

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

**A DECISION-MAKING MODEL PROPOSAL ON HUMAN RELIABILITY
ANALYSIS ON-BOARD SHIPS**

Ph.D. THESIS

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Maritime Transportation Engineering Programme

Anabilim Dalı : Herhangi Mühendislik, Bilim

Programı : Herhangi Program

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Programı : Herhangi Program

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

**GEMİLERDE İNSAN GÜVENİLİRLİĞİ ANALİZİ ÜZERİNE BİR KARAR
VERME MODEL ÖNERİSİ**

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In dedication to my lovely daughter and wife for supporting me all the way,

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ABBREVIATIONS

AHP	: Analytic Hierarchy Process
APOA	: Assessed Proportion of Affect
ATHEANA	: A Technique for Human Error Analysis
BN	: Bayesian Network
CARA	: Controller Action Reliability Assessment
COCOM	: Contextual Control Model
CPC	: Common Performance Condition
CR	: Consistency Ratio
CREAM	: Cognitive Reliability and Error Analysis Method
EFC	: Error-forcing Context
EPC	: Error Producing Conditions
GEP	: Generic Error Probability
GTT	: Generic Task Type
HEART	: Human Error Assessment and Reduction Technique
HFACS	: Human Factor Analysis and Classification System
HEP	: Human Error Probability
HRA	: Human Reliability Analysis
H-RAMS	: Human Reliability Analysis and Monitoring System Proposal in Shipboard Operations
HTA	: Hierarchical Task Analysis
IBC Code	: International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk
ILO	: International Labour Organization
IMDG Code	: International Maritime Dangerous Goods Code
IMO	: International Maritime Organization
MAHRA	: Maritime Human Reliability Analysis
MCDM	: Multi-criteria Decision Making
NARA	: Nuclear Action Reliability Assessment
NPP	: Nuclear Power Plant
PRA	: Probabilistic Risk Assessment
PSA	: Probabilistic Safety Assessments
PSF	: Performance Shaping Factor
PRA	: Probabilistic Risk Assessment
RARA	: Railway action reliability assessment
RI	: Random Index
SLIM	: Success Likelihood Index Methodology
SOLAS	: International Convention for the Safety of Life at Sea
SPAR-H	: Simplified Plant Analysis Risk Human Reliability Assessment
THERP	: Technique for Human Error Rate Prediction

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A DECISION-MAKING MODEL PROPOSAL ON HUMAN RELIABILITY ANALYSIS ON-BOARD SHIPS

SUMMARY

Recently, investigation of the human performance affecting factors has become one of the focal subjects of industrial and academic organizations. There are ongoing extensive studies about it in industries such as nuclear energy, petrochemical industry, health services, medical, defence industry, electronic systems and transportation. Despite the fact that marine incidents that happen and hazards occur on ships mostly on human factor, it is seen that there is not a sufficiently novel study that can meet the needs of maritime industry. In recent years, it is observed that international authorities such as IMO (International Maritime Organization), ILO (International Labour Organization), IACS (Ship Classification Societies e), etc. increased their studies. As statistical studies point out that human error proportion reaches 80% level and the problem becomes obstinate, the subject of human safety analysis on ships is chosen. Because of that this study is parallel to expectation of a solution to this problem of maritime industry decision-makers and their stakeholders.

The purpose of this thesis is to develop an unique human reliability analysis approach on-board ship based on a decision-making model proposal in order to eliminate and minimize the human error during critical shipboard operations. This approach, additionally contributing current human reliability analysis methods in academic literature, will be applicable on vessel fleets such as container, chemical tanker, petrol tanker, LGP tanker, bulk. With the study under this thesis, it is predicted to reach solid targets mentioned below: i) To minimize the error risk by assessing human reliability in shipboard operations, ii) To test proposed approach for critical shipboard operations such as loading or discharging cargo, bunkering, ballast operations, anchoring, shipboard contingency actions, working in enclosed space, maritime pollution prevention, iii) To create available solutions for shipboard operational concept by developing a valid approach to human error assessment, iv) To determine preventive actions (that improves human reliability) against pivotal factors that cause errors in shipboard operations, vi) To contribute to ship safety management system practices.

In human reliability analysis study of correlation among variables especially with incident causalities generic task types (GTT) and error producing conditions (EPC), suitable customization to ship platform, weighting of variables related to decision-making method, consistency in weighting and increasing sensitivity can be mentioned as original aspects of the project. In other words, EPC values will be re-determined by quantifying variables of an existing human reliability analysis method (HEART) with synthesis of human factor analyse and classification system (HFACS) approach. Also, this thesis proposes a smart solution utilising analytic hierarchy

process (AHP) technique to weight the importance of each EPC since they are weighted from 0 to 1. Because term descriptions of variables of existing studies in literature are in general structure and direct weighting is implemented on variables. With this study, via offering solutions to related points, implementation of management of human error analysis and reduction technique will be consistently provided in maritime industry. Specially, even though there are peculiar, developed human reliability analysis methods in aviation and railway as well as nuclear industries, there is no unique method for maritime industry yet. With the method presented by the thesis will both satisfy this requirement and it is expected to be utilized in similar sectors such as ports, shipyards, off-shore platforms, etc. To keep contact with academic and industrial experts to contribute researchers' careers. As a result, proposed thesis with these aspects, will be providing new perspective to human reliability assessment researches and will provide marine-specific HRA in transportation industry.

GEMİLERDE İNSAN GÜVENİRLİLİĞİ ANALİZİ ÜZERİNE BİR KARAR VERME MODELİ ÖNERİSİ

ÖZET

Denizde emniyet son yıllarda önemi artan bir konu olarak öne çıkmaktadır. Artan ticaret hacmi ve gemi filoları denizciliği önemli bir sektör haline getirmesine rağmen emniyet standartları hala yersiz kalabilmektedir. Bu kapsamda denizde emniyet ve çevrenin korunması için uluslararası otoriteler çalışmalarına devam etmektedir. Ayrıca akademik alanda denizde emniyeti geliştirecek ve çevre kirliliğini azaltacak yönde önleyici çalışmalar yapılmaktadır. Bu aşamada insan faktörü en önemli sebep olarak değerlendirilmektedir. Günümüzde gemi operasyonlarında meydana gelen kazalar ve tehlikeli oluşumlarda insan faktörü yüksek oranda ön plana çıkmaktadır. Bu oluşumları indirmek için eğitimler, uygulamalı talimler, sıkı denetimler ve yaptırımlar getirilmiş ancak gemide meydana gelen kazalar ve tehlikeli oluşumlar tam olarak engellenememiştir.

Günümüzde insan performansını etkileyen faktörlerin incelenmesi endüstriyel ve akademik organizasyonların odak konularından biri haline gelmiştir. Hali hazırda başta nükleer enerji olmak üzere sağlık hizmetleri, tıp, savunma sanayi, elektronik sistemler, petrokimya endüstrisi ve taşımacılık alanında konu ile ilgili kapsamlı çalışmalar devam etmektedir. Ancak, denizcilik endüstrisinin ihtiyaçlarına cevap verebilecek nitelikte bir çalışmanın olmadığı görülmektedir. Oysa gemilerde meydana gelen kazalar ve tehlikeli oluşumlarda insan faktörü yüksek oranda ön plana çıkmaktadır. Son yıllarda insan hataları üzerine uluslararası otoritelerin (Uluslararası Denizcilik Örgütü, Uluslararası Çalışma Örgütü, Gemi Klaslama Kurumları, vb.) çalışmalarını artırdığı görülmektedir. Bahsedilen insan hata oranlarının istatistiksel araştırmalarda %80 düzeylerini bulması ve problemin kronik bir hal alması nedeni ile gemilerde insan güvenirliliği analizi konusu seçilmiştir. Dolayısıyla bu çalışma denizcilik endüstrisi karar mercilerinin ve paydaşlarının bu konudaki çözüm beklentileri ile paralellik arz etmektedir.

Bu tezin amacı, gemi platformunda insa hatalarından doğabilecek operasyonel problemleri en aza indirmek için özgün bir insan güvenirliliği analiz ve takip sistemini geliştirilmiştir. Akademik literatürde mevcut insan güvenirliliği analizi yöntemlerine de katkı yaparak geliştirilecek bu sistem konteyner, kimyasal tanker, petrol tankeri, sıvılaştırılmış gaz tankeri, dökme yük gibi gemilerde uygulanabilir olması sağlanmıştır. Tez kapsamında yürütülen çalışma ile aşağıda sıralanan somut hedeflere ulaşılması öngörülmüştür: i) Gemi operasyonlarında insan güvenirliliğini ölçerek hata riskini en aza indirmek, ii) Önerilen yaklaşımı yükleme veya tahliye, yakıt alımı, balast işlemleri, demirleme, gemi acil durum eylemleri, kapalı mahalde çalışma, deniz kirliliği önleme gibi kritik gemi operasyonları için test etmek, iii)

İnsan hatası ölçümü için geçerli bir yaklaşım geliştirerek gemi operasyonel konseptine uygun çözümler üretmek, iv) Gemi operasyonlarında hataya neden olan odak faktörlere yönelik önleyici (insan güvenirliliği iyileştirici) faaliyetleri belirlemek, vi) Gemi emniyet yönetim sistemi uygulamalarına katkı sağlamak.

Bu tezin araştırma planı, operasyonel seviyedeki değişkenlerin analizi ile gemi platformunda insan hataları en aza indirgenerek, emniyet unsuru geliştirilebilir kuramsal yaklaşımı üzerine kurulmuştur. Bu tezde izlenecek yöntemin ana hatları kavramsal araştırma, yöntem geliştirme ve uygulama aşamaları üzerine tasarlanmıştır. İnsan güvenirliliği analizinde özellikle kaza nedensellikleri ile genel görev türleri (GGT) ve hata üreten koşullar (HÜK) gibi değişkenler arası korelasyonun araştırılması, gemi platformuna uygun olarak özelleştirilmesi, karar verme yöntemi ile ilgili değişkenlerin ağırlıklandırılması, ağırlıklandırmada tutarlılık ve hassasiyetin artırılması projenin özgün yönleri olarak ifade edilebilir. Bu kapsamda analitik hiyerarşi süreci yöntemi kullanılarak hata üreten koşulların göreceli ağırlıklandırılması sağlanmıştır. Ayrıca, literatürdeki mevcut bir insan güvenirliliği analiz modelinin değişkenleri, denizcilik endüstrisi kaza verilerinin sentezi ile sayısallaştırarak ilgili hata üreten koşullar değerleri yeniden belirlenmiştir. Çünkü literatürdeki mevcut çalışmalarda değişkenlerin koşul tanımları genel yapıdadır ve değişkenler üzerine doğrudan ağırlıklandırma yapılmaktadır. Bu tez kapsamında denizcilik için özgün hale getirilecek hata üreten koşullar (HÜK) yeniden hesaplanırken doğruluğunu ölçmek için farklı gemi tiplerinden farklı kaza örnekleri incelenmiştir. Bu incelemeler neticesinde elde edilen deniz kaza sebepleri tek tek ilgili sınıflara dağıtılmıştır. Bu dağılım neticesinde her bir kaza nedeni ilişkili olduğu HÜK' ler üzerine önem derecesine göre pay edilmiştir. Bu kapsamda sıralı ağırlıklandırma yöntemi kullanılmıştır. Farklı filo guruplarından (ham petrol tankeri, kimyasal tanker, konteyner, dökme yük ve general kargo gemi filoları) alınan uzman görüşleri neticesi ile sıralı ağırlıklandırma yapılarak HÜK değerleri bulunmuştur. Sonraki aşamada normalize edilen değerler ilk değerler ile bağımsız T testi ile karşılaştırılmış ve doğrulanmıştır.

Denizcilik için hesaplanan HÜK değerleri uygulama kısmında kullanılmış ve sonuçları değerlendirilmiştir. Bu kapsamda kimyasal tanker gemisinde propylen oksit yükü tahliyesi analiz edilmiştir. Uygulama gerçek gemi ortamında yapılmış ve gemi kaptanının değerlendirmesi ile operasyon sırasında insan güvenirlilik analizi yapılmıştır. Sonuçlar çerçevesinde insan güvenirliliği aralığı tespit edilmiş ve bu aralığı aşan değerler için önleyici faaliyet planı geliştirilmiştir.

Bu çalışma ile literatüre ilgili hususlarda çözümler önererek, insan hata değerlendirme ve indirgeme yönteminin denizcilik alanında tutarlı bir şekilde uygulanması sağlanmıştır. Özellikle havacılık, demiryolu ya da nükleer enerji sektöründe kendine has geliştirilmiş insan güvenirliliği analiz yöntemleri olmasına karşın denizcilik alanına özgün bir yöntem henüz yoktur. Bu tez ile ortaya konulacak yöntem (MAHRA) ilgili açığı gidermekle birlikte; liman, tersane, açık deniz platformları, petrol çıkarma kuyuları, yüzer-üretim-depolama-yükleme üniteleri gibi benzer alanlarda kullanılması öngörülmektedir. Tez kapsamında yürütülen çalışma ile sıralanan somut hedeflere ulaşılması ve ilgili ölçme ve karşılaştırmalar ile değerlendirilmesi öngörülmüştür. Bu hedefler; i) Gemi operasyonlarında insan güvenirliliğini ölçülmüş ve hata riski en aza indirgenmeye çalışılmıştır, ii) Önerilen MAHRA yaklaşımı ile kritik gemi operasyonları için uygulama fırsatı

oluşturulmuştur, iii) İnsan hatası ölçümü için geçerli bir yaklaşım geliştirerek gemi operasyonel konseptine uygun çözümler üretilmiştir, iv) Gemi operasyonlarında hataya neden olan odak faktörlere yönelik önleyici (insan güvenirliliği iyileştirici) faaliyetleri belirlenmiştir, v) Gemi emniyet yönetim sistemi uygulamalarına katkı sağlanmıştır.

Sonuç olarak, yukarıda belirtilen önlemleri ile önerilen çalışma, insan güvenilirlik değerlendirmesi araştırmalarına çeşitli yönlerden yeni bakış açıları getirirken, denizcilik alanında odak bir konuya çözüm üretecektir. Gemilerde insan hata olasılıklarını istenilen düzeylere indirgediğimiz takdirde, uygunsuzların, tehlikeli oluşumların hatta kazaların büyük ölçüde önlenebileceği görülmektedir. Bu yönü ile düşünüldüğünde, önerilen yöntem ile geliştirilecek olan insan güvenirliliği analiz yöntemi, uluslararası denizcilik örgütü ve ilgili denizcilik otoritelerinin stratejik hedef olarak ortaya koyduğu, sürdürülebilir deniz taşımacılığı konseptinin, gereklerini somut olarak destekleyecek bir adım olarak görülebilir. Yürütülen tezin ilk etapta ulusal düzeyde desteklenerek, disiplinlerarası yukarıda sıralanan ilkeler doğrultusunda çalışmanın sürdürmesi ile birlikte kısa vadede olgunlaştırılan denizcilikte insan güvenirliliğinin bilgi tabanlı ölçümü ve hassasiyet düzeyi kavramları, orta ve uzun vadede denizcilik otoritelerine yeni bir emniyet konsepti (gemi personeli güvenilirlik indeksi gibi) olarak sunulması ile ülkemizi uluslararası düzeyde denizcilik bilgi ve teknolojileri konularında çözüm öneren noktaya taşıyacaktır. Bu kapsamda tezin ortaya koyduğu teorik çalışmanın gemi platformunda insan güvenirliliğinin sürekli izlemesi için önerilen yaklaşımı kullanıcı arayüzü yazılımı ile desteklemesi çalışmanın sonraki etapları olarak planlanmaktadır.

