625
6	0.6875	0.6875	0.6875	0.6875	0.6875	0.65625
7	0.6875	0.6875	0.6875	0.6875	0.4375	0.60625
8	0.6875	0.6875	0.6875	0.6875	0.1875	0.55625
9	0.4375	0.4375	0.4375	0.4375	0.9375	0.50625
10	0.4375	0.4375	0.4375	0.4375	0.6875	0.45625
11	0.4375	0.4375	0.4375	0.4375	0.4375	0.40625
12	0.4375	0.4375	0.4375	0.4375	0.1875	0.35625
13	0.1875	0.1875	0.1875	0.1875	0.9375	0.30625
14	0.1875	0.1875	0.1875	0.1875	0.6875	0.25625
15	0.1875	0.1875	0.1875	0.1875	0.4375	0.20625
16	0.1875	0.1875	0.1875	0.1875	0.1875	0.15625
17	0.6875	0.9375	0.9375	0.9375	0.9375	0.85625
18	0.6875	0.9375	0.9375	0.9375	0.6875	0.80625
19	0.6875	0.9375	0.9375	0.9375	0.4375	0.75625
20	0.6875	0.9375	0.9375	0.9375	0.1875	0.70625
21	0.9375	0.6875	0.9375	0.9375	0.9375	0.85625
22	0.9375	0.6875	0.9375	0.9375	0.6875	0.80625
23	0.9375	0.6875	0.9375	0.9375	0.4375	0.75625
24	0.9375	0.6875	0.9375	0.9375	0.1875	0.70625
25	0.9375	0.9375	0.6875	0.9375	0.9375	0.85625
26	0.9375	0.9375	0.6875	0.9375	0.6875	0.80625
27	0.9375	0.9375	0.6875	0.9375	0.4375	0.75625
28	0.9375	0.9375	0.6875	0.9375	0.1875	0.70625
29	0.9375	0.9375	0.9375	0.6875	0.9375	0.85625
30	0.9375	0.9375	0.9375	0.6875	0.6875	0.80625
31	0.9375	0.9375	0.9375	0.6875	0.4375	0.75625
32	0.9375	0.9375	0.9375	0.6875	0.1875	0.70625
33	0.6875	0.6875	0.9375	0.9375	0.9375	0.80625
34	0.6875	0.6875	0.9375	0.9375	0.6875	0.75625
35	0.6875	0.6875	0.9375	0.9375	0.4375	0.70625
36	0.6875	0.6875	0.9375	0.9375	0.1875	0.65625
37	0.6875	0.9375	0.6875	0.9375	0.9375	0.80625
38	0.6875	0.9375	0.6875	0.9375	0.6875	0.75625
39	0.6875	0.9375	0.6875	0.9375	0.4375	0.70625
40	0.6875	0.9375	0.6875	0.9375	0.1875	0.65625
41	0.6875	0.9375	0.9375	0.6875	0.9375	0.80625
42	0.6875	0.9375	0.9375	0.6875	0.6875	0.75625
43	0.6875	0.9375	0.9375	0.6875	0.4375	0.70625
44	0.6875	0.9375	0.9375	0.6875	0.1875	0.65625
45	0.9375	0.6875	0.6875	0.9375	0.9375	0.80625
46	0.9375	0.6875	0.6875	0.9375	0.6875	0.75625
47	0.9375	0.6875	0.6875	0.9375	0.4375	0.70625
48	0.9375	0.6875	0.6875	0.9375	0.1875	0.65625

49	0.9375	0.6875	0.9375	0.6875	0.9375	0.80625
50	0.9375	0.6875	0.9375	0.6875	0.6875	0.75625
51	0.9375	0.6875	0.9375	0.6875	0.4375	0.70625
52	0.9375	0.6875	0.9375	0.6875	0.1875	0.65625
53	0.9375	0.9375	0.6875	0.6875	0.9375	0.80625
54	0.9375	0.9375	0.6875	0.6875	0.6875	0.75625
55	0.9375	0.9375	0.6875	0.6875	0.4375	0.70625
56	0.9375	0.9375	0.6875	0.6875	0.1875	0.65625
57	0.6875	0.6875	0.6875	0.9375	0.9375	0.75625
58	0.6875	0.6875	0.6875	0.9375	0.6875	0.70625
59	0.6875	0.6875	0.6875	0.9375	0.4375	0.65625
60	0.6875	0.6875	0.6875	0.9375	0.1875	0.60625
61	0.6875	0.6875	0.9375	0.6875	0.9375	0.75625
62	0.6875	0.6875	0.9375	0.6875	0.6875	0.70625
63	0.6875	0.6875	0.9375	0.6875	0.4375	0.65625
64	0.6875	0.6875	0.9375	0.6875	0.1875	0.60625
65	0.6875	0.9375	0.6875	0.6875	0.9375	0.75625
66	0.6875	0.9375	0.6875	0.6875	0.6875	0.70625
67	0.6875	0.9375	0.6875	0.6875	0.4375	0.65625
68	0.6875	0.9375	0.6875	0.6875	0.1875	0.60625
69	0.9375	0.6875	0.6875	0.6875	0.9375	0.75625
70	0.9375	0.6875	0.6875	0.6875	0.6875	0.70625
71	0.9375	0.6875	0.6875	0.6875	0.4375	0.65625
72	0.9375	0.6875	0.6875	0.6875	0.1875	0.60625
73	0.4375	0.6875	0.6875	0.6875	0.9375	0.65625
74	0.4375	0.6875	0.6875	0.6875	0.6875	0.60625
75	0.4375	0.6875	0.6875	0.6875	0.4375	0.55625
76	0.4375	0.6875	0.6875	0.6875	0.1875	0.50625
77	0.6875	0.4375	0.6875	0.6875	0.9375	0.65625
78	0.6875	0.4375	0.6875	0.6875	0.6875	0.60625
79	0.6875	0.4375	0.6875	0.6875	0.4375	0.55625
80	0.6875	0.4375	0.6875	0.6875	0.1875	0.50625
81	0.6875	0.6875	0.4375	0.6875	0.9375	0.65625
82	0.6875	0.6875	0.4375	0.6875	0.6875	0.60625
83	0.6875	0.6875	0.4375	0.6875	0.4375	0.55625
84	0.6875	0.6875	0.4375	0.6875	0.1875	0.50625
85	0.6875	0.6875	0.6875	0.4375	0.9375	0.65625
86	0.6875	0.6875	0.6875	0.4375	0.6875	0.60625
87	0.6875	0.6875	0.6875	0.4375	0.4375	0.55625
88	0.6875	0.6875	0.6875	0.4375	0.1875	0.50625
89	0.4375	0.4375	0.6875	0.6875	0.9375	0.60625
90	0.4375	0.4375	0.6875	0.6875	0.6875	0.55625
91	0.4375	0.4375	0.6875	0.6875	0.4375	0.50625
92	0.4375	0.4375	0.6875	0.6875	0.1875	0.45625
93	0.4375	0.6875	0.4375	0.6875	0.9375	0.60625
94	0.4375	0.6875	0.4375	0.6875	0.6875	0.55625
95	0.4375	0.6875	0.4375	0.6875	0.4375	0.50625
96	0.4375	0.6875	0.4375	0.6875	0.1875	0.45625
97	0.4375	0.6875	0.6875	0.4375	0.9375	0.60625
98	0.4375	0.6875	0.6875	0.4375	0.6875	0.55625
99	0.4375	0.6875	0.6875	0.4375	0.4375	0.50625
100	0.4375	0.6875	0.6875	0.4375	0.1875	0.45625
101	0.6875	0.4375	0.4375	0.6875	0.9375	0.60625
102	0.6875	0.4375	0.4375	0.6875	0.6875	0.55625
103	0.6875	0.4375	0.4375	0.6875	0.4375	0.50625
104	0.6875	0.4375	0.4375	0.6875	0.1875	0.45625

105	0.6875	0.4375	0.6875	0.4375	0.9375	0.60625
106	0.6875	0.4375	0.6875	0.4375	0.6875	0.55625
107	0.6875	0.4375	0.6875	0.4375	0.4375	0.50625
108	0.6875	0.4375	0.6875	0.4375	0.1875	0.45625
109	0.6875	0.6875	0.4375	0.4375	0.9375	0.60625
110	0.6875	0.6875	0.4375	0.4375	0.6875	0.55625
111	0.6875	0.6875	0.4375	0.4375	0.4375	0.50625
112	0.6875	0.6875	0.4375	0.4375	0.1875	0.45625
113	0.4375	0.4375	0.4375	0.6875	0.9375	0.55625
114	0.4375	0.4375	0.4375	0.6875	0.6875	0.50625
115	0.4375	0.4375	0.4375	0.6875	0.4375	0.45625
116	0.4375	0.4375	0.4375	0.6875	0.1875	0.40625
117	0.4375	0.4375	0.6875	0.4375	0.9375	0.55625
118	0.4375	0.4375	0.6875	0.4375	0.6875	0.50625
119	0.4375	0.4375	0.6875	0.4375	0.4375	0.45625
120	0.4375	0.4375	0.6875	0.4375	0.1875	0.40625
121	0.4375	0.6875	0.4375	0.4375	0.9375	0.55625
122	0.4375	0.6875	0.4375	0.4375	0.6875	0.50625
123	0.4375	0.6875	0.4375	0.4375	0.4375	0.45625
124	0.4375	0.6875	0.4375	0.4375	0.1875	0.40625
125	0.6875	0.4375	0.4375	0.4375	0.9375	0.55625
126	0.6875	0.4375	0.4375	0.4375	0.6875	0.50625
127	0.6875	0.4375	0.4375	0.4375	0.4375	0.45625
128	0.6875	0.4375	0.4375	0.4375	0.1875	0.40625
129	0.1875	0.4375	0.4375	0.4375	0.9375	0.45625
130	0.1875	0.4375	0.4375	0.4375	0.6875	0.40625
131	0.1875	0.4375	0.4375	0.4375	0.4375	0.35625
132	0.1875	0.4375	0.4375	0.4375	0.1875	0.30625
133	0.4375	0.1875	0.4375	0.4375	0.9375	0.45625
134	0.4375	0.1875	0.4375	0.4375	0.6875	0.40625
135	0.4375	0.1875	0.4375	0.4375	0.4375	0.35625
136	0.4375	0.1875	0.4375	0.4375	0.1875	0.30625
137	0.4375	0.4375	0.1875	0.4375	0.9375	0.45625
138	0.4375	0.4375	0.1875	0.4375	0.6875	0.40625
139	0.4375	0.4375	0.1875	0.4375	0.4375	0.35625
140	0.4375	0.4375	0.1875	0.4375	0.1875	0.30625
141	0.4375	0.4375	0.4375	0.1875	0.9375	0.45625
142	0.4375	0.4375	0.4375	0.1875	0.6875	0.40625
143	0.4375	0.4375	0.4375	0.1875	0.4375	0.35625
144	0.4375	0.4375	0.4375	0.1875	0.1875	0.30625
145	0.1875	0.1875	0.4375	0.4375	0.9375	0.40625
146	0.1875	0.1875	0.4375	0.4375	0.6875	0.35625
147	0.1875	0.1875	0.4375	0.4375	0.4375	0.30625
148	0.1875	0.1875	0.4375	0.4375	0.1875	0.25625
149	0.1875	0.4375	0.1875	0.4375	0.9375	0.40625
150	0.1875	0.4375	0.1875	0.4375	0.6875	0.35625
151	0.1875	0.4375	0.1875	0.4375	0.4375	0.30625
152	0.1875	0.4375	0.1875	0.4375	0.1875	0.25625
153	0.1875	0.4375	0.4375	0.1875	0.9375	0.40625
154	0.1875	0.4375	0.4375	0.1875	0.6875	0.35625
155	0.1875	0.4375	0.4375	0.1875	0.4375	0.30625
156	0.1875	0.4375	0.4375	0.1875	0.1875	0.25625
157	0.4375	0.1875	0.1875	0.4375	0.9375	0.40625
158	0.4375	0.1875	0.1875	0.4375	0.6875	0.35625
159	0.4375	0.1875	0.1875	0.4375	0.4375	0.30625
160	0.4375	0.1875	0.1875	0.4375	0.1875	0.25625