1. INTRODUCTION

Safety is very essential subject in maritime transportation. It directly affects human life, environment and commodity. Maritime safety requires a set of rules and activities on-board ships and most of them should have controlled by shore based organisation or maritime authorities. Although maritime authorities have adopted numerous regulations and codes, safety has not raised to the desired level.

Maritime industry is composed of numerous elements such as ships, crew, ownerships, management and administration authorities, classification and insurance society, maritime authorities, etc. which have a different effect on the overall performance. One of the most important elements of those is ship crew since various technical or maintenance operations on-board ship have been performed by human. Moreover, non-automated system shall require direct human inputs for shipboard operation or maintenance. It appears that human behaviour is often a root or significant contributing cause of system failure. Therefore, human reliability plays a crucial role since the statistics show that about eighty percent of marine accident had occurred due to human errors (Fotland, 2004).

Humans represent the largest contribution to system failure with an estimated percentage of more than 80% (Kirwan,1987). Nowadays, investigation of the human performance affecting factors has become one of the focal subjects of industrial and academic organizations. There are ongoing extensive studies about it in industries such as nuclear energy, health services, medical, defence industry, electronic systems and transportation. Despite the fact that accidents that happen and dangers occur on ships mostly on human factor (Wang, 2007), it is seen that there is not a sufficiently good practice that can meet the needs of maritime industry. In recent years, it is observed that international authorities (International Maritime Organization (IMO), International Labour Organization (ILO), Ship Classification Societies etc.) increased their studies. As statistical studies point out that mentioned human error proportion reaches 80% level and the problem becomes obstinate, the subject of human safety analysis on ships is chosen (Fotland, 2004). Because of that, this study

is parallel to expectation of a solution to this problem of maritime industry decision-makers and their stakeholders.

Maritime safety is very substantial topic because it covers an advance system of players. The consequences might affect those players (crew, environment and ships) drastically if the system is broken. Therefore, there is strong tendency for maritime safety analysis and seeking an advance creative solution for enhancement of safety, protection of the environment and loss of human life. In a broad sense, there are limited numbers of studies performed upon maritime safety analysis. For example, a quantitative risk assessment is conducted upon deficiency databases gathered from ship inspection (Heij et al., 2011). Furthermore, another study performed by Mullai and Paulsson (2011) was introduced as a new approach namely grounded theory model. This research mainly based on maritime accident statistics. A review of the formal safety analysis method is performed to review and criticize deficiency of IMO status (Psaraftis, 2012). Hence, strengths and weaknesses of them were revealed. Similarly, a new approach was proposed by Karahalios et al. (2011) to enable of assessment the implementation performance of international maritime regulation. Moreover, Yang et al., (2013) criticised the challenges of maritime safety analysis and the different approaches used to quantify the risks in maritime transportation industry. Furthermore, Akyuz and Celik (2014a) have conducted a study utilising hybrid decision-making approach in order to measure effectiveness of safety management system (SMS) implementations in the recent time. The main purpose of this research is to measure effectiveness of SMS and enhance its implementation on-board ship.

Since safety is one of the most significant topics in maritime industry, statistics show that human/crew factor is the major contributory factor of marine accidents (Mazzuchi et al., 1998). Therefore, human reliability plays crucial role to minimize marine accident that may results injury or loss of life, environment pollution and cargo damages. Within this context, this thesis aim is to analyse human reliability during shipboard operation. A smart technique for the quantification of human error in maritime industry will be developed. In order to achieve that, the thesis organized as follows. This section provides introduction concerning maritime safety and human reliability analysis (HRA) also highlight of the research aims, impacts and contribution to marine industry. The next section deals with literature review upon

HRA and its application on maritime industry as well as research alternative HRA techniques. The third section proposes a decision-making model for human reliability analysis on-board ship. Section four demonstrates the model with shipboard operations. The final section gives conclusion, discussion and contribution of the proposed model into marine industry.

1.1 Purpose of Thesis

In the light of above, the aim of this research is to analyse human reliability on-board ship based on a decision-making model proposal in order to eliminate and minimize the human error during shipboard operations and particularly to reduce the occurrence of human error incidence that may arise out due to human (crew) errors. Moreover, human reliability factor during shipboard operations will be widely discussed and analysed comprehensively in this thesis. A new perspective in marine industry will be introduced by minimising human error factor and enhancement of human reliability simultaneously. Thus, the proposed model is expected to contribute significantly for compensating shortfalls of human reliability enhancement in maritime industry.

This thesis, additionally contributing current HRA methods in academic literature, will be tested on vessel fleets such as container, chemical tanker, petrol tanker, bulk carrier and their operational feasibility and validity will be verified. Within this context, the research is predicted to reach solid targets mentioned below:

- i) Minimize the error risk by assessing human reliability in shipboard operations,
- ii) Test proposed approach for critical shipboard operations such as loading or discharging cargo, bunkering, ballast operations, anchoring, shipboard contingency actions, working in enclosed space, maritime pollution prevention,
- iii) Create available solutions for shipboard operational concept by developing a valid approach to human error assessment,
- iv) Support proposed approach to constant observation of human reliability on-board ship
- v) Determine preventive actions (that improves human reliability) against pivotal factors that cause errors in shipboard operations,
- vi) Contribute to ship safety management system practices.

1.2 Impact of Thesis

HRA is very substantial topic due to the contributions of humans to the systems flexibility and to possible adverse consequences of human errors or oversights when the human reliability is important part of the large systems. It describes how reliable the operator is to conduct the task successfully or how long the operator will perform task without committing error (Yip et al., 1984). This study is expected to give original contributions to the ship management companies, ship operators, safety engineers and maritime researchers during the analysing of human reliability on-board ship operations. Moreover, the proposed model remedies the gap between system reliability and maritime transportation industry in terms of adopting operational data in safety and reliability analysis. The following subjects of the thesis can be highlighted as a contribution;

- The proposed approach can utilize both qualitative and quantitative data in maritime safety and human reliability analysis.
- A novel HRA technique based on decision-making model will be developed to improve safety for maritime applications.
- It would be substantial advantage for literature in establishing a marine transportation-specific methodology to evaluate human reliability.
- The research provides unique parameter for marine industry to improve HRA calculation sensitivity.
- This research contributes evaluation human of reliability on-board ship.
- The model-based approach can assist ship management companies, safety engineers and reliability researchers to give their full attention on the most critical human error factor.

2. LITERATURE REVIEW

Human factor is very essential issue for safety. Especially, human reliability assessment has always been a critical issue for risk researchers, safety experts and engineers. The reasons of that human reliability assessment method are subjective and the data concerning human factor is impreciseness. Human reliability can be defined as human performance, which shows how reliable the person/operator can perform the action correctly or how long the person/operator can perform without failure (Pyy, 2000).

HRA is quite new disciplinary research which was introduced in three stages. The first stage is covering the date between 1970 -1990 where it is known as the first generation of human reliability methods. The second stage is between 1990 - 2005 years where it is introduced as the second generation. Since 2005, the third generation of human reliability methods have been introduced.

The first probabilistic HRA was performed after Second World War for weapon system feasibility (Swain, 1990). Thereafter, the method has applied in numerous disciplines such as nuclear power plant (Zubair and Zhijian, 2013; Chang et al., 2013; Groth and Mosleh, 2012; O'Hara et al., 2008; Kim and Jung, 2003), engine systems (Chang et al., 2010; Chang et al., 2004; Hong and Pai, 2006; Liang and Tong, 2001), electronic systems (Liang and Wang, 1993; Soi and Aggarwal, 1980), weapon and defence system (Hausken, 2008; Gary et al., 1988; Swain, 1990), manufacturing (Bertolini et al., 2010; Jones et al., 2010; Ke and Shen, 1999), transportation (Calhoun et al., 2014; Guo et al., 2012; Kirwan et al., 2008; Baysari, 2011; Vanderhaegen, 2001), software system (Podofillini and Dang, 2013; EI-Sebakhy, 2008; Costa et al., 2005), etc.

Numerous HRA techniques have been developed to determine human reliability. Totally, 31 potential HRA related methodology have been proposed so far. Table 2.1 provides potential HRA methods used in practice. However, among the mentioned

methods, THERP, SLIM, ATHEANA, CREAM, HEART, SPAR-H, NARA, CARA, RARA and Bayesian Network have been commonly used in literature.

Table 2.1 : HRA methods used in practice.

Abbreviated name	Methodology	Developed by
ASEP	Accident sequence evaluation programme	Swain, 1987
AIPA	Accident initiation and progression analysis	Raabe, 1976
APJ	Absolute probability judgement	Dalkey and Helmer, 1963
ATHEANA	A Technique for human error analysis	Cooper et al., 1996
BN	Bayesian network	Almond, 1992
CAHR	Connectionism assessment of human reliability	Sträter, 2000
CARA	Controller action reliability assessment	Kirwan and Gibson, 2008
CES	Cognitive environmental simulation	Woods and Roth, 1987
CESA	Commission errors search and assessment	Reer and Dang, 2007
COCOM	Contextual control model	Hollnagel, 1993
COGENT	Cognitive event tree	Swain and Gutterman, 1983
COSIMO	Cognitive simulation model	Cacciabue et al., 1992
CREAM	Cognitive reliability and error analysis method	Hollnagel, 1998
DREAMS	Dynamic reliability technique for error assessment in man-machine system	Cacciabue et al., 1993
FACE	Framework for analysing commission errors	Pyy, 2000
HCR	Human cognitive reliability	Hannaman et al., 1984
HEART	Human error assessment and reduction technique	Williams, 1992
HRMS	Human reliability management system	Reason, 2000
MAPPS	Maintenance personnel performance simulation	Knee et al., 1984
MERMOS	Méthode d’Evaluation de la réalisation des missions opérateur pour la sûreté	Bieder et al., 1998
NARA	Nuclear action reliability assessment	Kirwan et al., 2004
OATS	Operator action tree system	Wreathall et al., 1982
OHPR	Operational human performance reliability analysis	
PC	Pair comparisons method	Hunns, 1982
RARA	Railway action reliability assessment	Gibson et al., 2013
SHARP	Systematic human action reliability procedure	Nus Coporation, 1984
SLIM	Success likelihood index methodology	Embrey et al., 1984
SPAR-H	Simplified plant analysis risk human reliability assessment	Gertman et al., 2005
STahr	Socio-Technical assessment of human reliability	Phillips et al., 1985
TESEO	Empirical technique for estimating operator errors	Bello and Colombari, 1980
THERP	Technique for human error rate prediction	Swain and Gutterman, 1983

In a broad sense, HRA models take into account as many factors as the designers of the method thought desirable. The methods have following certain limitations.

- The knowledge of designer and experience of the system,
- Preciseness and comprehensiveness degree is needed,
- Structure and organization should be examined,

In this context, numerous of HRA techniques for estimating HEP value have been proposed in recent years. Some of these techniques conducted into practice while some are only theoretical. The one of this method developed for the HRA is the technique for human error rate prediction (THERP). This technique is considered as the first generation method that is still valid. The aim of the model is to assess human reliability by dealing with task analysis, failure definition and quantification of HEP values. It is developed for nuclear power plant in order to conduct probabilistic risk assessment (PRA) but might be applied in any other disciplines such as off-shore where human error risk involvement is comparatively high. Since the method has some advantages such as well used in practice or powerful HRA technique, there are some limitation in practice. It does not reflect impact of performance shaping factors (PSFs) on performance as well as time consuming and intensive for user.

Furthermore, success likelihood index methodology (SLIM) was proposed by Embrey et al. (1984) in order to assess failure in task or action sequences. The method has been applied for maintenance or operational cases and mainly based on expert's judgement to assess human performance. The method is a decision-analytic approach to HRA which uses expert judgement to quantify PSFs, concerning the individuals, environment or task. There are some restrictions of the method. Lacking of the quantitative element and relying on mainly expert judgement are the notable limitations.

Another HRA method is a technique for human error analysis (ATHEANA) which has been developed in recent years by the US Nuclear Regulatory Commission. The ATHEANA is considered as the second generation technique and provides a detailed search process for identifying human actions. It enables user to find EFC by utilising and combining experiences and knowledge in safety engineering, PRA and human factors. The method utilises a quantification technique for HFS probability relied on predict of how likely or typically the system conditions and PSF comparing the EPC occur. Even though the method can be applied in various disciplines, there have been some limitations. First of all it is impracticable and not cost-effective for users.

The guidance is very complicated and mainly depends on expert judgements. Moreover, the quantification method is weak as well as the quantitative results are invalidated. Also, the method does not produce HEP since it is one of the most significant outcomes of PRA.

The other HRA technique commonly used in literature is cognitive reliability and error analysis method (CREAM) which is considered as second generation technique Hollnagel (1998). There are two versions of the CREAM method; the basic and the extended. The basic method provides an overall evaluation of the performance reliability that might be expected for tasks while the extended version uses the results of the basic version to check or investigate actions of task more deeply. The method utilised CPC which determine the human error probability control mode. The CREAM technique has been derived from Contextual Control Model (COCOM). The aim of the COCOM was to provide conceptual and practical basis in order to enhance operator performance (Hollnagel, 1993). Therefore, control modes in four different characteristics are defined in accordance with the human cognition and action content. Some of restrictions with technique have been found such as the data needed to complete the analysis. Additionally, more development is required and could be linked to cognitive task analysis approach (Kirwan, 1998). The method has been mainly applied in NPP, however CPCs are considered as generic. Therefore, it is suitable to use in any other disciplines where human factor is crucial. There are a couple of studies performed upon marine industry by utilising CREAM. The method seems powerful tool for HRA and is still valid.

Williams (1988) originates another technique named as human error assessment and reduction technique (HEART) which is one of the few HRA methods that have been empirically validated. The practitioners utilise HEART in order to quantify error probability occurring throughout the completion of a particular task by applying weighting factors. The method is furtherly developed and applied in numerous disciplines. The method basically comprises GTT and EPC in order to assign nominal HEP values. Generic values for HEP values depend on generic tasks which can be adopted in most cases. HEART has been extensively used in NPP but it is cross toll that is applicable to any discipline where human reliability has potential importance. The method has been successfully modified and applied in various industries including chemical, nuclear plants, aviation, rail and medical. The method

is very easy tool to understand and apply in real human reliability problems. However, the system parameters should be modified for application in other industries such as maritime.

Standardized plant analysis risk - Human reliability (SPAR-H) method was introduced by US Nuclear Regulatory Commission (NRC) in 1994 to model the human reliability performance in NPP. This method was modified in 1999 after experience gathered in field testing (Gertman et al.,2005). The aim of this methodology is to identify HEP values based on human performance influences. The PSFs (mainly based on eight PSFs) are utilised by experts in order to define the human factor influence. The method is user-friendly and easy to apply. Yet, it is applicable only for NPP and oil&gas industry cases. The SPAR-H model has some disadvantages such as not taking in consideration the PSFs direct effect upon cases. The results are widely based on experts' opinion and provide accurate results up to experts' knowledge.

Another HRA method was proposed to monitor human reliability performance by offering PSA. The method is known as Nuclear Action Reliability Assessment (NARA), which is based on a data mining in UK NPP. This technique aims to develop a smart tool to quantify the reliability of human interactions in NPP. The method is derived from HEART since it is not always fit for NPP task being assessed. Therefore, Kirwan et al. (2004) was introduced NARA as a new tool based on more recent and relevant data. NARA have some advantages rather than HEART including a smooth understanding of core data are used to derive the GTT and EPC parameters. On the other hand, parameters used in NARA have merely specify for NPP industries.