161	0.4375	0.1875	0.4375	0.1875	0.9375	0.40625
162	0.4375	0.1875	0.4375	0.1875	0.6875	0.35625
163	0.4375	0.1875	0.4375	0.1875	0.4375	0.30625
164	0.4375	0.1875	0.4375	0.1875	0.1875	0.25625
165	0.4375	0.4375	0.1875	0.1875	0.9375	0.40625
166	0.4375	0.4375	0.1875	0.1875	0.6875	0.35625
167	0.4375	0.4375	0.1875	0.1875	0.4375	0.30625
168	0.4375	0.4375	0.1875	0.1875	0.1875	0.25625
169	0.1875	0.1875	0.1875	0.4375	0.9375	0.35625
170	0.1875	0.1875	0.1875	0.4375	0.6875	0.30625
171	0.1875	0.1875	0.1875	0.4375	0.4375	0.25625
172	0.1875	0.1875	0.1875	0.4375	0.1875	0.20625
173	0.1875	0.1875	0.4375	0.1875	0.9375	0.35625
174	0.1875	0.1875	0.4375	0.1875	0.6875	0.30625
175	0.1875	0.1875	0.4375	0.1875	0.4375	0.25625
176	0.1875	0.1875	0.4375	0.1875	0.1875	0.20625
177	0.1875	0.4375	0.1875	0.1875	0.9375	0.35625
178	0.1875	0.4375	0.1875	0.1875	0.6875	0.30625
179	0.1875	0.4375	0.1875	0.1875	0.4375	0.25625
180	0.1875	0.4375	0.1875	0.1875	0.1875	0.20625
181	0.4375	0.1875	0.1875	0.1875	0.9375	0.35625
182	0.4375	0.1875	0.1875	0.1875	0.6875	0.30625
183	0.4375	0.1875	0.1875	0.1875	0.4375	0.25625
184	0.4375	0.1875	0.1875	0.1875	0.1875	0.20625
185	0.8125	0.8125	0.8125	0.8125	0.8125	0.84375
186	0.8125	0.8125	0.8125	0.8125	0.5625	0.79375
187	0.8125	0.8125	0.8125	0.8125	0.3125	0.74375
188	0.8125	0.8125	0.8125	0.8125	0.0625	0.69375
189	0.5625	0.5625	0.5625	0.5625	0.8125	0.64375
190	0.5625	0.5625	0.5625	0.5625	0.5625	0.59375
191	0.5625	0.5625	0.5625	0.5625	0.3125	0.54375
192	0.5625	0.5625	0.5625	0.5625	0.0625	0.49375
193	0.3125	0.3125	0.3125	0.3125	0.8125	0.44375
194	0.3125	0.3125	0.3125	0.3125	0.5625	0.39375
195	0.3125	0.3125	0.3125	0.3125	0.3125	0.34375
196	0.3125	0.3125	0.3125	0.3125	0.0625	0.29375
197	0.0625	0.0625	0.0625	0.0625	0.8125	0.24375
198	0.0625	0.0625	0.0625	0.0625	0.5625	0.19375
199	0.0625	0.0625	0.0625	0.0625	0.3125	0.14375
200	0.0625	0.0625	0.0625	0.0625	0.0625	0.09375
201	0.5625	0.8125	0.8125	0.8125	0.8125	0.79375
202	0.5625	0.8125	0.8125	0.8125	0.5625	0.74375
203	0.5625	0.8125	0.8125	0.8125	0.3125	0.69375
204	0.5625	0.8125	0.8125	0.8125	0.0625	0.64375
205	0.8125	0.5625	0.8125	0.8125	0.8125	0.79375
206	0.8125	0.5625	0.8125	0.8125	0.5625	0.74375
207	0.8125	0.5625	0.8125	0.8125	0.3125	0.69375
208	0.8125	0.5625	0.8125	0.8125	0.0625	0.64375
209	0.8125	0.8125	0.5625	0.8125	0.8125	0.79375
210	0.8125	0.8125	0.5625	0.8125	0.5625	0.74375
211	0.8125	0.8125	0.5625	0.8125	0.3125	0.69375
212	0.8125	0.8125	0.5625	0.8125	0.0625	0.64375
213	0.8125	0.8125	0.8125	0.5625	0.8125	0.79375
214	0.8125	0.8125	0.8125	0.5625	0.5625	0.74375
215	0.8125	0.8125	0.8125	0.5625	0.3125	0.69375
216	0.8125	0.8125	0.8125	0.5625	0.0625	0.64375

217	0.5625	0.5625	0.8125	0.8125	0.8125	0.74375
218	0.5625	0.5625	0.8125	0.8125	0.5625	0.69375
219	0.5625	0.5625	0.8125	0.8125	0.3125	0.64375
220	0.5625	0.5625	0.8125	0.8125	0.0625	0.59375
221	0.5625	0.8125	0.5625	0.8125	0.8125	0.74375
222	0.5625	0.8125	0.5625	0.8125	0.5625	0.69375
223	0.5625	0.8125	0.5625	0.8125	0.3125	0.64375
224	0.5625	0.8125	0.5625	0.8125	0.0625	0.59375
225	0.5625	0.8125	0.8125	0.5625	0.8125	0.74375
226	0.5625	0.8125	0.8125	0.5625	0.5625	0.69375
227	0.5625	0.8125	0.8125	0.5625	0.3125	0.64375
228	0.5625	0.8125	0.8125	0.5625	0.0625	0.59375
229	0.8125	0.5625	0.5625	0.8125	0.8125	0.74375
230	0.8125	0.5625	0.5625	0.8125	0.5625	0.69375
231	0.8125	0.5625	0.5625	0.8125	0.3125	0.64375
232	0.8125	0.5625	0.5625	0.8125	0.0625	0.59375
233	0.8125	0.5625	0.8125	0.5625	0.8125	0.74375
234	0.8125	0.5625	0.8125	0.5625	0.5625	0.69375
235	0.8125	0.5625	0.8125	0.5625	0.3125	0.64375
236	0.8125	0.5625	0.8125	0.5625	0.0625	0.59375
237	0.8125	0.8125	0.5625	0.5625	0.8125	0.74375
238	0.8125	0.8125	0.5625	0.5625	0.5625	0.69375
239	0.8125	0.8125	0.5625	0.5625	0.3125	0.64375
240	0.8125	0.8125	0.5625	0.5625	0.0625	0.59375
241	0.5625	0.5625	0.5625	0.8125	0.8125	0.69375
242	0.5625	0.5625	0.5625	0.8125	0.5625	0.64375
243	0.5625	0.5625	0.5625	0.8125	0.3125	0.59375
244	0.5625	0.5625	0.5625	0.8125	0.0625	0.54375
245	0.5625	0.5625	0.8125	0.5625	0.8125	0.69375
246	0.5625	0.5625	0.8125	0.5625	0.5625	0.64375
247	0.5625	0.5625	0.8125	0.5625	0.3125	0.59375
248	0.5625	0.5625	0.8125	0.5625	0.0625	0.54375
249	0.5625	0.8125	0.5625	0.5625	0.8125	0.69375
250	0.5625	0.8125	0.5625	0.5625	0.5625	0.64375
251	0.5625	0.8125	0.5625	0.5625	0.3125	0.59375
252	0.5625	0.8125	0.5625	0.5625	0.0625	0.54375
253	0.8125	0.5625	0.5625	0.5625	0.8125	0.69375
254	0.8125	0.5625	0.5625	0.5625	0.5625	0.64375
255	0.8125	0.5625	0.5625	0.5625	0.3125	0.59375
256	0.8125	0.5625	0.5625	0.5625	0.0625	0.54375
257	0.3125	0.5625	0.5625	0.5625	0.8125	0.59375
258	0.3125	0.5625	0.5625	0.5625	0.5625	0.54375
259	0.3125	0.5625	0.5625	0.5625	0.3125	0.49375
260	0.3125	0.5625	0.5625	0.5625	0.0625	0.44375
261	0.5625	0.3125	0.5625	0.5625	0.8125	0.59375
262	0.5625	0.3125	0.5625	0.5625	0.5625	0.54375
263	0.5625	0.3125	0.5625	0.5625	0.3125	0.49375
264	0.5625	0.3125	0.5625	0.5625	0.0625	0.44375
265	0.5625	0.5625	0.3125	0.5625	0.8125	0.59375
266	0.5625	0.5625	0.3125	0.5625	0.5625	0.54375
267	0.5625	0.5625	0.3125	0.5625	0.3125	0.49375
268	0.5625	0.5625	0.3125	0.5625	0.0625	0.44375
269	0.5625	0.5625	0.5625	0.3125	0.8125	0.59375
270	0.5625	0.5625	0.5625	0.3125	0.5625	0.54375
271	0.5625	0.5625	0.5625	0.3125	0.3125	0.49375
272	0.5625	0.5625	0.5625	0.3125	0.0625	0.44375

273	0.3125	0.3125	0.5625	0.5625	0.8125	0.54375
274	0.3125	0.3125	0.5625	0.5625	0.5625	0.49375
275	0.3125	0.3125	0.5625	0.5625	0.3125	0.44375
276	0.3125	0.3125	0.5625	0.5625	0.0625	0.39375
277	0.3125	0.5625	0.3125	0.5625	0.8125	0.54375
278	0.3125	0.5625	0.3125	0.5625	0.5625	0.49375
279	0.3125	0.5625	0.3125	0.5625	0.3125	0.44375
280	0.3125	0.5625	0.3125	0.5625	0.0625	0.39375
281	0.3125	0.5625	0.5625	0.3125	0.8125	0.54375
282	0.3125	0.5625	0.5625	0.3125	0.5625	0.49375
283	0.3125	0.5625	0.5625	0.3125	0.3125	0.44375
284	0.3125	0.5625	0.5625	0.3125	0.0625	0.39375
285	0.5625	0.3125	0.3125	0.5625	0.8125	0.54375
286	0.5625	0.3125	0.3125	0.5625	0.5625	0.49375
287	0.5625	0.3125	0.3125	0.5625	0.3125	0.44375
288	0.5625	0.3125	0.3125	0.5625	0.0625	0.39375
289	0.5625	0.3125	0.5625	0.3125	0.8125	0.54375
290	0.5625	0.3125	0.5625	0.3125	0.5625	0.49375
291	0.5625	0.3125	0.5625	0.3125	0.3125	0.44375
292	0.5625	0.3125	0.5625	0.3125	0.0625	0.39375
293	0.5625	0.5625	0.3125	0.3125	0.8125	0.54375
294	0.5625	0.5625	0.3125	0.3125	0.5625	0.49375
295	0.5625	0.5625	0.3125	0.3125	0.3125	0.44375
296	0.5625	0.5625	0.3125	0.3125	0.0625	0.39375
297	0.3125	0.3125	0.3125	0.5625	0.8125	0.49375
298	0.3125	0.3125	0.3125	0.5625	0.5625	0.44375
299	0.3125	0.3125	0.3125	0.5625	0.3125	0.39375
300	0.3125	0.3125	0.3125	0.5625	0.0625	0.34375
301	0.3125	0.3125	0.5625	0.3125	0.8125	0.49375
302	0.3125	0.3125	0.5625	0.3125	0.5625	0.44375
303	0.3125	0.3125	0.5625	0.3125	0.3125	0.39375
304	0.3125	0.3125	0.5625	0.3125	0.0625	0.34375
305	0.3125	0.5625	0.3125	0.3125	0.8125	0.49375
306	0.3125	0.5625	0.3125	0.3125	0.5625	0.44375
307	0.3125	0.5625	0.3125	0.3125	0.3125	0.39375
308	0.3125	0.5625	0.3125	0.3125	0.0625	0.34375
309	0.5625	0.3125	0.3125	0.3125	0.8125	0.49375
310	0.5625	0.3125	0.3125	0.3125	0.5625	0.44375
311	0.5625	0.3125	0.3125	0.3125	0.3125	0.39375
312	0.5625	0.3125	0.3125	0.3125	0.0625	0.34375
313	0.0625	0.3125	0.3125	0.3125	0.8125	0.39375
314	0.0625	0.3125	0.3125	0.3125	0.5625	0.34375
315	0.0625	0.3125	0.3125	0.3125	0.3125	0.29375
316	0.0625	0.3125	0.3125	0.3125	0.0625	0.24375
317	0.3125	0.0625	0.3125	0.3125	0.8125	0.39375
318	0.3125	0.0625	0.3125	0.3125	0.5625	0.34375
319	0.3125	0.0625	0.3125	0.3125	0.3125	0.29375
320	0.3125	0.0625	0.3125	0.3125	0.0625	0.24375
321	0.3125	0.3125	0.0625	0.3125	0.8125	0.39375
322	0.3125	0.3125	0.0625	0.3125	0.5625	0.34375
323	0.3125	0.3125	0.0625	0.3125	0.3125	0.29375
324	0.3125	0.3125	0.0625	0.3125	0.0625	0.24375
325	0.3125	0.3125	0.3125	0.0625	0.8125	0.39375
326	0.3125	0.3125	0.3125	0.0625	0.5625	0.34375
327	0.3125	0.3125	0.3125	0.0625	0.3125	0.29375
328	0.3125	0.3125	0.3125	0.0625	0.0625	0.24375