Kirwan and Gibson (2008) recognized a similar approach CARA (Controller Action Reliability Assessment) as a new human reliability assessment tool. The objective of the method is to analyse human error probability relevant to ATC. This method, likewise NARA, is based on tailoring the basic principle of HEART. Unique GTT and EPC parameters were defined in accordance with aviation industry. Then, HEART methodology uses a simple calculation to integrate both parameters to get final HEP. The proposed method is widely used for aviation industry since it has specific parameters.

Railway Action reliability Assessment (RARA) has recently been proposed for a specific approach to human error quantification (Gibson et al., 2012). It is developed to encourage the consideration of human reliability performance in railway industry. The aim of the method is to improve consideration of human reliability factor and provide an easy tool for human error quantification in railway industry. The method has been derived from HEART methodology by using information and structural framework. The RARA uses the calculation methodology of HEART. The method specifies parameters for the railway industry.

Bayesian network (Almond, 1992) method has been proposed in recent years as a last generation of the HRA (Jensen and Nielsen, 2007). BN method can provide qualitatively model the causal relationships between organisational factors and human reliability as well as quantitatively measure human operational reliability, identifying the most likely root causes or prioritisation of root causes of human error. It provides nodes between the variables where dependency existing among them. The method based on a compact representation of a multivariate distribution function and applied in various disciplines. There are some limitation for the method such as difficulties in obtaining conditional probabilities in data bank and mainly based on expert judgements. However, the methodology has been widely applied in literature.

2.1 Literature Review of HRA on Marine Transportation

After having research application of HRA marine transportation, the results shows up that research are quite limited. There have been totally 34 researches existing in literature in respect of HRA application since 1995 years. Furthermore, 20 of those are fully research paper published in journals, 9 of them are conference proceeding papers and rest of them are books/brochures. Figure 2.1 shows graphical distribution of researches upon HRA on marine transportation in accordance with the recent years. Apparently, studies upon human reliability analysis have been increasing since 1995. Especially, the topic has clearly gained more importance in recent years since human error factor and recovery are key attributes of a reliability assessment approach.

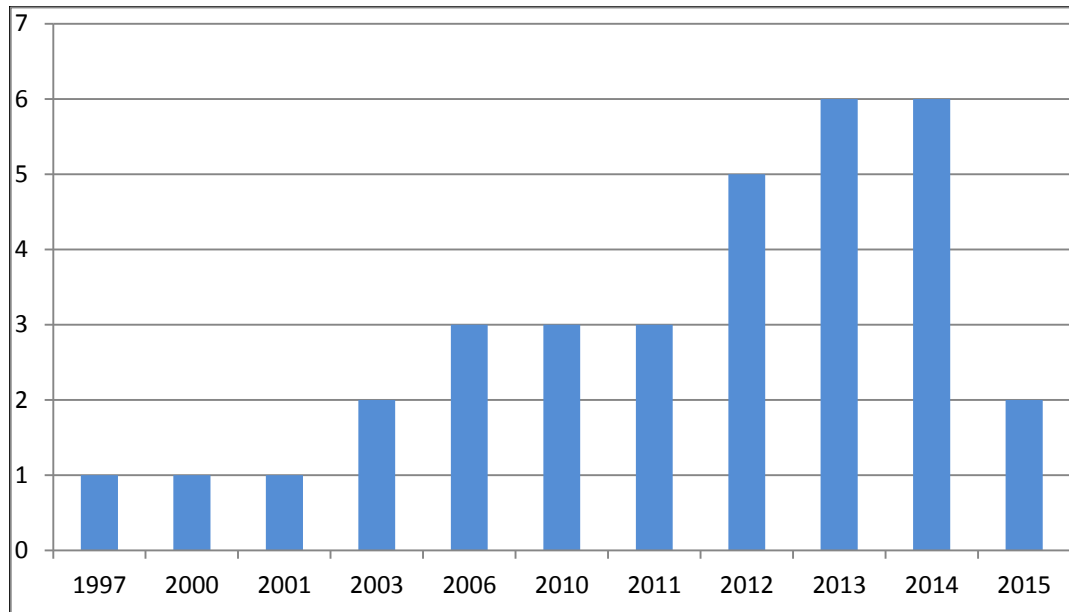


Figure 2.1 : Researches upon HRA on marine transportation in recent years.

Meantime, Reliability Engineering & System Safety and Safety Science journals appear the prominent publisher with totally 11 research papers. These articles analysing human reliability and applies alternative HRA methods focusing various emergency conditions such as collision, grounding, etc. Figure 2.2 provides graph for distribution of articles published in journals since 1995 years.

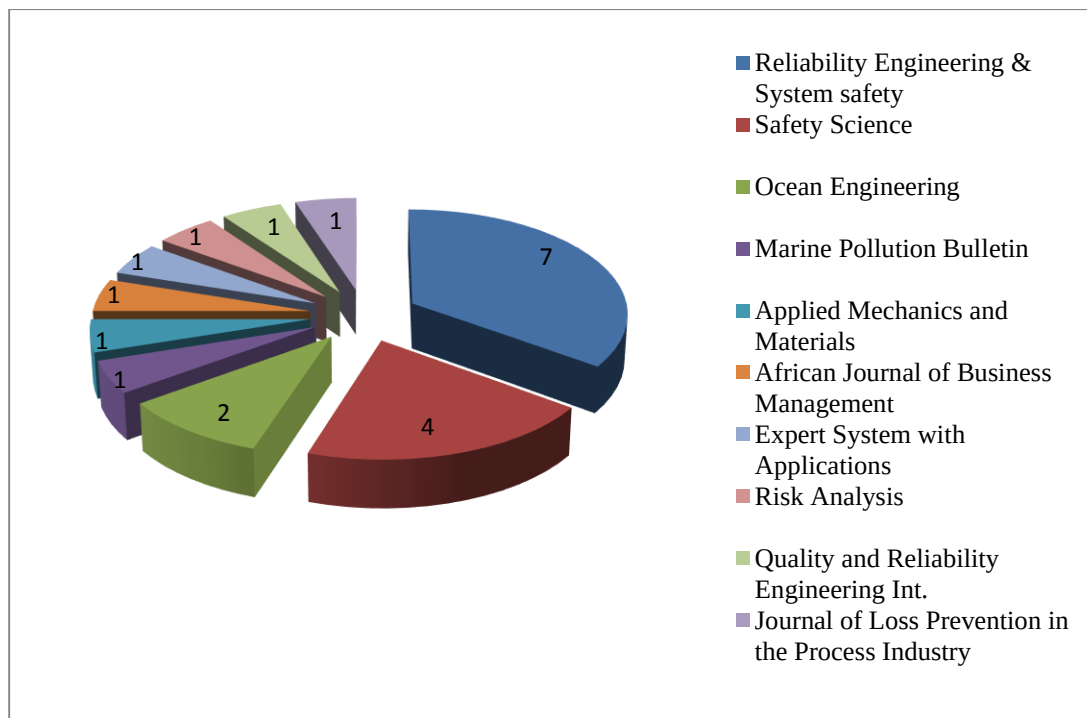


Figure 2.2 : Distribution of articles published in journals in recent years.

The HRA researches conducted upon marine industry have numerous topics. Most of them are utilised existing HRA methodology into various applications. The aim of the researches mainly focused on to minimise or prevent human error while critical marine operations/processes in advance. Figure 2.3 illustrates the research topics applied in journals and proceedings related to marine industry since 1995 years. In this context, collision of ships is one of the vital issues for HRA since human factor plays a crucial role. The second major topic related to HRA is maritime transportation system including container shipment on-board ship.

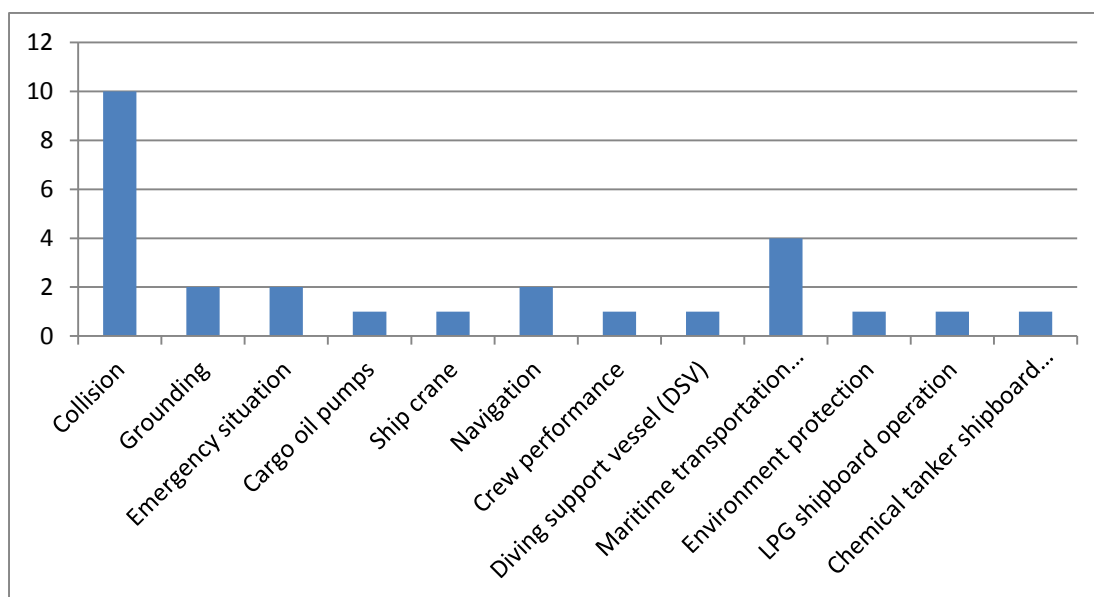


Figure 2.3 : Research topic related to marine transportation industry.

In the light of above, Table 2.2 shows the elaborative list including journal and conference papers gathered from literature research for HRA in marine transportation industry. Amrozowicz et al. (1997) proposed a probabilistic risk analysis method to identify tanker ships accident risks. The paper utilised fault trees and event trees and integrated them with THERP in order to quantify individual errors. The main goal of this research is to perceive the nature of the failures that may result vessel grounding. Thus, the paper demonstrated the proposed approach with tanker grounding.

Table 2.2 : Elaborative list for HRA in marine transportation industry.

Author	Methodology	Topic	Publisher (Journal or Conference paper)
Akyuz and Celik, 2015a	HEART-AHP	Shipboard operation	Safety Science
Akyuz and Celik, 2015b	CREAM	LPG cargo operation	Journal of Loss Prevention in the Proc. Ind.
Akyuz and Celik, 2015	HFACS-HEART-AHP	Shipboard operation	Conference
Goerlandt and Montewka, 2014	Bayesian network	Collision	Marine Pollution Bulletin
Montewka et al., 2014	Bayesian belief network	Collision	Reliability Engineering and System Safety
Goerlandt and Kujala, 2014	Quantitative risk analysis	Collision	Safety Science
Akthar and Utne, 2014	Bayesian network	Grounding	Safety Science
Gaonkar et al., 2013	Fuzzy set	Maritime transportation system	Ocean Engineering
Musharraf et al., 2013	Bayesian network and SLIM	Emergency situation	Safety Science
Martins and Maturana, 2013	Bayesian belief network	Collision	Reliability Engineering and System Safety
Yang et al., 2013	CREAM	Cargo oil pump	Ocean Engineering
Gao et al., 2013	Possibilistic theory	Ship crane	Conference
El-laden and Turan, 2012	Human entropy boundary conditions	Emergency situation	Reliability Engineering and System Safety
Yang and Wang, 2012	CREAM	Maritime transportation system	Conference
Sulaiman et al., 2012	-	Navigation	African Journal of Business Management
Riahi et al., 2012	Fuzzy logic and AHP	Crew performance	Conference
Xi and Guo, 2011	APJE-SLIM	Collision	Applied Mechanics and Materials
Turan et al., 2011	Fault tree analysis	Diving support vessel	Quality and Reliability Engineering Int.
Gaonkar et al., 2011	Fuzzy set	Maritime transportation system	Expert System with Application
Martins and Maturana, 2010	Formal safety assessment	Collision	Risk Analysis
Montewka et al., 2010	Monte Carlo method	Collision	Reliability Engineering and System Safety

Table 2.2 (continued) : Elaborative list for HRA in marine transportation industry.

Author	Methodology	Topic	Publisher (Journal or Conference paper)
Kenji et al., 2010	Cognitive reliability theory	Navigation	Conference
Konstandinidou et al., 2006	Fuzzy CREAM	-	Reliability Engineering and System Safety
Trucco et al., 2006	Bayesian network and fault tree analysis	Collision	Conference
Mennis et al., 2006	Markov theory	Environment protection	Conference
Chen and Moan, 2004	Quantitative risk analysis	Collision	Reliability Engineering and System Safety
Sii et al., 2001	Fuzzy If-Then rules	Maritime transportation system	Reliability Engineering and System Safety
Malone et al., 2000	-	Collision	Conference
Amrozowicz et al., 1997	THERP	Grounding	Conference

Likewise, Malone et al. (2000) presented another conference paper in order to enhance human reliability performance in port and shipping operations. The aim of this paper is to identify human factors engineering and reduce human errors. In order to fulfil that, the authors show some empirical data to illustrate the benefits of human factors engineering in minimizing the marine accident in port. A collision case at Harbour is demonstrated as an application.

Sii et al. (2001) explained a qualitative safety modelling for risk assessment in marine transportation system. The paper utilised fuzzy logic approach based on if-then rules in order to model numerous design parameters for marine engineering systems. An illustrative example in line of fire cases in fuel oil system failure is introduced as marine engineering systems. Thus, the proposed approach may help to carry out risk assessment in the initial design level. The development of fuzzy linguistic parameters and membership functions are identified in the paper. Furthermore, a probabilistic risk analysis was presented to demonstrate the collision case between shuttle tanker and floating-production-storage and offloading (FPSO) unit (Chen and Moan, 2004). The authors aim is to produce practical solution to carry out risk assessment in order to decrease the collusion frequency in offshore cargo loading operation. Therefore, quantitative risk analysis method based on collision frequency was developed. At the end of the study, the paper recommended some preventive actions which may reduce the probability of FPSO to shuttle tanker during offshore tandem loading.

Mennis et al. (2006) proposed a reliability modelling based on Markov theory for ship safety assessment. In order to prevent marine environmental pollution, the author introduced reliability model of Markov theory. Thus, the model is able to simulate reality and predict reasons that may induce accidents. The authors applied an illustrative case study to demonstrate the model process into ship safety systems. Since Markov theory has rarely used into HRA, the authors applied model into human reliability assessment successfully.

Another collision case was conducted by utilizing Bayesian Belief Network and fault tree analysis (Trucco et al., 2006). In this article, the authors present a creative tool integrating human and organization factors into risk analysis. The method allowed

identification of stochastic correlations between the basic events and Bayesian Belief Network model.

Konstandinidou et al. (2006) have proposed a different approach that combined the CREAM into a fuzzy logic in order to determine the human error actions probability. This paper offers a pilot model, which is successfully translating CREAM methodology into fuzzy logic. The authors use fuzzy logic in order to design CPC including nine input variables and one output variable. At the end of research, proposed methodology was tested with five different scenario and the results were found satisfactory. Fuzzy integrated CREAM approach extended in later years successfully in marine industry and aviation.

The method, called cognitive reliability theory, for estimating of HEP was proposed in order to establish a systematized technique for risk assessment (Kenji et al., 2010). In this research, authors have examined about more than six thousand marine accident in order to develop systematic approach for human factors. Thereafter, all marine accidents are classified into cases by the cognitive conditions. The simulator experiences are tested participation of experienced navigational officers.

Montewka et al. (2010) have proposed a new approach for collision probability modelling. In this article, authors combine Monte Carlo and generic models in order to conduct risk analysis during collision of vessels. The model applied into paper based on minimum distance to collision values and calculated with assumption that two ships doing manoeuvring in order to prevent collision. The results of study were compared with registered data which gathered from maritime traffic. The authors found them satisfactory.

Another approach based on a formal safety assessment theory was applied to perform a quantitative analysis of the human failure contribution in the collision and grounding of oil tankers (Martins and Maturana, 2010). The authors utilised the technique for estimating HEP values. At the end of study, the authors revealed that the operator should decide where he will work to reduce the probability of marine accidents such as collision or grounding. While the paper did not introduce a new concept with respect to HRA, it presented a different perspective into marine industry. A model for overcome the data problem proposed by Gaonkar et al. (2011) defines the application of fuzzy sets and logic as an alternative option to deal with

the data scarce in parameters. The authors reveal the different factors affecting marine transportation systems and model them as linguistic variables. Thus, the complexity of the maritime transportation system HRA can be achieved.

Another study upon HRA was performed by using Fault tree analyse tool with time-dependant dynamic gates (Turan et al., 2011). In order to validate the results of paper, the authors has utilised the Birnbaum and Criticality reliability importance measures. An application upon diving support vessel was demonstrated as a case study. The paper revealed the reliability analysis results of the main and sub-systems of vessel as well as their significant components. Then, necessary recommendations upon how to improve the overall reliability of the vessel systems were suggested by the authors.

A hybrid technique combining APJE and SLIM methodology was introduced for estimating marine human error probability (Xi and Guo, 2011). The paper focused on researching marine human errors and how the context effect human behaviuor. In this study, human reliability performance upon collision avoidance was investigated by utilizing hybrid methodology called APJE-SLIM. The results of study gave positive contribution theoretically in order to prevent collision accident at sea.

A seafarer's reliability assessment has been conducted by incorporating subjective judgements (Riahi et al., 2012). This article introduced a different approach to monitor the seafarer performance concerning conditional reliability by integrating fuzzy logic and analytical hierarchy process. The proposed methodology allows user to evaluate the seafarer performance during his or her seafaring period on-board ship in order to enhance maritime safety.

Sulaiman et al. (2012) performed another study which researched result of human error and human reliability derived from use of technology for ship navigation within coastal waters. In this approach, the author uses qualitative and quantitative tools such as marine accident reports and literature data. Another study was performed by Yang and Wang (2012) in order to develop generic method by modifying CREAM methodology. In this paper; in order to facilitate the quantification human failure in marine industry, the authors combined fuzzy evidential reasoning and Bayesian inference logic into CREAM methodology. The hybrid approach allowed user to link between nine CPCs and four control modes defined in COCOM technique.

A new approach namely called HENT (human entropy) was presented for marine and offshore applications (El-Laden and Turan, 2012). The research introduced quantitative and qualitative taxonomies of PFSs in order to find generic root causes of failures. The author defined nine generic human factors such as crew quality, training procedure, welfare, stress and environment conditions, etc. which are affecting reliability.

Gao et al. (2013) studied upon ship's crane structure reliability utilising possibility theory. Since cranes are significant components for shipping industry, reliability performance of component were analysed. The authors applied possibility theory instead of collecting large amount sample and the impact of human factors. Furthermore, Yang et al. (2013) presented another research paper, which used a modified CREAM methodology by incorporating the Bayesian reasoning model with fuzzy evidential reasoning. In this paper, authors applied evidential reasoning to set up fuzzy if-then rule bases and established Bayesian reasoning in order to accumulate all the rules for predicting its failure probability. The proposed model was shown through the illustrative example of analysing an oil tanker cargo oil pump shut down scenario.

Application of Bayesian belief network model into HRA was introduced to analyse human error probability (Martins and Maturana, 2013). The aim of this paper is to determine the most likely sequences of potential danger events in order to reduce potential risk. The authors demonstrated the proposed model with human factors related to the tanker collision case in order to reduce probability of collision. Likewise, Musharraf et al. (2013) introduced a quantitative approach for HRA during offshore emergency conditions. In this paper, authors combined BN method into evidence theory in order to provide dependency between the human factors and associated actions. Thereafter, the outcomes of the researches are compared with SLIM technique to provide an analytical approach. The proposed approach then applied an emergency hazardous operation case in marine industry.

Both fuzzy set theory and fuzzy logic were used to conduct the estimation procedures and provide the reliability value for vessel transportation operation (Gaonkar et al., 2013). In the paper, the authors applied the method to deal with the insufficient or unavailable data in marine industry. The authors utilised the first method to ensure

fuzzy arithmetic for vessel reliability prediction while second method is to integrate fuzzy interface system with rule base.

A BN approach for human fatigue has recently been introduced by Akhtar and Utne (2014). The method provides an enhancement for BN technique for modelling ship accident risk. In this paper, modified HFACS method has been integrated into BN approach to ensure qualitative part of the method while various marine accident investigations reports have been analysed for quantitative parts. The authors applied grounding case for demonstration. Another research paper has been proposed in recent months in order to evaluate HRA during ship-to-ship collision cases (Goerlandt and Kujala, 2014). The authors have studied the reliability of quantitative risk analysis (QRA) for ship collision cases. The paper main objective is to prove quantitative risk analysis have some limitations and might not be considered as a reliable method to evaluate the risk.

Montewka et al. (2014) have introduced a research paper recently to assess risk for marine transportation system. The article proposed a proactive tool for maritime transportation systems. In order to fulfil that BN has been utilised by authors as proactive model. The article assesses the probability of events concluding by ascertaining collision severity. A collision case study in which RoPax vessel involved has chosen as a demonstration. Likewise, the BN has been applied into accidental cargo oil outflow in ship collision cases (Goerlandt and Montewka, 2014). This paper introduces BN method for reasoning under uncertainty to evaluate the collision case study. The authors combined the damage extent model condition into impact scenario in order to reveal probabilistic oil flow model.

Recently, an application upon cargo loading process of LPG tanker have been recognised as a unique study (Akyuz and Celik, 2015b). In the paper, the main focus of the research is to systematically predict human error potentials for designated tasks and to determine the required safety control levels on-board LPG ships. To achieve this purpose, CREAM approach is used.

Likewise, Akyuz and Celik (2015a) have recently presented a novel approach by integrating AHP method into HEART approach to evaluate human reliability in chemical tanker ship. The paper conducts an empirical human reliability analysis for tank cleaning process on-board chemical tanker ship to enhance safety and

operational reliability in maritime industry. It provides a methodological development on decision making and human factors

In the light of above, literature research conducted between 1995 -2014 years for HRA in marine transportation industry, following significant points are revealed;

- There are limited studies performed upon HRA on marine transportation industry.
- Apparently, current HRA methods do not provide a consistent approach to human error quantification through the marine transportation industry.
- The HRA studies conducted upon marine transportation up to now have utilised existing HRA methodology.
- There are no specific articles upon HRA shipboard operations since human errors are important contributor factor to safety risk in many of the potential hazardous on-board ship.
- Even though there are numbers of HRA techniques covering a range of disciplines to assess human error, it has been no specific method to perform HRA in the marine transportation industry.
- In literature, existing HRA studies applicability in marine industry are seemingly inadequate and not practical.
- It would be substantial advantage in establishing a marine transportation-specific methodology to evaluate human reliability.

Within this context, it is necessary to develop a new approach for assessment human reliability. The aim of this thesis is to fill the gap in literature by proposing a new approach in which analyses human reliability on-board ship based on a decision-making model proposal. Next section introduces new model proposal basically called MAHRA (Maritime Human Reliability Analysis).

3. MARITIME HUMAN RELIABILITY ANALYSIS (MAHRA)

This chapter introduces an empirical human reliability analysis for shipboard operations on-board ship to enhance safety and operational reliability in maritime industry, providing a methodological extension through the integration of the AHP (Analytic Hierarchy Process) and HFACS (Human Factor Analysis and Classification System) technique into the HEART (Human Error Assessment and Reduction Technique) approach. The hybrid approach is namely called as MAHRA (Maritime Human Reliability Analysis). The conceptual framework, research methodologies and system design of proposed approach will be provided in this chapter. The MAHRA as a hybrid decision making model has been introduced to minimize the operational problems/errors that may arise from human errors on-board ship. Within this context, the chapter is organised as follows; this section gives brief information about the MAHRA approach. The next section introduces theoretical background of research methodologies. Then, system design will be provided to derive marine-specific EPC and calculate APOA (Assessed Proportion of Affect). The fourth section introduces system application where MAHRA approach defines step by step.

3.1 Conceptual Framework

MAHRA approach contains a couple of methodological process to create robust tool. Figure 3.1 depicts the conceptual framework to establish proposal approach. The concept consists of three main stages. The first one is data gathering where required data including marine accident causes are provided. Since obtaining quantitative human error data on the nature of maritime industry is very challenging, the aim of this phase is to gather data by analysing marine accident cases. In this sense, marine investigation branches such as MAIB, ATSB, NTSB and JTSB are exploited. The second stage is EPC derivation part where HFACS and AHP methods are combined to generate marine specific performance shaping factors. The last stage is system

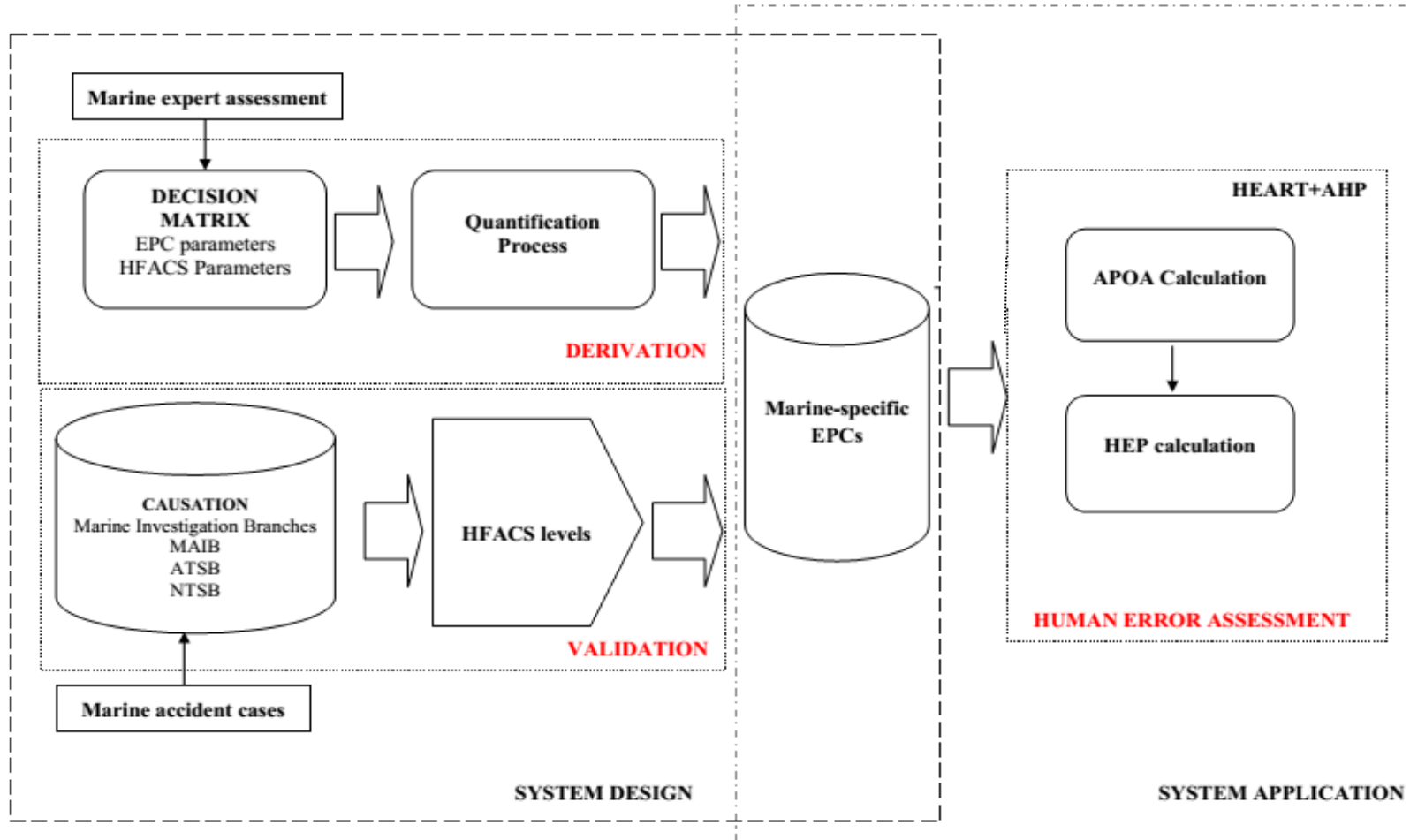


Figure 3.1 : Conceptual framework.

application part in order to assess human error. This part contains APOA and HEP calculation.

3.2 Methodological Background

This thesis conducts an empirical human reliability analysis for critical operations on-board ship to enhance safety and operational reliability in marine industry by integrating HEART and AHP as well as HFACS technique. The next section introduces research methodologies respectively.

3.2.1 HEART

HEART (human error assessment and reduction technique) is recognized as a well-known modelling tool in safety and reliability analysis where critical operation is performed. It is currently applicable to wide range of industry. Since the human error data is scarce in the literature, it is quite tough to apply stochastic models such as Bayesian Network or Markov chain into marine HRA concept in order to predict HEP value. Furthermore, the current HRA techniques are limited to reveal all of the significant aspects of human performance in marine industry such as insufficient data, subjectivity of expert judgement, uncertainty, etc. Therefore, using the empirical method such as HEART seems more reasonable and consistent to support the consideration of human performance. The technique is quick and flexible requiring few researches. It was presented to assess human tasks with defined values for HEP calculation (William, 1988). The fundamental is to depend on two parameters; the first one is generic task type (GT) and second one is error-producing condition (EPC). The GT allows user to find suitable task under HRA and then define the generic error probability (GEP) value (also known as nominal human unreliability), while EPC defines the PSF of human which influence the probability of human error in the related task. This means that EPCs are expected to affect human performance negatively and leading to increase HEP associated with generic task.

The impact of GEP and EPC value were derived by numerous researches of human factor performances for a long time. These data base includes a variety of HEP values derived from numerous industries such as nuclear power plant, petrochemical

industry, offshore platforms, service industry, etc. (William, 1988). However, MAHRA proposes a novel base approach deriving marine-specific value for EPCs since internal and external factors directly increase the probability of human error in marine industry distinctively.

The HEART method is easy to understand and the process starts with selecting a GT in order to employed GEP values as first parameter. As the GEP values are based on the nature of generic task to be performed and generic, they are regarded as the same value as adopted in HEART with given nominal likelihood within probabilistic limits. There are totally nine generic tasks associated with nine GEP values, which gives the probability of human error, occurred in perfect condition. The analysts have specific tasks that they need to quantify during HRA. In order to do that, specific task is compared with GT by experts and nominated respectively. Thereafter, EPC is selected by experts as a second parameter. These are the external and internal factors (operator experience, familiarity with situation, time pressure, fatigue, noise level, etc.) that might heavily affect the human performance and increase the probability of human error. There are thirty-eight different EPCs assigned in HEART approach and seventeen of those have the substantial influence to HEP values (Kirwan et al., 1996). The selection of relevant EPC is usually based on scenario for the task being applied. EPC has a maximum nominal value which to be inserted in equation (3.1).

$$HEP = GEP_{value} \times [(W_i - 1) \times APOA_1 + 1] \times [(W_j - 1) \times APOA_2 + 1] \times \dots \quad (3.1)$$

where W_i and W_j indicate weight for each context task chosen from EPC tables. The APOA (assess the proportion of affect) states the proportion of the effect which is weighted the each EPC basis of its importance.