329	0.0625	0.0625	0.3125	0.3125	0.8125	0.34375
330	0.0625	0.0625	0.3125	0.3125	0.5625	0.29375
331	0.0625	0.0625	0.3125	0.3125	0.3125	0.24375
332	0.0625	0.0625	0.3125	0.3125	0.0625	0.19375
333	0.0625	0.3125	0.0625	0.3125	0.8125	0.34375
334	0.0625	0.3125	0.0625	0.3125	0.5625	0.29375
335	0.0625	0.3125	0.0625	0.3125	0.3125	0.24375
336	0.0625	0.3125	0.0625	0.3125	0.0625	0.19375
337	0.0625	0.3125	0.3125	0.0625	0.8125	0.34375
338	0.0625	0.3125	0.3125	0.0625	0.5625	0.29375
339	0.0625	0.3125	0.3125	0.0625	0.3125	0.24375
340	0.0625	0.3125	0.3125	0.0625	0.0625	0.19375
341	0.3125	0.0625	0.0625	0.3125	0.8125	0.34375
342	0.3125	0.0625	0.0625	0.3125	0.5625	0.29375
343	0.3125	0.0625	0.0625	0.3125	0.3125	0.24375
344	0.3125	0.0625	0.0625	0.3125	0.0625	0.19375
345	0.3125	0.0625	0.3125	0.0625	0.8125	0.34375
346	0.3125	0.0625	0.3125	0.0625	0.5625	0.29375
347	0.3125	0.0625	0.3125	0.0625	0.3125	0.24375
348	0.3125	0.0625	0.3125	0.0625	0.0625	0.19375
349	0.3125	0.3125	0.0625	0.0625	0.8125	0.34375
350	0.3125	0.3125	0.0625	0.0625	0.5625	0.29375
351	0.3125	0.3125	0.0625	0.0625	0.3125	0.24375
352	0.3125	0.3125	0.0625	0.0625	0.0625	0.19375
353	0.0625	0.0625	0.0625	0.3125	0.8125	0.29375
354	0.0625	0.0625	0.0625	0.3125	0.5625	0.24375
355	0.0625	0.0625	0.0625	0.3125	0.3125	0.19375
356	0.0625	0.0625	0.0625	0.3125	0.0625	0.14375
357	0.0625	0.0625	0.3125	0.0625	0.8125	0.29375
358	0.0625	0.0625	0.3125	0.0625	0.5625	0.24375
359	0.0625	0.0625	0.3125	0.0625	0.3125	0.19375
360	0.0625	0.0625	0.3125	0.0625	0.0625	0.14375
361	0.0625	0.3125	0.0625	0.0625	0.8125	0.29375
362	0.0625	0.3125	0.0625	0.0625	0.5625	0.24375
363	0.0625	0.3125	0.0625	0.0625	0.3125	0.19375
364	0.0625	0.3125	0.0625	0.0625	0.0625	0.14375
365	0.3125	0.0625	0.0625	0.0625	0.8125	0.29375
366	0.3125	0.0625	0.0625	0.0625	0.5625	0.24375
367	0.3125	0.0625	0.0625	0.0625	0.3125	0.19375
368	0.3125	0.0625	0.0625	0.0625	0.0625	0.14375
369	0.875	0.875	0.875	0.875	0.875	0.875
370	0.875	0.875	0.875	0.875	0.625	0.825
371	0.875	0.875	0.875	0.875	0.375	0.775
372	0.875	0.875	0.875	0.875	0.125	0.725
373	0.625	0.625	0.625	0.625	0.875	0.675
374	0.625	0.625	0.625	0.625	0.625	0.625
375	0.625	0.625	0.625	0.625	0.375	0.575
376	0.625	0.625	0.625	0.625	0.125	0.525
377	0.375	0.375	0.375	0.375	0.875	0.475
378	0.375	0.375	0.375	0.375	0.625	0.425
379	0.375	0.375	0.375	0.375	0.375	0.375
380	0.375	0.375	0.375	0.375	0.125	0.325
381	0.125	0.125	0.125	0.125	0.875	0.275
382	0.125	0.125	0.125	0.125	0.625	0.225
383	0.125	0.125	0.125	0.125	0.375	0.175
384	0.125	0.125	0.125	0.125	0.125	0.125

385	0.625	0.875	0.875	0.875	0.875	0.825
386	0.625	0.875	0.875	0.875	0.625	0.775
387	0.625	0.875	0.875	0.875	0.375	0.725
388	0.625	0.875	0.875	0.875	0.125	0.675
389	0.875	0.625	0.875	0.875	0.875	0.825
390	0.875	0.625	0.875	0.875	0.625	0.775
391	0.875	0.625	0.875	0.875	0.375	0.725
392	0.875	0.625	0.875	0.875	0.125	0.675
393	0.875	0.875	0.625	0.875	0.875	0.825
394	0.875	0.875	0.625	0.875	0.625	0.775
395	0.875	0.875	0.625	0.875	0.375	0.725
396	0.875	0.875	0.625	0.875	0.125	0.675
397	0.875	0.875	0.875	0.625	0.875	0.825
398	0.875	0.875	0.875	0.625	0.625	0.775
399	0.875	0.875	0.875	0.625	0.375	0.725
400	0.875	0.875	0.875	0.625	0.125	0.675
401	0.625	0.625	0.875	0.875	0.875	0.775
402	0.625	0.625	0.875	0.875	0.625	0.725
403	0.625	0.625	0.875	0.875	0.375	0.675
404	0.625	0.625	0.875	0.875	0.125	0.625
405	0.625	0.875	0.625	0.875	0.875	0.775
406	0.625	0.875	0.625	0.875	0.625	0.725
407	0.625	0.875	0.625	0.875	0.375	0.675
408	0.625	0.875	0.625	0.875	0.125	0.625
409	0.625	0.875	0.875	0.625	0.875	0.775
410	0.625	0.875	0.875	0.625	0.625	0.725
411	0.625	0.875	0.875	0.625	0.375	0.675
412	0.625	0.875	0.875	0.625	0.125	0.625
413	0.875	0.625	0.625	0.875	0.875	0.775
414	0.875	0.625	0.625	0.875	0.625	0.725
415	0.875	0.625	0.625	0.875	0.375	0.675
416	0.875	0.625	0.625	0.875	0.125	0.625
417	0.875	0.625	0.875	0.625	0.875	0.775
418	0.875	0.625	0.875	0.625	0.625	0.725
419	0.875	0.625	0.875	0.625	0.375	0.675
420	0.875	0.625	0.875	0.625	0.125	0.625
421	0.875	0.875	0.625	0.625	0.875	0.775
422	0.875	0.875	0.625	0.625	0.625	0.725
423	0.875	0.875	0.625	0.625	0.375	0.675
424	0.875	0.875	0.625	0.625	0.125	0.625
425	0.625	0.625	0.625	0.875	0.875	0.725
426	0.625	0.625	0.625	0.875	0.625	0.675
427	0.625	0.625	0.625	0.875	0.375	0.625
428	0.625	0.625	0.625	0.875	0.125	0.575
429	0.625	0.625	0.875	0.625	0.875	0.725
430	0.625	0.625	0.875	0.625	0.625	0.675
431	0.625	0.625	0.875	0.625	0.375	0.625
432	0.625	0.625	0.875	0.625	0.125	0.575
433	0.625	0.875	0.625	0.625	0.875	0.725
434	0.625	0.875	0.625	0.625	0.625	0.675
435	0.625	0.875	0.625	0.625	0.375	0.625
436	0.625	0.875	0.625	0.625	0.125	0.575
437	0.875	0.625	0.625	0.625	0.875	0.725
438	0.875	0.625	0.625	0.625	0.625	0.675
439	0.875	0.625	0.625	0.625	0.375	0.625
440	0.875	0.625	0.625	0.625	0.125	0.575

441	0.375	0.625	0.625	0.625	0.875	0.625
442	0.375	0.625	0.625	0.625	0.625	0.575
443	0.375	0.625	0.625	0.625	0.375	0.525
444	0.375	0.625	0.625	0.625	0.125	0.475
445	0.625	0.375	0.625	0.625	0.875	0.625
446	0.625	0.375	0.625	0.625	0.625	0.575
447	0.625	0.375	0.625	0.625	0.375	0.525
448	0.625	0.375	0.625	0.625	0.125	0.475
449	0.625	0.625	0.375	0.625	0.875	0.625
450	0.625	0.625	0.375	0.625	0.625	0.575
451	0.625	0.625	0.375	0.625	0.375	0.525
452	0.625	0.625	0.375	0.625	0.125	0.475
453	0.625	0.625	0.625	0.375	0.875	0.625
454	0.625	0.625	0.625	0.375	0.625	0.575
455	0.625	0.625	0.625	0.375	0.375	0.525
456	0.625	0.625	0.625	0.375	0.125	0.475
457	0.375	0.375	0.625	0.625	0.875	0.575
458	0.375	0.375	0.625	0.625	0.625	0.525
459	0.375	0.375	0.625	0.625	0.375	0.475
460	0.375	0.375	0.625	0.625	0.125	0.425
461	0.375	0.625	0.375	0.625	0.875	0.575
462	0.375	0.625	0.375	0.625	0.625	0.525
463	0.375	0.625	0.375	0.625	0.375	0.475
464	0.375	0.625	0.375	0.625	0.125	0.425
465	0.375	0.625	0.625	0.375	0.875	0.575
466	0.375	0.625	0.625	0.375	0.625	0.525
467	0.375	0.625	0.625	0.375	0.375	0.475
468	0.375	0.625	0.625	0.375	0.125	0.425
469	0.625	0.375	0.375	0.625	0.875	0.575
470	0.625	0.375	0.375	0.625	0.625	0.525
471	0.625	0.375	0.375	0.625	0.375	0.475
472	0.625	0.375	0.375	0.625	0.125	0.425
473	0.625	0.375	0.625	0.375	0.875	0.575
474	0.625	0.375	0.625	0.375	0.625	0.525
475	0.625	0.375	0.625	0.375	0.375	0.475
476	0.625	0.375	0.625	0.375	0.125	0.425
477	0.625	0.625	0.375	0.375	0.875	0.575
478	0.625	0.625	0.375	0.375	0.625	0.525
479	0.625	0.625	0.375	0.375	0.375	0.475
480	0.625	0.625	0.375	0.375	0.125	0.425
481	0.375	0.375	0.375	0.625	0.875	0.525
482	0.375	0.375	0.375	0.625	0.625	0.475
483	0.375	0.375	0.375	0.625	0.375	0.425
484	0.375	0.375	0.375	0.625	0.125	0.375
485	0.375	0.375	0.625	0.375	0.875	0.525
486	0.375	0.375	0.625	0.375	0.625	0.475
487	0.375	0.375	0.625	0.375	0.375	0.425
488	0.375	0.375	0.625	0.375	0.125	0.375
489	0.375	0.625	0.375	0.375	0.875	0.525
490	0.375	0.625	0.375	0.375	0.625	0.475
491	0.375	0.625	0.375	0.375	0.375	0.425
492	0.375	0.625	0.375	0.375	0.125	0.375
493	0.625	0.375	0.375	0.375	0.875	0.525
494	0.625	0.375	0.375	0.375	0.625	0.475
495	0.625	0.375	0.375	0.375	0.375	0.425
496	0.625	0.375	0.375	0.375	0.125	0.375