In the light of above, the basic principles of HEART methodology are as follows:

- i) Task analysis
- ii) Define the scenario,
- iii) Nominate generic task type in accordance with scenario,
- iv) Select GEP as per generic task,
- v) Define the relevant EPC/s,
- vi) Assess the proportion of EPC affect,
- vii) Calculate final HEP,

3.2.1.1 HEART application overview

The HEART method has been successfully applied in numerous disciplines such as nuclear energy (Kirwan et al., 2004), petrochemical (Castiglia and Giardina, 2013), transportation (Akyuz and Celik, 2015; Gibson et al., 2012; Kirwan and Gibson, 2008), off-shore (Noroozi et al., 2014; Deacon et al., 2013), service industry etc. Particularly, studies upon NPP have become prominent since the human error risk involvement is comparatively high. For instance, Kirwan et al. (2004) are presented nuclear energy specific model (NARA) which is based on tailoring the basic principle of the HEART. Hence, the technique is successfully applied for NPP to be used for quantification of human error. Furthermore, another specific study is performed in petrochemical industry by comparing HEART results to CREAM (Castiglia and Giardina, 2013). The authors modified the both methodology on the basis of the fuzzy set theory and illustrated the techniques by analysing of human error in hydrogen refuelling station.

The use of HEART method in transportation industry is quite limited although transportation activities can pose potential hazard to human and environment. Nevertheless there have been some studies applied the HEART method such as RARA (Gibson et al., 2012) and CARA (Kirwan and Gibson, 2008). Both methods are based on tailoring the basic principle of the HEART and successfully applied. Likewise, Akyuz and Celik (2015) have recently proposed a hybrid method extension through the integration of the AHP technique into the HEART approach. The hybrid approach has applied into cargo tank cleaning operation as a demonstration to assess human reliability on-board chemical tanker ship.

The studies utilised HEART methodology upon off-shore industry are focused on risk assessment. Whilst this technique was developed for human error assessment, it was successfully applied into risk assessment case. For instance, Noroozi et al. (2014) were developed a risk-based methodology by using HEART method. The paper applied the method for determining HEP value for pre-and-post maintenance procedures of a condensate pump which is used with single buoy mooring units. Similar study was conducted by Deacon et al. (2013) to perform risk assessment for critical steps in the escape, evacuation and rescue process on off-shore unit. In this paper, the authors are used HEART method to determine HEP.

3.2.2 AHP methodology

The AHP is a powerful multi-criteria decision making (MCDM) method. It was first introduced by Saaty (1980) in order to provide relative weight of criteria according to hierarchical structure. The method depends on the pair-wise comparison matrix where alternatives are compared respectively. The technique is widely utilised to solve complicated decision problems. The method has been used in numerous disciplines to find out the complex decision problems. The AHP methodology basically divides the complicated problem into small parts in order to rank hierarchically. In this thesis, the AHP method which quantifies the subjective expert judgement and confirms the consistency of collected data is used to weight/prioritise proportion effect of EPCs as well as weighting EPCs during derivation process.

As the AHP is powerful tool to enable relevant weight for criteria, the first stage is to compose a pair-wise comparison matrix (A) as introduced by Saaty (1986). In order to fulfil that Saaty's 1-9 linguistic relative importance scale, provided in Table 3.1, has been utilised.

Table 3.1 : Saaty's pair-wise comparison scale.

Importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Absolute (extreme) importance
2,4,6,8	Intermediate values

The matrix A represents criteria pair-wise comparison matrix where each a_{ij} ($i, j = 1, 2, \dots, n$) has the relative importance of i^{th} elements compared to the j^{th} . This indicates that higher value of a_{ij} shows stronger preference of criteria a_i to a_j . In the light of comparison linguistic scale, the numbers of 1,3,5,7 and 9 verbal judgements can be defined as “equal importance”, “moderate importance”, “strong importance”, “very strong importance”, and “extreme (absolute) importance”. The intermediate values between the adjacent scale (such as 2 (weak); 4(moderate plus); 6 (strong plus); and 8 (very, very strong)) are used for compromise. The matrix A is provided in equation (3.2) accordingly.

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \quad a_{ii} = 1, a_{ji} = 1/a_{ij}, a_{ij} \neq 0 \quad (3.2)$$

After composing of a pair-wise comparison matrix, normalized value of matrix is found by dividing each entry in column to the sum of entries in column. Thereafter, the priority weights of criterion are calculated. The average of value in each row gives estimate of relative weights of criterion. The normalization of matrix and priority weights of criterions (w_i) will be found with equation (3.3).

$$w_i = \frac{1}{n} \sum_{j=1}^n \frac{a_{ij}}{\sum_{k=1}^n a_{kj}} \quad (3.3)$$

The next step in the AHP method is to prove consistency of data. The reason of this is introduced by Saaty (1986) who proposed a basic equation to control whether the comparison pair-wise matrix is consistent or not. The consistency index (CI) can be calculated by following formula.

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (3.4)$$

where ;

n : the order of the matrix

λ_{max} : the maximum matrix eigenvalue

λ_{max} can be found with equation (3.5) as proposed by Vargas (1982).

$$\sum_{j=1}^n a_{ij} w_j = \lambda_{max} w_i \quad (3.5)$$

A consistency ratio (CR) calculation is then needed to specify reasonable consistency. The CR value can be calculated by equation (3.6). The CR value will be equal or smaller than 0.10 otherwise the expert judgement will be revised to get consistent result.

$$CR = CI/CR \quad (3.6)$$

In the equation, RI stands for random index (RI) and introduced by Saaty (1994). It is subjected to the number of items that is compared in matrix. The RI value table is provided in Table 3.2. In this thesis, AHP method is used to generate marine-specific EPC as well as APOA calculation respectively.

Table 3.2 : Random index value.

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

3.2.2.1 AHP application overview

As the AHP technique enable to solve complex decision problems using qualitative and quantitative criteria measurement, it has been adopting in numerous disciplines such as logistic (Li and Kuo, 2008), marine industry (Akyuz et al., 2014; Akyuz and Celik, 2014a; Kandakoglu et al., 2009), waste management (Onut and Soner, 2008), supplier selection (Wang et al., 2009), performance measurement system (Bititci et al., 2001), etc. AHP technique has rarely been applied separately. The method has usually been used in the literature by integrating other disciplines such as TOPSIS, SWOT analysis, Fuzzy logic, Monte Carlo, BSC and etc. due to ease of use.

In the literature, the AHP technique has been successfully applied in numerous application in marine industry. For instance, there has been a recent study performed to assess compliance with the Maritime Labour Convention requirement at the operational level (Akyuz et al., 2014). Another hybrid study integrating HFACS into AHP has been conducted to analyse the role of human factor in marine accident case (Akyuz and Celik, 2014b). Furthermore, a qualitative research has been performed by using SWOT analysis in order to provide a strategy for the safe carriage of liquid chemical cargoes in chemical tankers (Arslan and Er, 2008). Another research attempting to examine the precaution priorities during cargo operation in chemical tankers have been studied by Arslan (2009). In this study, AHP method is utilized to prioritize the precautions in order to explain risk assessment options in chemical tanker fleet. Furthermore, Karahalios et al. (2011) have proposed a system of balanced scorecards integrated fuzzy sets and AHP in order to measure the regulatory performance of various stakeholders involved into the shipping industry.

3.2.3 HFACS

The HFACS is an analysis methodology tailored Swiss cheese model which was introduced by Reason (1990). A basic framework of the Swiss cheese model is depicted in Figure 1 for human error causation.

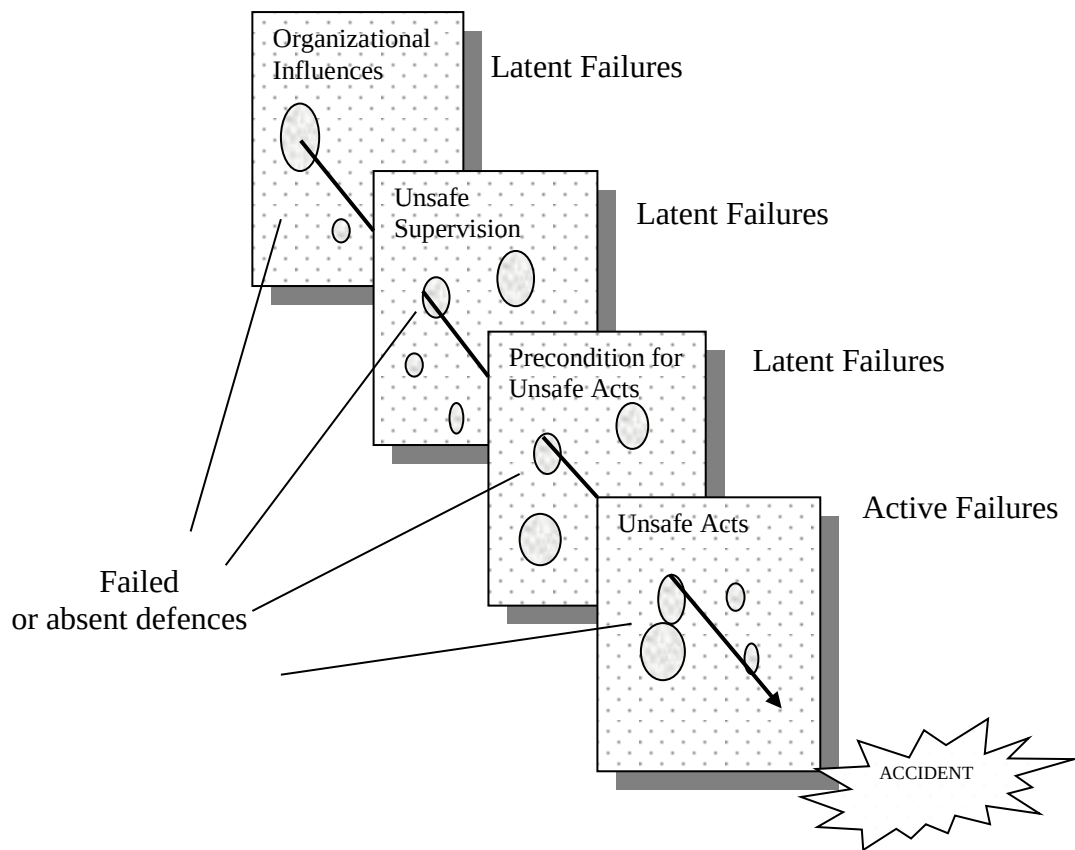


Figure 3.2 : Swiss cheese model for human error causation (Reason, 1990).

The method is fundamentally used for aviation industry to investigate and analyse role of human factor in accidents (Wiegmann and Shappell, 2003). The authors' aim is to propose a basic framework to help reserachers in investigating and analysing human error. In this context, the method enables the knowledge and instruments required to perform a human error investigation. Numbers of causal categories are depicted within four level of human failure. The HAFCS investigates and exemines the active and latent factors caused to accidents. The combination provided in HFACS method has contributed to raise capability of the framework in accident survey practice. The HFACS method contains four schematic levels;

i) *Organisational influences*: This level of human failures covers the organisation which may impact performance at all level. In this level; resource management, organisation climate and operational process are included as to address latent failure.

ii) *Unsafe supervision*: This level contains the inadequate supervision, planned inappropriate operation, failed to correct problem and supervisory violations which can pose a potential human failure due to unsafe supervision.

iii) *Pre-conditions for unsafe acts*: The level deals with the substandard condition and practice of operators such as adverse mental fatigue, poor communication, poor environment condition, etc. This level fundamentally covers crew resource management, personal readiness, physical/mental limitation, adverse physiological states and adverse mental states.

iv) *Unsafe acts*: As the last level of human failure, unsafe acts include two hint terms; errors and violations.

The objective evidence in conjunction with each level identifies the active and latent failures/causes in the system. The usage of HFACS concept provides practitioners to identify the latent or active failures (Reason, 1990). They might be utilised to decrease accident causes as derivable. So that, the application of HFACS can assist users to show up the shortfalls during the reducing marine accidents. In this thesis, the HFACS technique is utilised to generate specific EPC as well as validation part of MAHRA approach.

3.2.3.1 HFACS application overview

Numerous HFACS applications were adopted in recent years due to it is easy usage to analyse of accidents. In numerous applications, the HFACS framework was modified and re-organised. On the other hand, the modification did not change the original idea lies behind the concept. Wiegman and Shappell (2001) made substantial attempts to extend theory by introducing a comprehensive, user-friendly tool to contribute users in effectively investigating and analysing human error in aviation industry. However, unique model is needed for different fields such as petrochemical, railway or marine industry as the model was presented for aviation industry only.

The HFACS method has been successfully adopted to numerous disciplines such as maintenance (Krulak, 2004), railway traffic (Reinach and Viale, 2006), highway traffic (Iden and Shappell, 2006), medicine and surgery (ElBardissi et al., 2007), construction industry (Walker, 2007), mining (Patterson and Shappell, 2010), etc. However, adaptation of HFACS application in marine industry is scarce due to data mining difficulty. In order to tackle that, Celik and Er (2007) modified the HFACS framework to define the effect of design-based system failures in terms of human factor. Likewise, the article studied by Celik and Cebi (2009) was intended to decrease occupational accident rates in the Turkish shipyards by utilising HFACS framework.

An adapted version of the HFACS with limited modifications related to machinery space was used to figure out organizational factors that are identified during maritime accident investigation (Schröder-Hinrichs et al., 2010). Then, as a relatively new tool, systemic and multifactorial analysis of collision at sea aiming to identify different types of accidents has been introduced by Chauvin et al., (2013). A hybrid approach combining HFACS into cognitive mapping has recently been recognised to identify and prevent human errors in marine accidents (Akyuz and Celik, 2014b). The author demonstrated the model with real-case shipboard situation.

3.3 System Design

In order to design MAHRA approach as a marine-specific human reliability analysis technique, EPCs will be re-designed as unique parameter. Additionally, this thesis proposes a smart solution during assessed proportion of affect calculation. Thus, the modification will improve the consistency of the calculation during HEP assessment. In this context, this section presents how to design the system to create novel HRA approach for marine industry.

3.3.1 Derivation of EPC for marine industry

The traditional HEART method is based on data mining to generate EPC values from different industry such as power plant, petrochemical industry, offshore platforms, and service industry. Instead of using data mining, this thesis brings a new perspective to derive marine-specific EPCs. The study proposes a methodologic

approach by integrating HFACS and AHP to quantify the EPCs for MAHRA since obtaining historical data with respect to human error on the nature of maritime industry is very challenging and mostly unknown due to scarce of data. The EPC derivation process consists of seven steps. The flow chart is illustrated in Figure 3.3.

Step 1. Identifying HFACS-EPC relationships: In this step, HFACS-EPC relation matrix is established by distributing EPCs into relevant HFACS sub-levels in the light of marine experts' view. In order to fulfil that elaborative survey is performed with experts who are working in a prestigious shipping companies. The companies are selected as per deadweight tonnage of world merchant fleets which are bulk carriers, tanker ships, container ships, chemical tanker ships and general cargo ships. The expert profile contains professional managers (DPA or HSEQ) and marine superintendents who have seagoing background and professional execution experiences. Since there were more than one expert in each shipping company, consensus of group have been achieved. The experts are asked to distribute relevant EPCs under HFACS sub-levels which may potential affect on error production. In the light of above, the each HFACS-EPC relation matrix, which is established by the consensus of marine experts with respect to the ship fleet types, is provided in Appendix A respectively.