497	0.125	0.375	0.375	0.375	0.875	0.425
498	0.125	0.375	0.375	0.375	0.625	0.375
499	0.125	0.375	0.375	0.375	0.375	0.325
500	0.125	0.375	0.375	0.375	0.125	0.275
501	0.375	0.125	0.375	0.375	0.875	0.425
502	0.375	0.125	0.375	0.375	0.625	0.375
503	0.375	0.125	0.375	0.375	0.375	0.325
504	0.375	0.125	0.375	0.375	0.125	0.275
505	0.375	0.375	0.125	0.375	0.875	0.425
506	0.375	0.375	0.125	0.375	0.625	0.375
507	0.375	0.375	0.125	0.375	0.375	0.325
508	0.375	0.375	0.125	0.375	0.125	0.275
509	0.375	0.375	0.375	0.125	0.875	0.425
510	0.375	0.375	0.375	0.125	0.625	0.375
511	0.375	0.375	0.375	0.125	0.375	0.325
512	0.375	0.375	0.375	0.125	0.125	0.275
513	0.125	0.125	0.375	0.375	0.875	0.375
514	0.125	0.125	0.375	0.375	0.625	0.325
515	0.125	0.125	0.375	0.375	0.375	0.275
516	0.125	0.125	0.375	0.375	0.125	0.225
517	0.125	0.375	0.125	0.375	0.875	0.375
518	0.125	0.375	0.125	0.375	0.625	0.325
519	0.125	0.375	0.125	0.375	0.375	0.275
520	0.125	0.375	0.125	0.375	0.125	0.225
521	0.125	0.375	0.375	0.125	0.875	0.375
522	0.125	0.375	0.375	0.125	0.625	0.325
523	0.125	0.375	0.375	0.125	0.375	0.275
524	0.125	0.375	0.375	0.125	0.125	0.225
525	0.375	0.125	0.125	0.375	0.875	0.375
526	0.375	0.125	0.125	0.375	0.625	0.325
527	0.375	0.125	0.125	0.375	0.375	0.275
528	0.375	0.125	0.125	0.375	0.125	0.225
529	0.375	0.125	0.375	0.125	0.875	0.375
530	0.375	0.125	0.375	0.125	0.625	0.325
531	0.375	0.125	0.375	0.125	0.375	0.275
532	0.375	0.125	0.375	0.125	0.125	0.225
533	0.375	0.375	0.125	0.125	0.875	0.375
534	0.375	0.375	0.125	0.125	0.625	0.325
535	0.375	0.375	0.125	0.125	0.375	0.275
536	0.375	0.375	0.125	0.125	0.125	0.225
537	0.125	0.125	0.125	0.375	0.875	0.325
538	0.125	0.125	0.125	0.375	0.625	0.275
539	0.125	0.125	0.125	0.375	0.375	0.225
540	0.125	0.125	0.125	0.375	0.125	0.175
541	0.125	0.125	0.375	0.125	0.875	0.325
542	0.125	0.125	0.375	0.125	0.625	0.275
543	0.125	0.125	0.375	0.125	0.375	0.225
544	0.125	0.125	0.375	0.125	0.125	0.175
545	0.125	0.375	0.125	0.125	0.875	0.325
546	0.125	0.375	0.125	0.125	0.625	0.275
547	0.125	0.375	0.125	0.125	0.375	0.225
548	0.125	0.375	0.125	0.125	0.125	0.175
549	0.375	0.125	0.125	0.125	0.875	0.325
550	0.375	0.125	0.125	0.125	0.625	0.275
551	0.375	0.125	0.125	0.125	0.375	0.225
552	0.375	0.125	0.125	0.125	0.125	0.175

553	1	1	1	1	1	1
554	1	1	1	1	0.75	0.95
555	1	1	1	1	0.5	0.9
556	1	1	1	1	0.25	0.85
557	1	1	1	1	0	0.8
558	0.75	0.75	0.75	0.75	1	0.8
559	0.75	0.75	0.75	0.75	0.75	0.75
560	0.75	0.75	0.75	0.75	0.5	0.7
561	0.75	0.75	0.75	0.75	0.25	0.65
562	0.75	0.75	0.75	0.75	0	0.6
563	0.5	0.5	0.5	0.5	1	0.6
564	0.5	0.5	0.5	0.5	0.75	0.55
565	0.5	0.5	0.5	0.5	0.5	0.5
566	0.5	0.5	0.5	0.5	0.25	0.45
567	0.5	0.5	0.5	0.5	0	0.4
568	0.25	0.25	0.25	0.25	1	0.4
569	0.25	0.25	0.25	0.25	0.75	0.35
570	0.25	0.25	0.25	0.25	0.5	0.3
571	0.25	0.25	0.25	0.25	0.25	0.25
572	0.25	0.25	0.25	0.25	0	0.2
573	0	0	0	0	1	0.2
574	0	0	0	0	0.75	0.15
575	0	0	0	0	0.5	0.1
576	0	0	0	0	0.25	0.05
577	0	0	0	0	0	0
578	0.75	1	1	1	1	0.95
579	0.75	1	1	1	0.75	0.9
580	0.75	1	1	1	0.5	0.85
581	0.75	1	1	1	0.25	0.8
582	0.75	1	1	1	0	0.75
583	1	0.75	1	1	1	0.95
584	1	0.75	1	1	0.75	0.9
585	1	0.75	1	1	0.5	0.85
586	1	0.75	1	1	0.25	0.8
587	1	0.75	1	1	0	0.75
588	1	1	0.75	1	1	0.95
589	1	1	0.75	1	0.75	0.9
590	1	1	0.75	1	0.5	0.85
591	1	1	0.75	1	0.25	0.8
592	1	1	0.75	1	0	0.75
593	1	1	1	0.75	1	0.95
594	1	1	1	0.75	0.75	0.9
595	1	1	1	0.75	0.5	0.85
596	1	1	1	0.75	0.25	0.8
597	1	1	1	0.75	0	0.75
598	0.75	0.75	1	1	1	0.9
599	0.75	0.75	1	1	0.75	0.85
600	0.75	0.75	1	1	0.5	0.8
601	0.75	0.75	1	1	0.25	0.75
602	0.75	0.75	1	1	0	0.7
603	0.75	1	0.75	1	1	0.9
604	0.75	1	0.75	1	0.75	0.85
605	0.75	1	0.75	1	0.5	0.8
606	0.75	1	0.75	1	0.25	0.75
607	0.75	1	0.75	1	0	0.7
608	0.75	1	1	0.75	1	0.9

609	0.75	1	1	0.75	0.75	0.85
610	0.75	1	1	0.75	0.5	0.8
611	0.75	1	1	0.75	0.25	0.75
612	0.75	1	1	0.75	0	0.7
613	1	0.75	0.75	1	1	0.9
614	1	0.75	0.75	1	0.75	0.85
615	1	0.75	0.75	1	0.5	0.8
616	1	0.75	0.75	1	0.25	0.75
617	1	0.75	0.75	1	0	0.7
618	1	0.75	1	0.75	1	0.9
619	1	0.75	1	0.75	0.75	0.85
620	1	0.75	1	0.75	0.5	0.8
621	1	0.75	1	0.75	0.25	0.75
622	1	0.75	1	0.75	0	0.7
623	1	1	0.75	0.75	1	0.9
624	1	1	0.75	0.75	0.75	0.85
625	1	1	0.75	0.75	0.5	0.8
626	1	1	0.75	0.75	0.25	0.75
627	1	1	0.75	0.75	0	0.7
628	0.75	0.75	0.75	1	1	0.85
629	0.75	0.75	0.75	1	0.75	0.8
630	0.75	0.75	0.75	1	0.5	0.75
631	0.75	0.75	0.75	1	0.25	0.7
632	0.75	0.75	0.75	1	0	0.65
633	0.75	0.75	1	0.75	1	0.85
634	0.75	0.75	1	0.75	0.75	0.8
635	0.75	0.75	1	0.75	0.5	0.75
636	0.75	0.75	1	0.75	0.25	0.7
637	0.75	0.75	1	0.75	0	0.65
638	0.75	1	0.75	0.75	1	0.85
639	0.75	1	0.75	0.75	0.75	0.8
640	0.75	1	0.75	0.75	0.5	0.75
641	0.75	1	0.75	0.75	0.25	0.7
642	0.75	1	0.75	0.75	0	0.65
643	1	0.75	0.75	0.75	1	0.85
644	1	0.75	0.75	0.75	0.75	0.8
645	1	0.75	0.75	0.75	0.5	0.75
646	1	0.75	0.75	0.75	0.25	0.7
647	1	0.75	0.75	0.75	0	0.65
648	0.5	0.75	0.75	0.75	1	0.75
649	0.5	0.75	0.75	0.75	0.75	0.7
650	0.5	0.75	0.75	0.75	0.5	0.65
651	0.5	0.75	0.75	0.75	0.25	0.6
652	0.5	0.75	0.75	0.75	0	0.55
653	0.75	0.5	0.75	0.75	1	0.75
654	0.75	0.5	0.75	0.75	0.75	0.7
655	0.75	0.5	0.75	0.75	0.5	0.65
656	0.75	0.5	0.75	0.75	0.25	0.6
657	0.75	0.5	0.75	0.75	0	0.55
658	0.75	0.75	0.5	0.75	1	0.75
659	0.75	0.75	0.5	0.75	0.75	0.7
660	0.75	0.75	0.5	0.75	0.5	0.65
661	0.75	0.75	0.5	0.75	0.25	0.6
662	0.75	0.75	0.5	0.75	0	0.55
663	0.75	0.75	0.75	0.5	1	0.75
664	0.75	0.75	0.75	0.5	0.75	0.7

665	0.75	0.75	0.75	0.5	0.5	0.65
666	0.75	0.75	0.75	0.5	0.25	0.6
667	0.75	0.75	0.75	0.5	0	0.55
668	0.5	0.5	0.75	0.75	1	0.7
669	0.5	0.5	0.75	0.75	0.75	0.65
670	0.5	0.5	0.75	0.75	0.5	0.6
671	0.5	0.5	0.75	0.75	0.25	0.55
672	0.5	0.5	0.75	0.75	0	0.5
673	0.5	0.75	0.5	0.75	1	0.7
674	0.5	0.75	0.5	0.75	0.75	0.65
675	0.5	0.75	0.5	0.75	0.5	0.6
676	0.5	0.75	0.5	0.75	0.25	0.55
677	0.5	0.75	0.5	0.75	0	0.5
678	0.5	0.75	0.75	0.5	1	0.7
679	0.5	0.75	0.75	0.5	0.75	0.65
680	0.5	0.75	0.75	0.5	0.5	0.6
681	0.5	0.75	0.75	0.5	0.25	0.55
682	0.5	0.75	0.75	0.5	0	0.5
683	0.75	0.5	0.5	0.75	1	0.7
684	0.75	0.5	0.5	0.75	0.75	0.65
685	0.75	0.5	0.5	0.75	0.5	0.6
686	0.75	0.5	0.5	0.75	0.25	0.55
687	0.75	0.5	0.5	0.75	0	0.5
688	0.75	0.5	0.75	0.5	1	0.7
689	0.75	0.5	0.75	0.5	0.75	0.65
690	0.75	0.5	0.75	0.5	0.5	0.6
691	0.75	0.5	0.75	0.5	0.25	0.55
692	0.75	0.5	0.75	0.5	0	0.5
693	0.75	0.75	0.5	0.5	1	0.7
694	0.75	0.75	0.5	0.5	0.75	0.65
695	0.75	0.75	0.5	0.5	0.5	0.6
696	0.75	0.75	0.5	0.5	0.25	0.55
697	0.75	0.75	0.5	0.5	0	0.5
698	0.5	0.5	0.5	0.75	1	0.65
699	0.5	0.5	0.5	0.75	0.75	0.6
700	0.5	0.5	0.5	0.75	0.5	0.55
701	0.5	0.5	0.5	0.75	0.25	0.5
702	0.5	0.5	0.5	0.75	0	0.45
703	0.5	0.5	0.75	0.5	1	0.65
704	0.5	0.5	0.75	0.5	0.75	0.6
705	0.5	0.5	0.75	0.5	0.5	0.55
706	0.5	0.5	0.75	0.5	0.25	0.5
707	0.5	0.5	0.75	0.5	0	0.45
708	0.5	0.75	0.5	0.5	1	0.65
709	0.5	0.75	0.5	0.5	0.75	0.6
710	0.5	0.75	0.5	0.5	0.5	0.55
711	0.5	0.75	0.5	0.5	0.25	0.5
712	0.5	0.75	0.5	0.5	0	0.45
713	0.75	0.5	0.5	0.5	1	0.65
714	0.75	0.5	0.5	0.5	0.75	0.6
715	0.75	0.5	0.5	0.5	0.5	0.55
716	0.75	0.5	0.5	0.5	0.25	0.5
717	0.75	0.5	0.5	0.5	0	0.45
718	0.25	0.5	0.5	0.5	1	0.55
719	0.25	0.5	0.5	0.5	0.75	0.5
720	0.25	0.5	0.5	0.5	0.5	0.45