Step 2. Applying majority rules: The purpose of this step is to select the available EPCs with respect to the HFACS sub-levels. After having identified HFACS-EPC relationships in the view of marine experts' consensus for bulk carriers, tanker ships, container ships, chemical tanker ships and general cargo ships; majority rules will be applied since there are a variety of relationships among the HFACS and EPC. The majority rule enables to select alternatives which have more than half of the votes. The technique is widely used in decision-making problem.

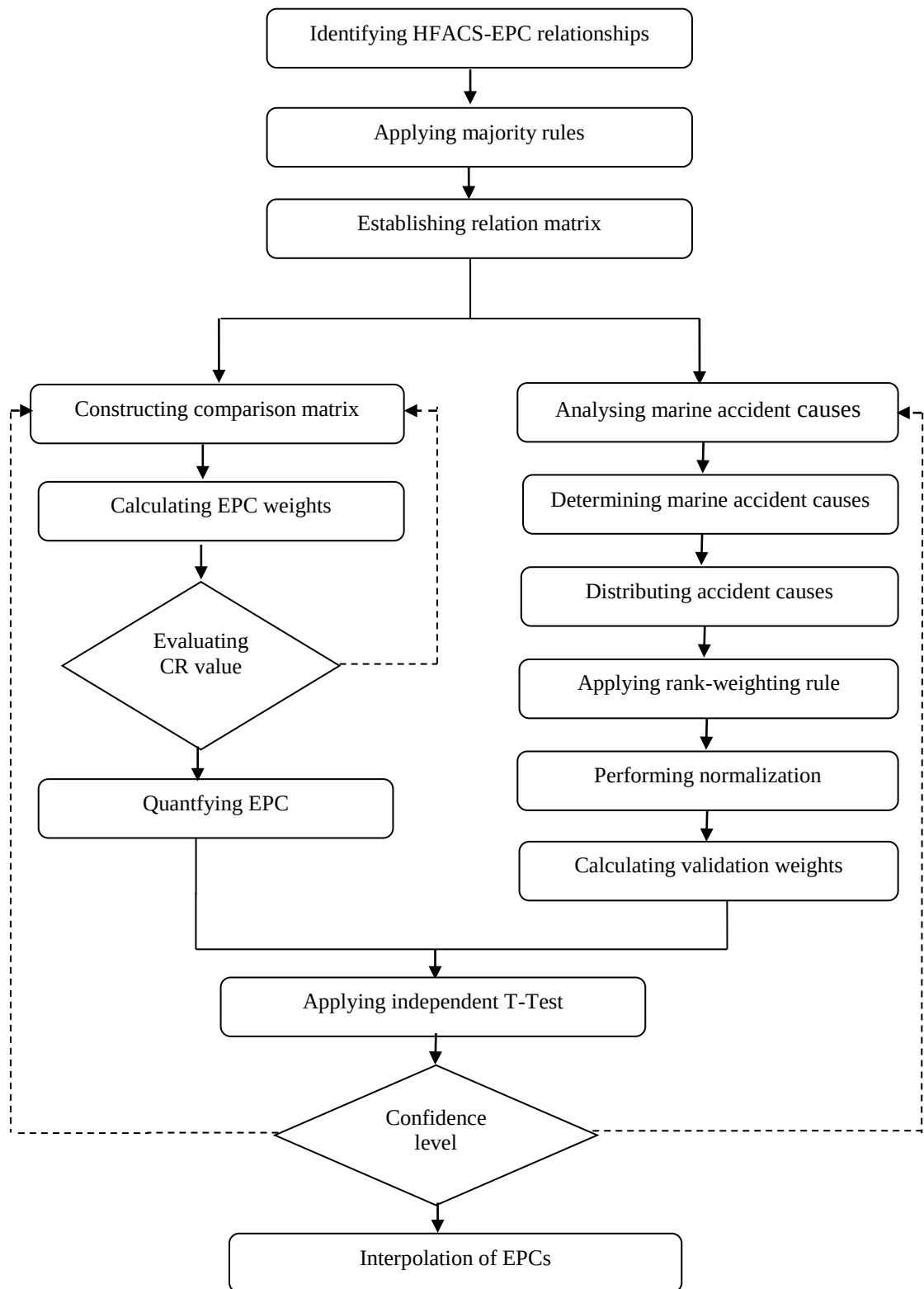


Figure 3.3 : EPC derivation and validation flow chart.

In this thesis, majority rule is used to sort out EPCs which have been selected by the marine experts. For instance, there are five different HFACS-EPC relationship

matrices created by the consensus of marine experts from the five different shipping companies. In the first matrix (Appendix A); EPC4, EPC11, EPC19, EPC20, EPC22, EPC23 and EPC27 are selected by the marine experts who are working in chemical tanker shipping company in accordance with resource management. On the other hand, marine experts who are working on bulk carrier shipping company chooses EPC5, EPC11, EPC16, EPC19, EPC20, EPC22, EPC23 and EPC36 in conjunction with resource management (Appendix A). Likewise, marine experts who are working on container shipping company selects EPC10, EPC11, EPC16, EPC19, EPC20, EPC21, EPC22, EPC23 and EPC29 under resource management (Appendix A). For tanker ships, EPC11, EPC16, EPC20, EPC21, EPC23 and EPC26 are selected (Appendix A). The last selection is made for general cargo ships and EPC11, EPC14, EPC19, EPC22 and EPC31 are selected by consensus of marine experts who are working on general cargo shipping company in conjunction with resource management (Appendix A). As there are a set of different EPCs are selected by marine experts in conjunction with resource management, the majority rule is adopted to select prominent ones. Since the technique requires to select alternative that have more than half choices, EPC11, EPC16, EPC19, EPC20, EPC22, EPC23 are become prominent factors. Therefore, they are inserted in final HFACS-EPC relation matrix. The rest of EPCs selection is carried out in compliance with majority rule.

Step 3. Establishing relation matrix: After having applied majority rule into the entire levels, final relation matrix is constructed by distributing EPCs into relevant HFACS sub-levels. Figure 3.4 shows the relation matrix between EPCs and HFACS. For instance, human errors which are caused by resource management may generate error producing conditions such as “Poor feedback (EPC 11)”, “Impoverished information (EPC16)”, “No diversity (EPC19)”, Educational mismatch (EPC20)”, “Lack of exercise (EPC22)” and “Unreliable instruments (EPC23)”. Another example is to be showed up in skill-based error. Human errors which are classified under skill-based error are triggering to generate EPC1, EPC9, EPC10, EPC14, EPC23 and EPC38 respectively Accordingly, Figure 3.5 depicts distribution of EPCs in conjunction with HFACS.

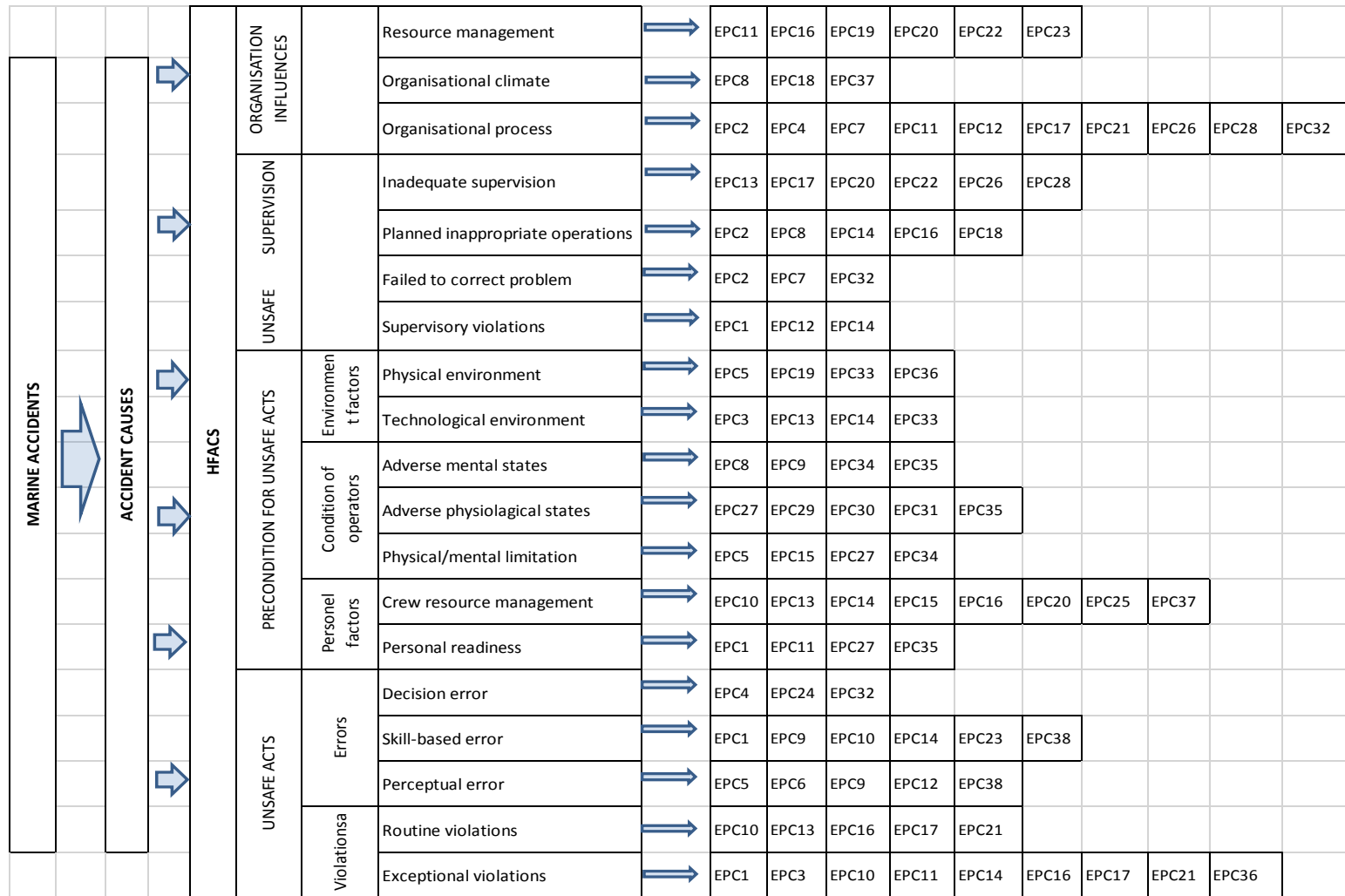


Figure 3.5 : EPC derivation flow chart.

Step 4. Constructing comparison matrix: This step provides a pair-wise comparison matrix in order to prioritise EPCs which are distributed under each HFACS sub-levels. In this context, equation 3.2 is used. A pair-wise comparison matrices are established in accordance with 1-9 linguistic scale of the analytic hierarchy process which are showing the intensity of importance each criterion (Table 3.1). The judgements on EPCs for each HFACS level were received from the marine experts to construct a pair-wise comparison matrix. Since group opinion is considering in decision process, the survey results should be reduced to one comparison matrix by getting geometric means of judgements. Accordingly, EPCs pair wise comparison matrices for each HFACS levels are established respectively. For instance, “Performance ambiguity (EPC11)” has slightly moderate importance than “Impoverished information (EPC16)” in resource management level. Therefore, number 4 is assigned according to the Saaty’s linguistic scale for this comparison. Likewise, the reciprocal equation of EPC16 to EPC11 is assigned 1/4 as proposed in equation (3.2). To give another example, the EPC19 (No diversity) has moderate importance when compared to EPC22 (lack of exercise).

Within this context, Table 3. shows a pair-wise comparison matrix for resource management, Table 3.4 provides a pair-wise comparison matrix for organisational climate, Table 3.5 for organisational process, Table 3.6 for inadequate supervision, Table 3.7 for planned inappropriate operations, Table 3.8 for failed to correct problem, Table 3.9 for supervisory violations, Table 3.10 for physical environment, Table 3.11 for technological environment, Table 3.12 for adverse mental states, Table 3.13 for adverse physiological states, Table 3.14 for physical/mental limitation, Table 3.15 for crew resource management, Table 3.16 for personal readiness, Table 3.17 for decision error, Table 3.18 for skill-based error, Table 3.19 for perceptual error, Table 3.20 for routine violations, Table 3.21 for exceptional violations.

Table 3.3 : A pair-wise comparison matrix for resource management.

	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23
EPC11	1.00	4.00	3.00	3.00	5.00	2.00
EPC16	0.25	1.00	3.00	4.00	2.00	0.33
EPC19	0.33	0.33	1.00	2.00	3.00	0.50
EPC20	0.33	0.25	0.50	1.00	0.50	0.33
EPC22	0.20	0.50	0.33	2.00	1.00	0.33
EPC23	0.50	3.00	2.00	3.00	3.00	1.00

Table 3.4 : A pair-wise comparison matrix for organisational climate.

	EPC8	EPC18	EPC37
EPC8	1.00	4.00	2.00
EPC18	0.25	1.00	0.33
EPC37	0.50	3.00	1.00

Table 3.5 : A pair-wise comparison matrix for organisational process.

	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
EPC2	1.00	3.00	5.00	4.00	2.00	6.00	3.00	2.00	3.00
EPC4	0.33	1.00	4.00	3.00	0.50	3.00	2.00	3.00	4.00
EPC7	0.20	0.25	1.00	0.50	0.33	2.00	0.33	0.50	1.00
EPC11	0.25	0.33	2.00	1.00	3.00	2.00	0.50	2.00	0.33
EPC12	0.50	2.00	3.00	0.33	1.00	3.00	0.33	2.00	3.00
EPC17	0.17	0.33	0.50	0.50	0.33	1.00	0.33	0.50	0.33
EPC21	0.33	0.50	3.00	2.00	3.00	3.00	1.00	1.00	3.00
EPC26	0.50	0.33	2.00	0.50	0.50	2.00	1.00	1.00	2.00
EPC28	0.33	0.25	1.00	3.00	0.33	3.00	0.33	0.50	1.00

Table 3.6 : A pair-wise comparison matrix for inadequate supervision.

	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28
EPC13	1.00	5.00	3.00	3.00	4.00	3.00
EPC17	0.20	1.00	0.33	3.00	0.33	0.50
EPC20	0.33	3.00	1.00	3.00	0.50	0.50
EPC22	0.33	0.33	0.33	1.00	0.33	0.50
EPC26	0.25	3.00	2.00	3.00	1.00	2.00
EPC28	0.33	2.00	2.00	2.00	0.50	1.00

Table 3.7 : A pair-wise comparison matrix for planned inappropriate operations.

	EPC2	EPC8	EPC14	EPC16	EPC18
EPC2	1.00	3.00	2.00	3.00	5.00
EPC8	0.33	1.00	3.00	2.00	3.00
EPC14	0.50	0.33	1.00	0.50	3.00
EPC16	0.33	0.50	2.00	1.00	4.00
EPC18	0.20	0.33	0.33	0.25	1.00

Table 3.8 : A pair-wise comparison matrix for failed to correct problem.

	EPC2	EPC7	EPC32
EPC2	1.00	3.00	2.00
EPC7	0.33	1.00	0.33
EPC32	0.50	3.00	1.00

Table 3.9 : A pair-wise comparison matrix for supervisory violations.