721	0.25	0.5	0.5	0.5	0.25	0.4
722	0.25	0.5	0.5	0.5	0	0.35
723	0.5	0.25	0.5	0.5	1	0.55
724	0.5	0.25	0.5	0.5	0.75	0.5
725	0.5	0.25	0.5	0.5	0.5	0.45
726	0.5	0.25	0.5	0.5	0.25	0.4
727	0.5	0.25	0.5	0.5	0	0.35
728	0.5	0.5	0.25	0.5	1	0.55
729	0.5	0.5	0.25	0.5	0.75	0.5
730	0.5	0.5	0.25	0.5	0.5	0.45
731	0.5	0.5	0.25	0.5	0.25	0.4
732	0.5	0.5	0.25	0.5	0	0.35
733	0.5	0.5	0.5	0.25	1	0.55
734	0.5	0.5	0.5	0.25	0.75	0.5
735	0.5	0.5	0.5	0.25	0.5	0.45
736	0.5	0.5	0.5	0.25	0.25	0.4
737	0.5	0.5	0.5	0.25	0	0.35
738	0.25	0.25	0.5	0.5	1	0.5
739	0.25	0.25	0.5	0.5	0.75	0.45
740	0.25	0.25	0.5	0.5	0.5	0.4
741	0.25	0.25	0.5	0.5	0.25	0.35
742	0.25	0.25	0.5	0.5	0	0.3
743	0.25	0.5	0.25	0.5	1	0.5
744	0.25	0.5	0.25	0.5	0.75	0.45
745	0.25	0.5	0.25	0.5	0.5	0.4
746	0.25	0.5	0.25	0.5	0.25	0.35
747	0.25	0.5	0.25	0.5	0	0.3
748	0.25	0.5	0.5	0.25	1	0.5
749	0.25	0.5	0.5	0.25	0.75	0.45
750	0.25	0.5	0.5	0.25	0.5	0.4
751	0.25	0.5	0.5	0.25	0.25	0.35
752	0.25	0.5	0.5	0.25	0	0.3
753	0.5	0.25	0.25	0.5	1	0.5
754	0.5	0.25	0.25	0.5	0.75	0.45
755	0.5	0.25	0.25	0.5	0.5	0.4
756	0.5	0.25	0.25	0.5	0.25	0.35
757	0.5	0.25	0.25	0.5	0	0.3
758	0.5	0.25	0.5	0.25	1	0.5
759	0.5	0.25	0.5	0.25	0.75	0.45
760	0.5	0.25	0.5	0.25	0.5	0.4
761	0.5	0.25	0.5	0.25	0.25	0.35
762	0.5	0.25	0.5	0.25	0	0.3
763	0.5	0.5	0.25	0.25	1	0.5
764	0.5	0.5	0.25	0.25	0.75	0.45
765	0.5	0.5	0.25	0.25	0.5	0.4
766	0.5	0.5	0.25	0.25	0.25	0.35
767	0.5	0.5	0.25	0.25	0	0.3
768	0.25	0.25	0.25	0.5	1	0.45
769	0.25	0.25	0.25	0.5	0.75	0.4
770	0.25	0.25	0.25	0.5	0.5	0.35
771	0.25	0.25	0.25	0.5	0.25	0.3
772	0.25	0.25	0.25	0.5	0	0.25
773	0.25	0.25	0.5	0.25	1	0.45
774	0.25	0.25	0.5	0.25	0.75	0.4
775	0.25	0.25	0.5	0.25	0.5	0.35
776	0.25	0.25	0.5	0.25	0.25	0.3

777	0.25	0.25	0.5	0.25	0	0.25
778	0.25	0.5	0.25	0.25	1	0.45
779	0.25	0.5	0.25	0.25	0.75	0.4
780	0.25	0.5	0.25	0.25	0.5	0.35
781	0.25	0.5	0.25	0.25	0.25	0.3
782	0.25	0.5	0.25	0.25	0	0.25
783	0.5	0.25	0.25	0.25	1	0.45
784	0.5	0.25	0.25	0.25	0.75	0.4
785	0.5	0.25	0.25	0.25	0.5	0.35
786	0.5	0.25	0.25	0.25	0.25	0.3
787	0.5	0.25	0.25	0.25	0	0.25
788	0	0.25	0.25	0.25	1	0.35
789	0	0.25	0.25	0.25	0.75	0.3
790	0	0.25	0.25	0.25	0.5	0.25
791	0	0.25	0.25	0.25	0.25	0.2
792	0	0.25	0.25	0.25	0	0.15
793	0.25	0	0.25	0.25	1	0.35
794	0.25	0	0.25	0.25	0.75	0.3
795	0.25	0	0.25	0.25	0.5	0.25
796	0.25	0	0.25	0.25	0.25	0.2
797	0.25	0	0.25	0.25	0	0.15
798	0.25	0.25	0	0.25	1	0.35
799	0.25	0.25	0	0.25	0.75	0.3
800	0.25	0.25	0	0.25	0.5	0.25
801	0.25	0.25	0	0.25	0.25	0.2
802	0.25	0.25	0	0.25	0	0.15
803	0.25	0.25	0.25	0	1	0.35
804	0.25	0.25	0.25	0	0.75	0.3
805	0.25	0.25	0.25	0	0.5	0.25
806	0.25	0.25	0.25	0	0.25	0.2
807	0.25	0.25	0.25	0	0	0.15
808	0	0	0.25	0.25	1	0.3
809	0	0	0.25	0.25	0.75	0.25
810	0	0	0.25	0.25	0.5	0.2
811	0	0	0.25	0.25	0.25	0.15
812	0	0	0.25	0.25	0	0.1
813	0	0.25	0	0.25	1	0.3
814	0	0.25	0	0.25	0.75	0.25
815	0	0.25	0	0.25	0.5	0.2
816	0	0.25	0	0.25	0.25	0.15
817	0	0.25	0	0.25	0	0.1
818	0	0.25	0.25	0	1	0.3
819	0	0.25	0.25	0	0.75	0.25
820	0	0.25	0.25	0	0.5	0.2
821	0	0.25	0.25	0	0.25	0.15
822	0	0.25	0.25	0	0	0.1
823	0.25	0	0	0.25	1	0.3
824	0.25	0	0	0.25	0.75	0.25
825	0.25	0	0	0.25	0.5	0.2
826	0.25	0	0	0.25	0.25	0.15
827	0.25	0	0	0.25	0	0.1
828	0.25	0	0.25	0	1	0.3
829	0.25	0	0.25	0	0.75	0.25
830	0.25	0	0.25	0	0.5	0.2
831	0.25	0	0.25	0	0.25	0.15
832	0.25	0	0.25	0	0	0.1

833	0.25	0.25	0	0	1	0.3
834	0.25	0.25	0	0	0.75	0.25
835	0.25	0.25	0	0	0.5	0.2
836	0.25	0.25	0	0	0.25	0.15
837	0.25	0.25	0	0	0	0.1
838	0	0	0	0.25	1	0.25
839	0	0	0	0.25	0.75	0.2
840	0	0	0	0.25	0.5	0.15
841	0	0	0	0.25	0.25	0.1
842	0	0	0	0.25	0	0.05
843	0	0	0.25	0	1	0.25
844	0	0	0.25	0	0.75	0.2
845	0	0	0.25	0	0.5	0.15
846	0	0	0.25	0	0.25	0.1
847	0	0	0.25	0	0	0.05
848	0	0.25	0	0	1	0.25
849	0	0.25	0	0	0.75	0.2
850	0	0.25	0	0	0.5	0.15
851	0	0.25	0	0	0.25	0.1
852	0	0.25	0	0	0	0.05
853	0.25	0	0	0	1	0.25
854	0.25	0	0	0	0.75	0.2
855	0.25	0	0	0	0.5	0.15
856	0.25	0	0	0	0.25	0.1
857	0.25	0	0	0	0	0.05

Appendix 5. The Pairwise Comparisons of the Missions in terms of the Human Error Failure Consequence Probability and Severity Criteria using Fuzzy Set Theory

Table A5.1. The pairwise comparisons of the missions in oil cargo handling in terms of human error failure consequence probability criteria using fuzzy set theory

	Approach & berthing	Connection	Start up	Steady rate	Stripping	Disconnection	Departure
Steady rate	0.5 strongly, 0.5 absolutely	1.0 slightly	1.0 equally	1.0 equally	0.4 equally, 0.4 slightly	0.8 moderately, 0.2 fairly	0.5 strongly, 0.5 absolutely

Table A5.2. The pairwise comparisons of the missions in oil cargo handling in terms of human error severity criteria using fuzzy set theory

	Approach & berthing	Connection	Start up	Steady rate	Stripping	Disconnection	Departure
Steady rate	0.2 fairly, 0.8 strongly	0.8 moderately, 0.2 fairly	0.8 slightly, 0.2 moderately	1.0 equally	0.3 equally, 0.3 slightly	0.5 moderately, 0.5 fairly	0.2 fairly, 0.8 strongly

Appendix 6. The Pairwise Comparisons of the Steps in Each Mission in terms of Human Error Probability of Occurrence Criteria using Fuzzy Set Theory

Table A6.1. The pairwise comparisons of the steps in the approach and berthing mission in terms of human error probability of occurrence criteria using fuzzy set theory

	Berth selection	Approach with escort tugs	Ship positioning	Berth approach	Line handling	Final positioning
Berth approach	0.4 strongly, 0.6 absolutely	0.6 moderately, 0.4 fairly	0.5 slightly, 0.5 moderately	1.0 equally	0.6 fairly, 0.4 strongly	0.3 fairly, 0.7 strongly

Table A6.2. The pairwise comparisons of the steps in the connection mission in terms of human error probability of occurrence criteria using fuzzy set theory

	Pre-transfer conference	Removal of face plates	Examination of o-rings	Loading arms connection	Alignment check
Loading arms connection	0.9 strongly, 0.1 absolutely	0.5 moderately, 0.5 fairly	0.6 slightly, 0.4 moderately	1.0 equally	1.0 equally

Table A6.3. The pairwise comparisons of the steps in the start up mission in terms of human error probability of occurrence criteria using fuzzy set theory

	Valve operations by the receiving parity	Valve operations by the initiating party	Commencement of pumping by the initiating party	All connections checked for leaks	Observation of loading arms	Gradual increase of flow
All connections checked for leaks	0.9 moderately, 0.1 slightly	0.9 moderately, 0.1 slightly	0.6 strongly, 0.4 absolutely	1.0 equally	1.0 slightly	0.4 moderately, 0.6 fairly