	EPC1	EPC12	EPC14
EPC1	1.00	0.50	2.00
EPC12	2.00	1.00	3.00
EPC14	0.50	0.33	1.00

Table 3.10 : A pair-wise comparison matrix for physical environment.

	EPC5	EPC19	EPC33	EPC36
EPC5	1.00	3.00	0.25	0.33
EPC19	0.33	1.00	0.33	0.50
EPC33	4.00	3.00	1.00	2.00
EPC36	3.00	2.00	0.50	1.00

Table 3.11 : A pair-wise comparison matrix for technological environment.

	EPC3	EPC13	EPC14	EPC32	EPC33
EPC3	1.00	0.33	2.00	2.00	0.33
EPC13	3.00	1.00	3.00	2.00	0.50
EPC14	0.50	0.33	1.00	0.50	0.33
EPC32	0.50	0.50	2.00	1.00	0.33
EPC33	3.00	2.00	3.00	3.00	1.00

Table 3.12 : A pair-wise comparison matrix for adverse mental states.

	EPC8	EPC9	EPC34	EPC35
EPC8	1.00	3.00	2.00	2.00
EPC9	0.33	1.00	3.00	1.00
EPC34	0.50	0.33	1.00	0.33
EPC35	0.50	1.00	3.00	1.00

Table 3.13 : A pair-wise comparison matrix for adverse physiological states.

	EPC27	EPC29	EPC30	EPC31	EPC35
EPC27	1.00	2.00	3.00	0.33	0.25
EPC29	0.50	1.00	3.00	0.50	0.33
EPC30	0.33	0.33	1.00	0.33	0.33
EPC31	3.00	2.00	3.00	1.00	0.50
EPC35	4.00	3.00	3.00	2.00	1.00

Table 3.14 : A pair-wise comparison matrix for physical-mental limitation.

	EPC5	EPC15	EPC27	EPC34
EPC5	1.00	0.33	2.00	3.00
EPC15	3.00	1.00	5.00	3.00
EPC27	0.50	0.20	1.00	2.00
EPC34	0.33	0.33	0.50	1.00

Table 3.15 : A pair-wise comparison matrix for crew resource management.

	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37
EPC10	1.00	2.00	3.00	0.20	2.00	3.00	4.00	5.00
EPC13	0.50	1.00	3.00	0.33	3.00	5.00	3.00	4.00
EPC14	0.33	0.33	1.00	0.20	0.50	3.00	0.33	3.00
EPC15	5.00	3.00	5.00	1.00	3.00	5.00	3.00	6.00
EPC16	0.50	0.33	2.00	0.33	1.00	3.00	1.00	5.00
EPC20	0.33	0.20	0.33	0.20	0.33	1.00	0.33	3.00
EPC25	0.25	0.33	3.00	0.33	1.00	3.00	1.00	5.00
EPC37	0.20	0.25	0.33	0.17	0.20	0.33	0.20	1.00

Table 3.16 : A pair-wise comparison matrix for personal readiness.

	EPC1	EPC11	EPC27	EPC35
EPC1	1.00	3.00	5.00	3.00
EPC11	0.33	1.00	4.00	0.50
EPC27	0.20	0.25	1.00	0.33
EPC35	0.33	2.00	3.00	1.00

Table 3.17 : A pair-wise comparison matrix for decision error.

	EPC4	EPC24	EPC32
EPC4	1.00	5.00	2.00
EPC24	0.20	1.00	0.25
EPC32	0.50	4.00	1.00

Table 3.18 : A pair-wise comparison matrix for skill-based error.

	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38
EPC1	1.00	3.00	2.00	5.00	2.00	3.00
EPC9	0.33	1.00	0.50	3.00	0.33	1.00
EPC10	0.50	2.00	1.00	3.00	0.50	2.00
EPC14	0.20	0.33	0.33	1.00	0.25	0.33
EPC23	0.50	3.00	2.00	4.00	1.00	3.00
EPC38	0.33	1.00	0.50	3.00	0.33	1.00

Table 3.19 : A pair-wise comparison matrix for perceptual error.

	EPC5	EPC6	EPC9	EPC12	EPC38
EPC5	1.00	0.50	0.33	0.25	0.50
EPC6	2.00	1.00	3.00	0.33	2.00
EPC9	3.00	0.33	1.00	0.33	0.25
EPC12	4.00	3.00	3.00	1.00	2.00
EPC38	2.00	0.50	4.00	0.50	1.00

Table 3.20 : A pair-wise comparison matrix for routine violations.

	EPC10	EPC13	EPC16	EPC17	EPC21
EPC10	1.00	2.00	3.00	5.00	3.00
EPC13	0.50	1.00	2.00	3.00	2.00
EPC16	0.33	0.50	1.00	3.00	2.00
EPC17	0.20	0.33	0.33	1.00	0.50
EPC21	0.33	0.50	0.50	2.00	1.00

Table 3.21 : A pair-wise comparison matrix for exceptional violations.

	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36
EPC1	1.00	3.00	2.00	4.00	5.00	4.00	6.00	5.00	6.00
EPC3	0.33	1.00	0.50	2.00	3.00	1.00	3.00	3.00	4.00
EPC10	0.50	2.00	1.00	2.00	3.00	2.00	4.00	3.00	5.00
EPC11	0.25	0.50	0.50	1.00	3.00	2.00	0.50	2.00	0.33
EPC14	0.20	0.33	0.33	0.33	1.00	0.50	3.00	2.00	3.00
EPC16	0.25	1.00	0.50	0.50	2.00	1.00	3.00	2.00	3.00
EPC17	0.17	0.33	0.25	2.00	0.33	0.33	1.00	0.50	1.00
EPC21	0.20	0.33	0.33	0.50	0.50	0.50	2.00	1.00	2.00
EPC36	0.17	0.25	0.20	3.00	0.33	0.33	1.00	0.50	1.00

Step 5. Calculating EPC weights: This step provides weighting of the EPC under relevant HFACS level by using equation (3.3). Thus, the prioritization of EPCs will be provided by quantification the subjective judgement of experts and confirm the consistency of data.

Step 6. Evaluating CR value: In this step, consistency of each comparison matrix is checked in order to get reasonable results. The CR values will be calculated in accordance with equation (3.4), (3.5) and (3.6). In this context, Table 3.22 shows priority weight of each EPCs as well as maximum matrix eigenvalue (λ_{max}), CI and CR values under corresponding HFACS levels. If the CR values are found equal or less than 0.10, the judgements of experts inserted in comparison matrix are considered as consistent. As can be seen in the Table, the findings of almost each comparison matrix are reasonable and consistent since the results of CR calculations are found more than 0.10.

Step 7. Quantifying EPC: After having weighted of each EPC under corresponding HFACS levels by adopting AHP method, each EPC column is accumulated vertically to find total EPC effect at the end. Table 3.23 illustrates the result of quantified EPCs. In the table, PW stands for priority weight of each EPC which is calculated

Table 3.22 : Priority weight, maximum matrix eigenvalue, CI and CR.

	EPCs	Priority weight	$\lambda_{\max}$	CI	CR
Resource management	EPC11	0.35	6.512	0.100	0.082
	EPC16	0.16			
	EPC19	0.12			
	EPC20	0.06			
	EPC22	0.07			
	EPC23	0.23			
Organisational climate	EPC8	0.56	3.018	0.009	0.015
	EPC18	0.12			
	EPC37	0.32			
Organisational process	EPC2	0.25	10.267	0.158	0.107
	EPC4	0.16			
	EPC7	0.05			
	EPC11	0.10			
	EPC12	0.13			
	EPC17	0.03			
	EPC21	0.13			
	EPC26	0.08			
	EPC28	0.07			
Inadequate supervision	EPC13	0.38	6.513	0.102	0.082
	EPC17	0.08			
	EPC20	0.13			
	EPC22	0.06			
	EPC26	0.19			
	EPC28	0.14			
Planned inappropriate operations	EPC2	0.40	5.308	0.077	0.068
	EPC8	0.24			
	EPC14	0.13			
	EPC16	0.18			
	EPC18	0.06			
Failed to correct problem	EPC2	0.52	3.053	0.026	0.046
	EPC7	0.14			
	EPC32	0.33			

Table 3.22 (continued) : Priority weight, maximum matrix eigenvalue, CI and CR.

	EPCs	Priority weight	$\lambda_{\max}$	CI	CR
Supervisory violation	EPC1	0.30	3.009	0.004	0.007
	EPC12	0.54			
	EPC14	0.16			
Physical environment	EPC5	0.17	4.298	0.099	0.088
	EPC19	0.11			
	EPC33	0.45			
	EPC36	0.27			
Technological environment	EPC3	0.15	5.194	0.048	0.043
	EPC13	0.26			
	EPC14	0.09			
	EPC32	0.12			
	EPC33	0.38			
Adverse mental states	EPC8	0.42	4.236	0.078	0.070
	EPC9	0.22			
	EPC34	0.12			
	EPC35	0.24			
Adverse physiological states	EPC27	0.15	5.343	0.085	0.076
	EPC29	0.13			
	EPC30	0.07			
	EPC31	0.25			
	EPC35	0.39			
Physical-mental limitation	EPC5	0.24	4.178	0.059	0.053
	EPC15	0.52			
	EPC27	0.14			
	EPC34	0.10			
Crew resource management	EPC10	0.18	8.762	0.108	0.077
	EPC13	0.17			
	EPC14	0.06			
	EPC15	0.32			
	EPC16	0.10			
	EPC20	0.04			
	EPC25	0.10			

Table 3.22 (continued) : Priority weight, maximum matrix eigenvalue, CI and CR.

	EPCs	Priority weight	$\lambda_{\max}$	CI	CR
Personal readiness	EPC1	0.51	4.164	0.054	0.048
	EPC11	0.19			
	EPC27	0.07			
	EPC35	0.23			
Decision error	EPC4	0.57	3.024	0.012	0.021
	EPC24	0.10			
	EPC32	0.33			
Skill-based error	EPC1	0.33	6.145	0.029	0.023
	EPC9	0.10			
	EPC10	0.17			
	EPC14	0.05			
	EPC23	0.25			
	EPC38	0.10			
Perceptual error	EPC5	0.08	5.476	0.119	0.106
	EPC6	0.22			
	EPC9	0.12			
	EPC12	0.38			
	EPC38	0.20			
Routine violations	EPC10	0.41	5.088	0.022	0.019
	EPC13	0.24			
	EPC16	0.17			
	EPC17	0.07			
	EPC21	0.12			
Exceptional violations	EPC1	0.30	10.190	0.148	0.101
	EPC3	0.13			
	EPC10	0.17			
	EPC11	0.09			
	EPC14	0.07			
	EPC16	0.10			
	EPC17	0.05			
	EPC21	0.05			
	EPC36	0.05			

calculated in step 6 and figured out in Table 3.22 entirely. Then, the total rough EPC effect is found by getting sum of each column vertically. For example, 1.42 is found for total EPC effect for EPC1. Accordingly, Table 3.24 shows rough marine-specific EPC values for MAHRA concept.

Table 3.23 : Quantification of EPCs.

	Resource	Organisational	Organisational	Inadequate	Planned
	P	W	P	W	P
	W		W		W
EPC38					
EPC37		0.32			
EPC36					
EPC35					
EPC34					
EPC33					
EPC32					
EPC31					
EPC30					
EPC29					
EPC28			0.07	0.14	
EPC27					
EPC26			0.08	0.19	
EPC25					
EPC24					
EPC23	0.23				
EPC22	0.07			0.06	
EPC21			0.13		
EPC20	0.06				
EPC19	0.12			0.13	
EPC18		0.12			0.06
EPC17				0.08	
EPC16	0.16		0.03		0.18
EPC15					
EPC14					0.13
EPC13				0.38	
EPC12			0.13		
EPC11	0.35		0.10		
EPC10					
EPC9					
EPC8		0.56			0.24
EPC7			0.05		
EPC6					
EPC5					
EPC4			0.16		
EPC3					
EPC2			0.25		0.40
EPC1					

Table 3.23 (continued) : Quantification of EPCs.

	Adverse mental	Technological	Physical	Supervisory	Failed to correct	
	PW	P W	P W	P W	P W	
EPC38						
EPC37						
EPC36	42'0		0.27			
EPC35	21'0					
EPC34						
EPC33		0.38	0.45		0.33	
EPC32		0.12				
EPC31						
EPC30						
EPC29						
EPC28						
EPC27						
EPC26						
EPC25						
EPC24						
EPC23						
EPC22						
EPC21						
EPC20			0.11			
EPC19						
EPC18						
EPC17						
EPC16						
EPC15				0.16		
EPC14		0.09				
EPC13		0.26				
EPC12				0.54		
EPC11						
EPC10	22'0					
EPC9	24'0					
EPC8					0.14	
EPC7						
EPC6			0.17			
EPC5						
EPC4		0.15				
EPC3						
EPC2					0.52	
EPC1				0.30		

Table 3.23 (continued) : Quantification of EPCs.

	Crew resource Physical/mental Adverse states				Personal	Decision error
	P	W	P	W	P	W
EPC38						
EPC37				0.03		
EPC36						
EPC35	0.39			0.23		
EPC34		0.10				
EPC33						0.33
EPC32						
EPC31	0.25					
EPC30	0.07					
EPC29	0.13					
EPC28						
EPC27	0.15	0.14		0.07		
EPC26						
EPC25			0.10			
EPC24						0.10
EPC23						
EPC22						
EPC21						
EPC20			0.04			
EPC19						
EPC18						
EPC17						
EPC16		0.52	0.10			
EPC15			0.32			
EPC14			0.06			
EPC13			0.17			
EPC12						
EPC11				0.19		
EPC10			0.18			
EPC9						
EPC8						
EPC7						
EPC6		0.24				
EPC5						
EPC4						0.57
EPC3						
EPC2						
EPC1				0.51		

Table 3.23 (continued) : Quantification of EPCs.

	Skill-based	Perceptual	Routine violations	Exceptional violations	TOTAL
EPC38	0.10	0.20			0.30
EPC37					0.35
EPC36				0.05	0.32
EPC35					0.86
EPC34					0.22
EPC33					0.83
EPC32					0.79
EPC31					0.25
EPC30					0.07
EPC29					0.13
EPC28					0.21
EPC27					0.36
EPC26					0.28
EPC25					0.10
EPC24					0.10
EPC23	0.25				0.48
EPC22					0.14
EPC21			0.12	0.05	0.30
EPC20					0.24
EPC19					0.23
EPC18					0.18
EPC17			0.07	0.05	0.23
EPC16			0.17	0.10	0.71
EPC15					0.84
EPC14	0.05			0.07	0.56
EPC13			0.24		1.05
EPC12		0.38		0.09	1.05
EPC11				0.17	0.72
EPC10	0.17		0.41		0.92
EPC9	0.10	0.12			0.44
EPC8					1.21
EPC7					0.19
EPC6		0.22			0.22
EPC5		0.08			0.48
EPC4					0.73
EPC3				0.13	0.28
EPC2					1.17
EPC1	0.33			0.30	1.42

Table 3.24 : Rough marine-specific EPC values.