Table A6.4. The pairwise comparisons of the steps in the steady rate mission in terms of human error probability of occurrence criteria using fuzzy set theory

	Gradual increase of flow to steady rate	Continuous calculation and periodical verification of the volume of transfer
Continuous calculation and periodical verification of the volume of transfer	0.5 fairly, 0.5 strongly	1.0 equally

Table A6.5. The pairwise comparisons of the steps in the stripping mission in terms of human error probability of occurrence criteria using fuzzy set theory

	Prior warning	Closing valves slowly by the initiating party	Shutting down pump	Closing valves completely by the initiating party
Prior warning	1.0 equally	0.5 slightly, 0.5 moderately	0.3 moderately, 0.7 fairly	0.3 moderately, 0.7 fairly

Table A6.6. The pairwise comparisons of the steps in the disconnection mission in terms of human error probability of occurrence criteria using fuzzy set theory

	Drain of lines	Disconnection of flanges	Disconnection of loading arms from the ship	Examination of o-rings and securing of face plates	Use of a plastic bag covering loading arms
Examination of o-rings and securing of face plates	1.0 slightly	0.1 slightly, 0.9 moderately	0.1 slightly, 0.9 moderately	1.0 equally	0.7 fairly, 0.7 strongly

Table A6.7. The pairwise comparisons of the steps in the departure mission in terms of human error probability of occurrence criteria using fuzzy set theory

	Ship lines let go	Vessel pulled away from the wharf by assisting tugs
Vessel pulled away from the wharf by assisting tugs	0.4 moderately, 0.6 fairly	1.0 equally

Appendix 7. The Pairwise Comparisons of the Steps in Each Mission in terms of the Human Error Failure Consequence Probability Criteria using Fuzzy Set Theory

Table A7.1. The pairwise comparisons of the steps in the approach and berthing mission in terms of human error failure consequence probability criteria using fuzzy set theory

	Berth selection	Approach with escort tugs	Ship positioning	Berth approach	Line handling	Final positioning
Approach with escort tugs	0.2 fairly, 0.8 strongly	1.0 equally	0.1 moderately, 0.9 slightly	0.1 moderately, 0.9 slightly	0.8 moderately, 0.2 fairly	0.2 moderately, 0.8 fairly

Table A7.2. The pairwise comparisons of the steps in the connection mission in terms of human error failure consequence probability criteria using fuzzy set theory

	Pre-transfer conference	Removal of face plates	Examination of o-rings	Loading arms connection	Alignment check
Examination of o-rings	0.2 fairly, 0.8 strongly	0.5 slightly, 0.5 moderately	1.0 equally	0.4 moderately, 0.6 fairly	1.0 slightly

Table A7.3. The pairwise comparisons of the steps in the start up mission in terms of human error failure consequence probability criteria using fuzzy set theory

	Valve operations by the receiving parity	Valve operations by the initiating party	Commencement of pumping by the initiating party	All connections checked for leaks	Observation of loading arms	Gradual increase of flow
All connections checked for leaks	0.9 slightly, 0.1 moderately	0.3 moderately, 0.7 fairly	0.1 fairly, 0.9 strongly	1.0 equally	0.5 slightly, 0.5 moderately	0.5 moderately, 0.5 fairly

Table A7.4. The pairwise comparisons of the steps in the steady rate mission in terms of human error failure consequence probability criteria using fuzzy set theory

	Gradual increase of flow to steady rate	Continuous calculation and periodical verification of the volume of transfer
Continuous calculation and periodical verification of the volume of transfer	1.0 moderately	1.0 equally

Table A7.5. The pairwise comparisons of the steps in the stripping mission in terms of human error failure consequence probability criteria using fuzzy set theory

	Prior warning	Closing valves slowly by the initiating party	Shutting down pump	Closing valves completely by the initiating party
Prior warning	1.0 equally	0.5 slightly, 0.5 moderately	0.7 slightly, 0.3 moderately	0.7 slightly, 0.3 moderately

Table A7.6. The pairwise comparisons of the steps in the disconnection mission in terms of human error failure consequence probability criteria using fuzzy set theory

	Drain of lines	Disconnection of flanges	Disconnection of loading arms from the ship	Examination of o-rings and securing of face plates	Use of a plastic bag covering loading arms
Drain of lines	1.0 equally	0.6 moderately, 0.4 fairly	0.6 moderately, 0.4 fairly	0.1 slightly, 0.9 moderately	0.8 strongly, 0.2 absolutely

Table A7.7. The pairwise comparisons of the steps in the departure mission in terms of human error failure consequence probability criteria using fuzzy set theory

	Ship lines let go	Vessel pulled away from the wharf by assisting tugs
Vessel pulled away from the wharf by assisting tugs	0.4 moderately, 0.6 fairly	1.0 equally

Appendix 8. The Pairwise Comparisons of the Steps in Each Mission in terms of the Human Error Severity Criteria using Fuzzy Set Theory

Table A8.1. The pairwise comparisons of the steps in the approach and berthing mission in terms of human error severity criteria using fuzzy set theory

	Berth selection	Approach with escort tugs	Ship positioning	Berth approach	Line handling	Final positioning
Approach with escort tugs	0.4 strongly, 0.6 absolutely	1.0 equally	0.8 fairly, 0.2 strongly	1.0 moderately	0.8 slightly, 0.2 moderately	0.8 strongly, 0.2 absolutely

Table A8.2. The pairwise comparisons of the steps in the connection mission in terms of human error severity criteria using fuzzy set theory

	Pre-transfer conference	Removal of face plates	Examination of o-rings	Loading arms connection	Alignment check
Loading arms connection	1.0 slightly	0.7 slightly, 0.3 moderately	0.4 moderately, 0.6 fairly	1.0 equally	0.6 moderately, 0.4 fairly

Table A8.3. The pairwise comparisons of the steps in the start up mission in terms of human error severity criteria using fuzzy set theory

	Valve operations by the receiving parity	Valve operations by the initiating party	Commencement of pumping by the initiating party	All connections checked for leaks	Observation of loading arms	Gradual increase of flow
Gradual increase of flow	0.9 slightly, 0.1 moderately	0.3 moderately, 0.7 fairly	0.1 fairly, 0.9 strongly	0.4 slightly, 0.6 moderately	0.5 slightly, 0.5 moderately	1.0 equally

Table A8.4. The pairwise comparisons of the steps in the steady rate mission in terms of human error severity criteria using fuzzy set theory

	Gradual increase of flow to steady rate	Continuous calculation and periodical verification of the volume of transfer
Continuous calculation and periodical verification of the volume of transfer	1.0 moderately	1.0 equally

Table A8.5. The pairwise comparisons of the steps in the stripping mission in terms of human error severity criteria using fuzzy set theory

	Prior warning	Closing valves slowly by the initiating party	Shutting down pump	Closing valves completely by the initiating party
Prior warning	1.0 equally	0.3 equally, 0.3 slightly	0.4 moderately, 0.6 fairly	0.5 fairly, 0.5 strongly

Table A8.6. The pairwise comparisons of the steps in the disconnection mission in terms of human error severity criteria using fuzzy set theory

	Drain of lines	Disconnection of flanges	Disconnection of loading arms from the ship	Examination of o-rings and securing of face plates	Use of a plastic bag covering loading arms
Drain of lines	1.0 equally	0.1 slightly, 0.9 moderately	0.1 slightly, 0.9 moderately	0.6 moderately, 0.4 fairly	0.8 strongly, 0.2 absolutely

Table A8.7. The pairwise comparisons of the steps in the departure mission in terms of human error severity criteria using fuzzy set theory

	Ship lines let go	Vessel pulled away from the wharf by assisting tugs
Vessel pulled away from the wharf by assisting tugs	0.4 moderately, 0.6 fairly	1.0 equally

Appendix 9. The Evaluation of Each RCO based on Each Criterion and the Combined Belief Degrees of All Criteria by Expert 1

Table A9.1. The evaluation of each RCO based on each criterion by Expert 1

		H_1	H_2	H_3	H_4	H_5
RCO 1	e_1	0	0	0.2	0.7	0.1
	e_2	0.2	0.7	0.1	0	0
	e_3	0	0.1	0.6	0.3	0
	e_4	0	0.2	0.8	0	0
	e_5	0	0	0.2	0.3	0.5
RCO 2	e_1	0	0.5	0.5	0	0
	e_2	0	0	0.6	0.2	0.2
	e_3	0.1	0.1	0.8	0	0
	e_4	0	0.6	0.3	0.1	0
	e_5	0.4	0.3	0.3	0	0
RCO 3	e_1	0.1	0.8	0.1	0	0
	e_2	0.2	0.7	0.1	0	0
	e_3	0	0.7	0.2	0.1	0
	e_4	0	0.5	0.4	0.1	0
	e_5	0.5	0.4	0.1	0	0
RCO 4	e_1	0	0	0.3	0.1	0.6
	e_2	0	0	0.7	0.2	0.1
	e_3	0	0.1	0.7	0.2	0
	e_4	0	0	0.3	0.7	0
	e_5	0	0	0.1	0.8	0.1
RCO 5	e_1	0.5	0.5	0	0	0
	e_2	0.1	0.8	0.1	0	0
	e_3	0	0.7	0.3	0	0
	e_4	0	0.6	0.4	0	0
	e_5	0	0.8	0.2	0	0
RCO 6	e_1	0	0.1	0.8	0.1	0
	e_2	0	0.2	0.7	0.1	0
	e_3	0	0.1	0.8	0.1	0
	e_4	0	0.2	0.7	0.1	0
	e_5	0	0.1	0.9	0	0
RCO 7	e_1	0	0	0	0	1.0
	e_2	1.0	0	0	0	0
	e_3	0	0	1.0	0	0
	e_4	0	1.0	0	0	0
	e_5	0	0	1.0	0	0
RCO 8	e_1	0	0.9	0.1	0	0
	e_2	0	0	0.1	0.9	0
	e_3	0	0.8	0.2	0	0
	e_4	0	0	0.2	0.8	0
	e_5	0	0.7	0.3	0	0
RCO 9	e_1	0.9	0.1	0	0	0
	e_2	0.8	0.1	0.1	0	0
	e_3	0.7	0.2	0.1	0	0
	e_4	0.8	0.2	0	0	0
	e_5	0.8	0.1	0.1	0	0
RCO 10	e_1	0	0	0	0.1	0.9
	e_2	0	0	0.1	0.1	0.8
	e_3	0	0	0.1	0.2	0.7

	e_4	0	0	0.1	0.1	0.8
	e_5	0	0	0	0.1	0.9
RCO 11	e_1	0	0.1	0.9	0	0
	e_2	0	0	0.8	0.2	0
	e_3	0	0.1	0.9	0	0
	e_4	0	0	0.8	0.2	0
	e_5	0	0	0.9	0.1	0
RCO 12	e_1	0	0	0.1	0.9	0
	e_2	0	0	0.1	0.7	0.2
	e_3	0	0	0.3	0.7	0
	e_4	0	0	0.1	0.8	0.1
	e_5	0	0	0	1.0	0
RCO 13	e_1	0.1	0.9	0	0	0
	e_2	0.1	0.7	0.2	0	0
	e_3	0.3	0.7	0	0	0
	e_4	0.1	0.8	0.1	0	0
	e_5	0	1.0	0	0	0
RCO 14	e_1	0	0	0	0.5	0.5
	e_2	0	0	0.1	0.4	0.5
	e_3	0	0	0.1	0.5	0.4
	e_4	0	0	0.1	0.3	0.6
	e_5	0	0	0	0.6	0.4
RCO 15	e_1	0	0	0	0.8	0.2
	e_2	0	0.8	0.2	0	0
	e_3	0	0	0	0.7	0.3
	e_4	0	0.7	0.2	0.1	0
	e_5	0	0	0.1	0.7	0.2

Table A9.2. The combined belief degrees of all criteria of each RCO by Expert 1 (%)

	H_1	H_2	H_3	H_4	H_5
RCO 1	7.96	30.56	23.61	31.29	5.36
RCO 2	1.62	24.90	58.31	7.93	7.23
RCO 3	11.94	76.45	10.64	0.97	0
RCO 4	0	0.43	50.89	21.13	27.55
RCO 5	21.42	70.72	7.86	0	0
RCO 6	0	12.03	80.36	7.60	0
RCO 7	42.02	7.30	8.67	0	42.02
RCO 8	0	44.61	11.77	43.62	0
RCO 9	87.72	8.60	3.69	0	0
RCO 10	0	0	4.0	8.0	88.07
RCO 11	0	3.38	89.16	7.46	0
RCO 12	0	0	8.26	84.93	6.81
RCO 13	8.26	84.93	6.81	0	0
RCO 14	0	0	4.48	44.53	50.99
RCO 15	0	38.79	9.81	41.20	10.20

Appendix 10. The Evaluation of Each RCO based on Each Criterion and the Combined Belief Degrees of All Criteria by Experts 2-4

Table A10.1. The evaluation of each RCO based on each criterion by Expert 2

		H_1	H_2	H_3	H_4	H_5
RCO 1	e_1	0	0	0.2	0.8	0
	e_2	0.2	0.8	0	0	0
	e_3	0	0	0.5	0.5	0
	e_4	0	0.4	0.6	0	0
	e_5	0	0	0.1	0.1	0.8
RCO 2	e_1	0	0.4	0.5	0.1	0
	e_2	0	0	0.8	0.1	0.1
	e_3	0.2	0.2	0.6	0	0
	e_4	0	0.5	0.4	0.1	0
	e_5	0.4	0.4	0.2	0	0
RCO 3	e_1	0.2	0.8	0	0	0
	e_2	0.2	0.8	0	0	0
	e_3	0	0.8	0.1	0.1	0
	e_4	0	0.5	0.5	0	0
	e_5	0.3	0.5	0.2	0	0
RCO 4	e_1	0	0	0.1	0.1	0.8
	e_2	0	0	0.9	0.1	0
	e_3	0	0.2	0.7	0.1	0
	e_4	0	0	0.4	0.6	0
	e_5	0	0	0.1	0.7	0.2
RCO 5	e_1	0.5	0.4	0.1	0	0
	e_2	0	0.8	0.2	0	0
	e_3	0.1	0.6	0.3	0	0
	e_4	0	0.6	0.4	0	0
	e_5	0	0.7	0.2	0.1	0
RCO 6	e_1	0	0.1	0.7	0.2	0
	e_2	0	0.2	0.6	0.2	0
	e_3	0	0	0.8	0.2	0
	e_4	0	0.1	0.8	0.1	0
	e_5	0	0.2	0.8	0	0
RCO 7	e_1	0	0	0	0.2	0.8
	e_2	0.9	0.1	0	0	0
	e_3	0	0	1.0	0	0
	e_4	0	0.9	0.1	0	0
	e_5	0	0	0.8	0.2	0
RCO 8	e_1	0	0.8	0.1	0.1	0
	e_2	0	0	0.1	0.8	0.1
	e_3	0	0.7	0.2	0.1	0
	e_4	0	0.1	0.2	0.7	0
	e_5	0	0.6	0.3	0.1	0
RCO 9	e_1	0.8	0.1	0.1	0	0
	e_2	0.9	0.1	0	0	0
	e_3	0.5	0.5	0	0	0
	e_4	0.7	0.3	0	0	0
	e_5	0.7	0.2	0.1	0	0
RCO 10	e_1	0	0	0	0.4	0.6
	e_2	0	0	0.1	0.2	0.7
	e_3	0	0	0.1	0.2	0.7

	e_4	0	0	0.1	0.2	0.7
	e_5	0	0	0	0.2	0.8
RCO 11	e_1	0	0.1	0.8	0.1	0
	e_2	0	0.1	0.8	0.1	0
	e_3	0	0.2	0.8	0	0
	e_4	0	0.1	0.8	0.1	0
	e_5	0	0	0.9	0.1	0
RCO 12	e_1	0	0	0.1	0.8	0.1
	e_2	0	0	0.2	0.6	0.2
	e_3	0	0	0.5	0.5	0
	e_4	0	0	0.1	0.8	0.1
	e_5	0	0	0.1	0.9	0
RCO 13	e_1	0.1	0.8	0.1	0	0
	e_2	0	0.7	0.3	0	0
	e_3	0	0.7	0.3	0	0
	e_4	0	0.7	0.3	0	0
	e_5	0	0.8	0.2	0	0
RCO 14	e_1	0	0	0.1	0.4	0.5
	e_2	0	0	0	0.4	0.6
	e_3	0	0	0.1	0.3	0.6
	e_4	0	0	0.1	0.4	0.5
	e_5	0	0	0	0.8	0.2
RCO 15	e_1	0	0	0	0.7	0.3
	e_2	0	0.7	0.2	0.1	0
	e_3	0	0	0.1	0.7	0.2
	e_4	0	0.8	0.1	0.1	0
	e_5	0	0	0.3	0.6	0.1

Table A10.2. The combined belief degrees of all criteria of each RCO by Expert 2 (%)

	H_1	H_2	H_3	H_4	H_5
RCO 1	8.09	36.62	16.13	36.49	2.66
RCO 2	2.0	20.55	65.99	7.95	3.51
RCO 3	14.62	81.26	3.74	0.38	0
RCO 4	0	0.91	51.47	15.78	31.84
RCO 5	18.07	65.46	16.18	0.29	0
RCO 6	0	11.65	72.61	15.74	0
RCO 7	37.61	11.13	8.69	9.13	33.43
RCO 8	0	39.45	11.55	45.18	3.82
RCO 9	85.61	11.01	3.38	0	0
RCO 10	0	0	4.33	25.04	70.63
RCO 11	0	7.80	84.95	7.26	0
RCO 12	0	0	13.59	75.49	10.92
RCO 13	3.19	79.15	17.66	0	0
RCO 14	0	0	4.47	40.28	55.25
RCO 15	0	34.91	10.13	41.87	13.09

Table A10.3. The evaluation of each RCO based on each criterion by Expert 3

		H_1	H_2	H_3	H_4	H_5
RCO 1	e_1	0	0	0.5	0.5	0
	e_2	0.4	0.6	0	0	0
	e_3	0	0	0.5	0.5	0
	e_4	0	0.5	0.5	0	0
	e_5	0	0	0.1	0.2	0.7

RCO 2	e_1	0	0.3	0.5	0.2	0
	e_2	0	0	0.7	0.2	0.1
	e_3	0	0.4	0.6	0	0
	e_4	0	0.4	0.5	0.1	0
	e_5	0.4	0.4	0.2	0	0
RCO 3	e_1	0.1	0.8	0.1	0	0
	e_2	0.1	0.8	0.1	0	0
	e_3	0	0.6	0.3	0.1	0
	e_4	0	0.6	0.4	0	0
	e_5	0.1	0.7	0.2	0	0
RCO 4	e_1	0	0	0.1	0.1	0.8
	e_2	0	0.1	0.8	0.1	0
	e_3	0	0.2	0.7	0.1	0
	e_4	0	0.1	0.8	0.1	0
	e_5	0	0	0.2	0.7	0.1
RCO 5	e_1	0.3	0.6	0.1	0	0
	e_2	0.1	0.6	0.3	0	0
	e_3	0	0.6	0.4	0	0
	e_4	0.1	0.6	0.3	0	0
	e_5	0	0.5	0.4	0.1	0
RCO 6	e_1	0	0.3	0.5	0.2	0
	e_2	0	0	1.0	0	0
	e_3	0	0	0.8	0.2	0
	e_4	0	0	1.0	0	0
	e_5	0	0.4	0.6	0	0
RCO 7	e_1	0	0	0.1	0.1	0.8
	e_2	0.8	0.1	0.1	0	0
	e_3	0	0	0.6	0.4	0
	e_4	0.8	0.1	0.1	0	0
	e_5	0	0	0.6	0.4	0
RCO 8	e_1	0	0.6	0.3	0.1	0
	e_2	0	0.1	0.2	0.7	0
	e_3	0	0.6	0.3	0.1	0
	e_4	0	0.1	0.2	0.7	0
	e_5	0	0.5	0.4	0.1	0
RCO 9	e_1	0.6	0.3	0.1	0	0
	e_2	0.9	0.1	0	0	0
	e_3	0.4	0.6	0	0	0
	e_4	0.9	0.1	0	0	0
	e_5	0.7	0.2	0.1	0	0
RCO 10	e_1	0	0	0	0.5	0.5
	e_2	0	0	0.1	0.2	0.7
	e_3	0	0	0.1	0.4	0.5
	e_4	0	0	0.1	0.2	0.7
	e_5	0	0	0	0	1.0
RCO 11	e_1	0	0	0.9	0.1	0
	e_2	0	0.1	0.8	0.1	0
	e_3	0	0.5	0.5	0	0
	e_4	0	0.1	0.8	0.1	0
	e_5	0	0.3	0.6	0.1	0
RCO 12	e_1	0	0	0.3	0.6	0.1
	e_2	0	0	0.1	0.7	0.2
	e_3	0	0	0.5	0.5	0
	e_4	0	0	0	0.8	0.2
	e_5	0	0	0	1.0	0
RCO 13	e_1	0	1.0	0	0	0

	e_2	0	0.5	0.5	0	0
	e_3	0	0.7	0.3	0	0
	e_4	0	0.5	0.5	0	0
	e_5	0.2	0.7	0.1	0	0
RCO 14	e_1	0	0	0.2	0.5	0.3
	e_2	0	0	0.1	0.1	0.8
	e_3	0	0	0.1	0.3	0.6
	e_4	0	0	0.1	0.1	0.8
	e_5	0	0	0	0.5	0.5
RCO 15	e_1	0	0	0	0.5	0.5
	e_2	0	0.8	0.1	0.1	0
	e_3	0	0	0	1.0	0
	e_4	0	0.8	0.1	0.1	0
	e_5	0	0	0.3	0.6	0.1

Table A10.4. The combined belief degrees of all criteria of each RCO by Expert 3 (%)

	H_1	H_2	H_3	H_4	H_5
RCO 1	16.09	28.96	28.49	24.14	2.32
RCO 2	1.16	17.08	62.41	15.81	3.53
RCO 3	6.87	81.72	11.04	0.37	0
RCO 4	0	5.51	51.67	11.72	31.11
RCO 5	15.20	64.14	20.38	0.28	0
RCO 6	0	10.90	81.83	7.28	0
RCO 7	40.72	4.78	14.75	7.51	32.25
RCO 8	0	34.84	25.38	39.78	0
RCO 9	78.65	17.84	3.5	0	0
RCO 10	0	0	4.41	29.86	65.73
RCO 11	0	6.50	86.19	7.31	0
RCO 12	0	0	16.41	71.82	11.78
RCO 13	0.54	77.13	22.32	0	0
RCO 14	0	0	12.25	26.97	60.78
RCO 15	0	39.38	5.66	35.05	19.92

Table A10.5. The evaluation of each RCO based on each criterion by Expert 4

		H_1	H_2	H_3	H_4	H_5
RCO 1	e_1	0	0	0.2	0.7	0.1
	e_2	0.3	0.4	0.3	0	0
	e_3	0	0	0.7	0.3	0
	e_4	0.3	0.4	0.3	0	0
	e_5	0	0	0	0.2	0.8
RCO 2	e_1	0	0.3	0.7	0	0
	e_2	0	0	0.7	0.2	0.1
	e_3	0	0.4	0.6	0	0
	e_4	0	0	0.7	0.2	0.1
	e_5	0.3	0.5	0.2	0	0
RCO 3	e_1	0	0.7	0.2	0.1	0
	e_2	0.1	0.8	0.1	0	0
	e_3	0	0	0.5	0.5	0
	e_4	0.1	0.8	0.1	0	0
	e_5	0	0.8	0.2	0	0
RCO 4	e_1	0	0	0.1	0.2	0.7
	e_2	0	0	0.8	0.2	0
	e_3	0	0.1	0.7	0.2	0

	e_4	0	0	0.8	0.2	0
	e_5	0	0	0.5	0.5	0
RCO 5	e_1	0.1	0.6	0.3	0	0
	e_2	0.1	0.5	0.4	0	0
	e_3	0	0.6	0.4	0	0
	e_4	0	0.5	0.5	0	0
	e_5	0	0.7	0.2	0.1	0
RCO 6	e_1	0	0.1	0.8	0.1	0
	e_2	0	0	0.8	0.2	0
	e_3	0	0	0.8	0.2	0
	e_4	0	0	0.8	0.2	0
	e_5	0	0.2	0.6	0.2	0
RCO 7	e_1	0	0	0.1	0.1	0.8
	e_2	0.8	0.1	0.1	0	0
	e_3	0	0	0.5	0.3	0.2
	e_4	0.8	0.1	0.1	0	0
	e_5	0	0	0.6	0.3	0.1
RCO 8	e_1	0	0.3	0.5	0.2	0
	e_2	0	0	0.2	0.8	0
	e_3	0	0.4	0.4	0.2	0
	e_4	0	0.1	0.2	0.7	0
	e_5	0	0.6	0.2	0.2	0
RCO 9	e_1	0.5	0.4	0.1	0	0
	e_2	0.9	0.1	0	0	0
	e_3	0.5	0.5	0	0	0
	e_4	0.9	0.1	0	0	0
	e_5	0.5	0.4	0.1	0	0
RCO 10	e_1	0	0	0	0.3	0.7
	e_2	0	0	0	0.2	0.8
	e_3	0	0	0.1	0.4	0.5
	e_4	0	0	0.1	0.2	0.7
	e_5	0	0	0	0.2	0.8
RCO 11	e_1	0	0.1	0.8	0.1	0
	e_2	0	0.1	0.8	0.1	0
	e_3	0	0.7	0.3	0	0
	e_4	0	0.1	0.8	0.1	0
	e_5	0	0.2	0.7	0.1	0
RCO 12	e_1	0	0	0.2	0.7	0.1
	e_2	0	0	0	0.8	0.2
	e_3	0	0	0.5	0.5	0
	e_4	0	0	0.1	0.7	0.2
	e_5	0	0	0	1.0	0
RCO 13	e_1	0	0.8	0.2	0	0
	e_2	0	0.5	0.5	0	0
	e_3	0	0.5	0.5	0	0
	e_4	0	0.5	0.5	0	0
	e_5	0.2	0.8	0	0	0
RCO 14	e_1	0	0	0.1	0.6	0.3
	e_2	0	0	0.1	0.1	0.8
	e_3	0	0	0	0.3	0.7
	e_4	0	0	0.1	0.1	0.8
	e_5	0	0	0	0.5	0.5
RCO 15	e_1	0	0	0	0.3	0.7
	e_2	0	0.6	0.3	0.1	0
	e_3	0	0	0	1.0	0
	e_4	0	0.6	0.3	0.1	0

	e_5	0	0	0.2	0.5	0.3

Table A10.6. The combined belief degrees of all criteria of each RCO by Expert 4 (%)

	H_1	H_2	H_3	H_4	H_5
RCO 1	14.38	19.35	28.71	30.80	6.75
RCO 2	0.84	13.76	73.30	8.09	4.01
RCO 3	3.92	76.64	14.07	5.37	0
RCO 4	0	0.44	52.41	20.84	26.30
RCO 5	7.06	58.21	34.46	0.28	0
RCO 6	0	3.66	83.77	12.57	0
RCO 7	40.51	4.75	14.12	6.60	34.02
RCO 8	0	16.04	33.38	50.58	0
RCO 9	74.14	22.27	3.59	0	0
RCO 10	0	0	0.94	21.53	77.53
RCO 11	0	10.85	81.65	7.51	0
RCO 12	0	0	9.23	79.35	11.41
RCO 13	0.55	66.58	32.87	0	0
RCO 14	0	0	7.92	30.79	61.30
RCO 15	0	29.64	15.23	25.84	29.30

Appendix 11. The Utility Levels of the Evaluation Grades Expressed by Experts 2-4

Table A11.1. The utility levels of the evaluation grades expressed by Expert 2 using the belief degree method

	0	1	2	3	4	5	6	7	8	9	10
H_1	1.0	0	0	0	0	0	0	0	0	0	0
H_2	0	0.1	0.1	0.6	0.2	0	0	0	0	0	0
H_3	0	0	0	0.1	0.2	0.6	0.1	0	0	0	0
H_4	0	0	0	0	0	0	0.1	0.1	0.6	0.2	0
H_5	0	0	0	0	0	0	0	0	0	0	1.0

Table A11.2. The utility levels of the evaluation grades expressed by Expert 3 using the belief degree method

	0	1	2	3	4	5	6	7	8	9	10
H_1	1.0	0	0	0	0	0	0	0	0	0	0
H_2	0	0	0.1	0.5	0.3	0.1	0	0	0	0	0
H_3	0	0	0	0	0.2	0.8	0	0	0	0	0
H_4	0	0	0	0	0	0	0.1	0.1	0.7	0.1	0
H_5	0	0	0	0	0	0	0	0	0	0	1.0

Table A11.3. The utility levels of the evaluation grades expressed by Expert 4 using the belief degree method

	0	1	2	3	4	5	6	7	8	9	10
H_1	1.0	0	0	0	0	0	0	0	0	0	0
H_2	0	0	0.2	0.7	0.1	0	0	0	0	0	0
H_3	0	0	0	0	0.2	0.7	0.1	0	0	0	0
H_4	0	0	0	0	0	0	0	0.1	0.8	0.1	0
H_5	0	0	0	0	0	0	0	0	0	0	1.0

Appendix 12. Standard Normal Probability Distribution Table for Positive Z Values

Z	0	1	2	3	4	5	6	7	8	9
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.	0.9987	0.9990	0.9993	0.9995	0.9997	0.9998	0.9998	0.9999	0.9999	1.0000

Appendix 13. DPMO-To-Process Sigma Conversion Table

Process	Defects Per Million Opportunities									
Sigma	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	933,200	931,900	930,600	929,200	927,900	926,500	925,100	923,600	922,200	920,700
0.1	919,200	917,700	916,200	914,700	913,100	911,500	909,900	908,200	906,600	904,900
0.2	903,200	901,500	899,700	898,000	896,200	894,400	892,500	890,700	888,800	886,900
0.3	884,900	883,000	881,000	879,000	877,000	874,900	872,900	870,800	868,600	866,500
0.4	864,300	862,100	859,900	857,700	855,400	853,100	850,800	848,500	846,100	843,800
0.5	841,300	838,900	836,500	834,000	831,500	828,900	826,400	823,800	821,200	818,600
0.6	815,900	813,300	810,600	807,800	805,100	802,300	799,500	796,700	793,900	791,000
0.7	788,100	785,200	782,300	779,400	776,400	773,400	770,400	767,300	764,200	761,100
0.8	758,000	754,900	751,700	748,600	745,400	742,200	738,900	735,700	732,400	729,100
0.9	725,700	722,400	719,000	715,700	712,300	708,800	705,400	701,900	698,500	695,000
1.0	691,500	687,900	684,400	680,800	677,200	673,600	670,000	666,400	662,800	659,100
1.1	655,400	651,700	648,000	644,300	640,600	636,800	633,100	629,300	625,500	621,700
1.2	617,900	614,100	610,300	606,400	602,600	598,700	594,800	591,000	587,100	583,200
1.3	579,300	575,300	571,400	567,500	563,600	559,600	555,700	551,700	547,800	543,800
1.4	539,800	535,900	531,900	527,900	523,900	519,900	516,000	512,000	508,000	504,000
1.5	500,000	496,000	492,000	488,000	484,000	480,100	476,100	472,100	468,100	464,100
1.6	460,200	456,200	452,200	448,300	444,300	440,400	436,400	432,500	428,600	424,700
1.7	420,700	416,800	412,900	409,000	405,200	401,300	397,400	393,600	389,700	385,900
1.8	382,100	378,300	374,500	370,700	366,900	363,200	359,400	355,700	352,000	348,300
1.9	344,600	340,900	337,200	333,600	330,000	326,400	322,800	319,200	315,600	312,100
2.0	308,500	305,000	301,500	298,100	294,600	291,200	287,700	284,300	281,000	277,600
2.1	274,300	270,900	267,600	264,300	261,100	257,800	254,600	251,400	248,300	245,100
2.2	242,000	238,900	235,800	232,700	229,600	226,600	223,600	220,600	217,700	214,800
2.3	211,900	209,000	206,100	203,300	200,500	197,700	194,900	192,200	189,400	186,700
2.4	184,100	181,400	178,800	176,200	173,600	171,100	168,500	166,000	163,500	161,100
2.5	158,700	156,200	153,900	151,500	149,200	146,900	144,600	142,300	140,100	137,900
2.6	135,700	133,500	131,400	129,200	127,100	125,100	123,000	121,000	119,000	117,000
2.7	115,100	113,100	111,200	109,300	107,500	105,600	103,800	102,000	100,300	98,530
2.8	96,800	95,100	93,420	91,760	90,120	88,510	86,920	85,340	83,790	82,260
2.9	80,760	79,270	77,800	76,360	74,930	73,530	72,150	70,780	69,440	68,110
3.0	66,810	65,520	64,260	63,010	61,780	60,570	59,380	58,210	57,050	55,920
3.1	54,800	53,700	52,620	51,550	50,500	49,470	48,460	47,460	46,480	45,510
3.2	44,570	43,630	42,720	41,820	40,930	40,060	39,200	38,360	37,540	36,730
3.3	35,930	35,150	34,380	33,620	32,880	32,160	31,440	30,740	30,050	29,380
3.4	28,720	28,070	27,430	26,800	26,190	25,590	25,000	24,420	23,850	23,300
3.5	22,750	22,220	21,690	21,180	20,680	20,180	19,700	19,230	18,760	18,310
3.6	17,860	17,430	17,000	16,590	16,180	15,780	15,390	15,000	14,630	14,260
3.7	13,900	13,550	13,210	12,870	12,550	12,220	11,910	11,600	11,300	11,010
3.8	10,720	10,440	10,170	9,903	9,642	9,387	9,137	8,894	8,656	8,424
3.9	8,198	7,976	7,760	7,549	7,344	7,143	6,947	6,756	6,569	6,387
4.0	6,210	6,037	5,868	5,703	5,543	5,386	5,234	5.085	4,940	4,799
4.1	4,661	4,527	4,397	4,269	4,145	4,025	3,907	3,793	3,681	3,573
4.2	3,467	3,364	3,264	3,167	3,072	2,980	2,890	2,803	2,718	2,635
4.3	2,555	2,477	2,401	2,327	2,256	2,186	2,118	2,052	1,988	1,926
4.4	1,866	1,807	1,750	1,695	1,641	1,589	1,538	1,489	1,441	1,395

4.5	1,350	1,306	1,264	1,223	1,183	1,144	1,107	1,070	1,035	1,001
4.6	968	936	904	874	845	816	789	762	736	711
4.7	687	664	641	619	598	577	557	538	519	501
4.8	483	467	450	434	419	404	390	376	362	350
4.9	337	325	313	302	291	280	270	260	251	242
5.0	233	224	216	208	200	193	185	179	172	165
5.1	159	153	147	142	136	131	126	121	117	112
5.2	108	104	100	96	92	88	85	82	78	75
5.3	72	70	67	64	62	59	57	54	52	50
5.4	48	46	44	42	41	39	37	36	34	33
5.5	32	30	29	28	27	26	25	24	23	22
5.6	21	20	19	18	17	17	16	15	15	14
5.7	13	13	12	12	11	11	10	10	9	9
5.8	9	8	8	7	7	7	7	6	6	6
5.9	5	5	5	5	5	4	4	4	4	4
6.0	3.4	3.2	3.1	3.0	2.8	2.7	2.6	2.4	2	2