Code	Error producing condition	Maximum affect
EPC1	Unfamiliarity with a situation which is potentially important but which only occurs infrequently or which is novel	1.42
EPC2	A shortage of time available for error detection and correction	1.17
EPC3	A low signal-noise ratio	0.28
EPC4	A means of suppressing or over-riding information of features which is too easily accessible.	0.73
EPC5	No means of conveying spatial and functional information to operators in a form which they can readily assimilate	0.48
EPC6	A mismatch between an operator's model of the world and that imagined by a designer	0.22
EPC7	No obvious means of reversing an unintended action	0.19
EPC8	A channel capacity overload, particularly one caused by simultaneous presentation of non-redundant information.	1.21
EPC9	A need to unlearn a technique and apply one which requires the application of an opposing philosophy	0.44
EPC10	The need to transfer specific knowledge from task to task without loss	0.92
EPC11	Ambiguity in the required performance standard	0.72
EPC12	A mismatch between perceived and real risk	1.05
EPC13	Poor, ambiguous or ill-matched system feedback	1.05
EPC14	No clear direct and timely confirmation of an intended action from the portion of th system over which control is to be exerted	0.56
EPC15	Operator inexperience	0.84
EPC16	An impoverished quality of information conveyed by person/person interaction	0.71
EPC17	Little or no independent checking or testing of output	0.23
EPC18	A conflict between immediate and long-term objectives	0.18

Table 3.24 (continued) : Rough marine-specific EPC values.

Code	Error producing condition	Maximum affect
EPC19	No diversity of information input for veracity checks	0.23
EPC20	A mismatch between the educational achievement level of an individual and the requirements of the task	0.24
EPC21	An incentive to use other more dangerous procedures	0.30
EPC22	Little opportunity to exercise mind and body outside the immediate confines of a job	0.14
EPC23	Unreliable instrumentation	0.48
EPC24	A need for absolute judgements which are beyond the capabilities or experience of an operator	0.10
EPC25	Unclear allocation of function and responsibility	0.10
EPC26	No obvious way to keep track of progress during an activity	0.28
EPC27	A danger that finite physical capabilities will be exceeded	0.36
EPC28	Little or no intrinsic meaning in a task	0.21
EPC29	High level emotional stress	0.13
EPC30	Evidence of ill-health among operatives, especially fever	0.07
EPC31	Low workforce morale	0.25
EPC32	Inconsistency of meaning of displays and procedures	0.79
EPC33	A poor or hostile environment	0.83
EPC34	Prolonged inactivity or highly repetitious cycling of low mental workload	0.22
EPC35	Disruption of normal work-sleep cycles	0.86
EPC36	Task pacing caused by the intervention of others	0.32
EPC37	Additional team members over and above those necessary to perform task normally and satisfactorily	0.35
EPC38	Age of personnel performing perceptual tasks	0.30

3.3.2 Validation of EPC

The traditional HEART method is based on data mining from different industry such as power plant, petrochemical industry, offshore platforms, and service industry to validate the EPCs. Instead of using data mining, this thesis utilises real marine accident causes for validation. The validation process of marine-specific EPC consists of six main steps which is provided in Figure 3.3. Since validation mainly utilises marine accident causality, the process begins with analysing of marine accident cases.

Step 1. Analysing marine accident cases: The purpose of this step is to provide real data using marine accident causes since the human factor is one of the most significant contributory factor of marine incidents. Therefore, totally 100 marine accident cases are examined and analysed to find out the causes of the marine incident. In order to reach accurate findings, those cases were selected in accordance with distribution of world fleet by principal dwt tonnage and percentage of accident causality (collisions, groundings, fires/explosions, machinery damage, listing, and other significant accidents) during 2014. Accordance to the UNCTAD report (2014), the world fleet consists of 42.9% bulk carriers, 28.5% oil tankers, 12.8% container ships, gas carrier & chemicals and continuing. Table 3.25 shows the detail of world fleet dwt tonnage in 2014.

Table 3.25 : Frequency of world fleet by principal dwt tonnage in 2014.

Vessel type	Percentage
Bulk carrier	42.9
Oil tanker	28.5
Container ship	12.8
Gas carrier+chemical	10.3
General cargo ship	4.6
Others (Ferry+passenger, etc.)	0.9

The EMSA report (2013) reveals that the majority of marine accident consists of collisions/contacts with 44%. The rest of causalities are sequentially 25% grounding, 12% fire&explosion, 8% machinery damage, 3% listing/capsizing, 4% flooding and 4% others. Table 3.26 illustrates marine accident causality around the Europe in accordance with EMSA 2013 report.

Table 3.26 : Marine accident causality in 2013.

Casualty type	Percentage
Collision/Contact	44
Grounding	25
Fire/Explosion	12
Machinery damage	8
Listing/Capesizing	3
Flooding	4
Others(FFO+cargo handling damage+weather damage,etc..)	4

The numbers of ship types upon marine accident causality with respect to percentage of 2013 is shown in table 3.27.

Table 3.27 : The number of ship frequency upon marine accident causality.

Vessel type	Collision/Contact	Grounding	Fire/Explosion	Machinery damage	Listing/Capsizing	Flooding	Others
Bulk carrier	19	10	5	3	1	2	2
Oil tanker	13	8	4	2	1	1	1
Container ship	6	3	2	1	0	0	1
Gas carrier+chemical	4	3	1	1	0	1	0
General cargo ship	2	1	1	0	1	0	0
Others (ferry+passenger..)	0	0	0	0	0	0	0

Step 2. Determining marine accident causes: The aim of this step is to determine and define marine accident causes in order to distribute towards HFACS level. After having analysed 100 different types of marine accident cases including collision/contact, groundings, fires/explosions, machinery damage, listing/capsizing, flooding and others (FFO, cargo handling damage, weather damage, etc.), relevant marine accident causes are identified. In conclusion, 692 marine causes were found out in 100 marine accidents around the world. This database involves approximately 406 different types of human errors from range of different investigation branches such as Marine Accident Investigation Branch (MAIB), Australian Transportation Safety Bureau (ATSB), National Transportation Safety Board (NTSB), Japan Transport Safety Board (JTSB) and Turkish Accident Investigation Board (KAİK). Table 3.28 provides an example of marine accident analysis in particular collision/contact case and their causes for bulk carrier vessels MV Paula C & MV Darya Gayatri (MAIB, 2013). In this table, “Ineffectively using the electronic aids during bridge watch” is one of the cause of collision/contact accident caused by human error. Likewise, “Inappropriate and not timely intervention on VHF radio” is

another example of marine accident cause. The entire list covering marine accident causes, type of accidents and vessel names are provided in Appendix B . In the table, “Insufficient anchor cable was deployed (C170)” is an example accident cause of grounding accident or “Using improper fire extinguisher (C220)” is one of the marine accident causes due to fire/explosion incident on-board ship.

Step 3. Distributing accident causes: This step utilizes the HFACS methodology in order to distribute 692 marine accident causes into relevant EPCs. Before distribution of marine accident causes, each of them is classified in respect of the HFACS framework under four-level hierarchical structure. For instance, “Ineffectively using the electronic aids during bridge watch (C1)” is kind of an active failure and classified under unsafe acts since it is typical error related with skill-based. Therefore, it is classified under unsafe acts-skill based error level. Similarly, “Poor watch keeping standards (C8)” is type of an accident cause (latent failures) and is classified under “organisation influences-organisational process” level since it involves standards determined by procedures.

Shappell and Wiegmann (2003) presented a detailed framework indicating how to make a proper classification for marine accident causes under HFACS levels. Accordingly, Table 3.29 illustrates the classification approach for organisational influences (Shappell and Wiegmann, 2003). For example, “Officer on watch (OOW) was the sole lookout on the bridge (C4)” is kind of a human error accumulated under organisation influences-resource management sub-level since the ship management company did not provide that the ship to be safely manned against principles of safe manning on-board. Therefore, the reason of C4 is due to negligence of staffing/manning. Likewise, “Not to comply with the requirements to keep a look out (C27)” is an example of human error accumulated under organisational influences-organisational climate. The COLREG clearly defines the requirements for lookout that every vessel shall at all times maintain a proper lookout to avoid risk of collision. Thus, the reason of C27 is not to comply with rules stipulated regulations.

Table 3.28 : An example of marine accident analysis in particular collision/contact case and their causes.

Type of accident	Vessel name	Cause code	Marine accident causes
Collision/ Contact	MV Paula C & MV Darya Gayatri	C1	Ineffectively using the electronic aids during bridge watch
		C2	Inappropriate and not timely intervention on VHF radio
		C3	Inexperienced OOW and insufficient competency to keep a bridge watch in constrain waters
		C4	OOW was the sole lookout on bridge
		C5	Not calling Master although clear instruction was given by ship management company
		C6	Unaware of the capabilities and limitations of the electronic systems (AIS, ARPA, ECDIS)
		C7	Not giving any sound signals when manoeuvring during the vessels were in close proximity
		C8	Poor watchkeeping standards

Table 3.29 : Classification approach for organisational influences.

ORGANISATIONAL INFLUENCES	Resource/Acquisition Management	Organisational Climate	Organisational Process
	Human resources	Structure	Operations
	Selection	Chain of command	Operational tempo
	Staffing/manning	Delegation of authority	Time pressure
	Training	Communication	Production quotas
		Formal accountability for actions	
	Monetary/budget resources		Incentives
	Excessive cost cutting	Policies	Measurement/appraisal
	Lack of funding	Hiring and firing	Schedules
	Equipment/facility resources	Promotion	Deficient planning
	Poor design	Drugs and alcohol	Procedures
	Purchasing of unsuitable equipment	Culture	Standards
		Norms and rules	Clearly defined objectives
		Values and beliefs	Documentation
		Organisational justice	Instructions
			Oversight
			Risk management
			Safety programs

In the light of above, Table 3.30 provides the classification approach for unsafe supervision level (Shappell and Wiegmann, 2003). For example, “Safety Management System (SMS) non-conformities were not identified during internal audit performed by management company (C31)” is a typical example of human error due to unsafe supervision-inadequate supervision since the internal audit was not properly inspected by the Designated person ashore (DPA). Therefore, C1 is classified under inadequate supervision due to failed to track performance. Similarly, “Late corrective action was performed (C48)” is classified under unsafe supervision-failed to correct problem level since the crew/operator failed to initiate corrective action on time.

Table 3.30 : Classification approach for unsafe supervision.

UNSAFE SUPERVISION	Inadequate Supervision	Planned Inappropriate Operations
	Failed to provide guidance	Failed to provide correct data
	Failed to provide operational doctrine	Failed to provide adequate brief time
	Failed to provide oversight	Improper manning
	Failed to provide training	Mission not in accordance with
	Failed to track qualifications	rules/regulations
	Failed to track performance	Provide inadequate opportunity for crew rest
	Failed to Correct Problem	Supervisory Violations
	Failed to correct document in error	Authorized unnecessary hazard
	Failed to identify an at-risk	Failed to enforce rules and regulations
	Failed to initiate corrective action	Authorized unqualified crew for flight
	Failed to report unsafe tendencies	

Furthermore, Table 3.31 shows the classification approach for precondition for unsafe acts (Shappell and Wiegmann, 2003). The table defines which conditions each sub-level contain in order to do correct classification of human error. For instance, “OOW was distracted by other tasks rather than keeping a lookout (C16)” is an example of human error classified under precondition for unsafe acts-adverse mental state since the error is occurred due to distraction. Likewise, “Master did not receive close navigational support from the chief officer (C40)” is another example of human error which is classified under precondition for unsafe acts-crew resource management. The reason of this classification is that the error is caused due to failing of communication/coordination.

The last classification system for active human failures are covered by unsafe acts. Table 3.32 illustrates the how classification approach is performed for unsafe acts (Shappell and Wiegmann, 2003). For example, “Unaware of both capabilities and limitations of the electronic systems (AIS, ARPA, ECDIS,etc..) (C6)” is kind of a human error classified under unsafe acts-skill based error since using of electronic systems basically depends on the ability and comprehensive skills of person. To give another example, “Not giving any sound signals when manoeuvring during the vessels in close proximity (C7)” is a human error classified under decision error type.

Table 3.31 : Classification approach for precondition for unsafe acts.

PRECONDITION FOR UNSAFE ACTS	Adverse Mental States	Crew Resource Management
	Channelized attention	Failed to back-up
	Complacency	Failed to communicate/coordinate
	Distraction	Failed to conduct adequate brief
	Mental fatigue	Failed to use all available resources
	Get-home-it is	Failure of leadership
	Haste	Misinterpretation of traffic calls
	Loss of situational awareness	
	Misplaced motivation	
	Task saturation	
	Adverse Physiological States	Personal Readiness
	Impaired physiological state	Excessive physical training
	Medical illness	Self-medicating
	Physiological incapacitation	Violation of crew rest requirement
	Physical fatigue	Violation of bottle to throttle requirement
	Physical/Mental Limitation	
	Insufficient reaction time	
	Visual limitation	
	Incompatible intelligence/aptitude	
	Incompatible physical capability	

According to the COLREG, if there is any doubt for risk of collision, each vessel shall use all available means appropriate such as giving sound signal, making proper manoeuvring or calling on VHF to avoid collision. Therefore, the reason of C7 is caused inappropriate manoeuvre performed by OOW and classified under decision errors.

The rest of marine accident causes are classified with same manner and then distributed into relevant EPCs for validation process. Accordingly, distribution of 692 marine accident causes under relevant HFACS levels are provided in Appendix B.

Step 4. Applying rank-weighting rule: In this step, each EPC is ranked in accordance with their importance level and weighted respectively under relevant HFACS sub-level. In the step, the experts provide the rank order for each EPC, which is inserted into relevant HFACS sub-level, with respect to the influence.

Table 3.32 : Classification approach for unsafe acts.

UNSAFE ACTS	Errors	Violations
	Skill-based errors	Failed to adhere to brief
	Breakdown in visual scan	Failed to use the radar altimeter
	Failed to prioritize attention	Flew an unauthorized approach
	Inadvertent use of controls	Violated training rules
	Omitted step in procedure	Flew an overaggressive manoeuvre
	Omitted checklist item	Failed to properly prepare for the flight
	Poor technique	Briefed unauthorized flight
	Over-controlled the craft	Not current/qualified for the mission
	Decision Errors	Intentionally exceeded the limits of the aircraft
	Improper procedure	Continued low-altitude flight in VMC
	Misdiagnosed emergency	Unauthorized low-altitude canyon running
	Wrong response to emergency	
	Exceeded ability	
	Inappropriate manoeuvre	
	Poor decision	
	Perceptual Errors (due to)	
	Misjudged distance/altitude/airs	
	Spatial disorientation	
	Visual illusion	

For instance, “Ineffectively using the electronic aids during bridge watch (C1)” has been classified under unsafe acts and distributed into skill-based error. There are six different EPC nominated in conjunction with skill-based error; EPC1, EPC9, EPC10, EPC14, EPC23 and EPC38. Since the effect of C1 will not be same for each EPC, it is necessary to determine each EPC effect related with marine accident cause. Therefore, rank-weighting rule is applied to rank the six EPCs with respect to their importance weight. In this context, rank reciprocal weights formula, provided in equation 3.7, is used (Stillwell et al., 1981).

$$w_j = \left(\frac{1}{r_j}\right) / \left(\sum_{k=1}^n \frac{1}{r_k}\right) \quad (3.7)$$

In the equation, r_j is the rank of j th attribute and n is the number of attributes at the handled problem. If more than one attributes have the same row or rank, their mean ranking is used. Marine experts list the most important attribute first and least important attribute last. Since there are five different expert judgements which have been obtained during elaborative survey, the data is reduced to one by getting

arithmetic mean of judgements. Appendix B illustrates the ranking and weighting result of each EPC in conjunction with marine accident causes. In the Table, first column shows the cause code of marine accident, the second column denotes the times of repeating causes and third column shows the ranking & weighting of EPCs. In the third column, the first row gives the EPCs in conjunction with accident cause, the second row provides the ranking order of EPCs and the last rows gives the EPC weights for each marine accident cause. To find out the EPC weights, equation (3.7) is used.

Step 5. Performing normalization: After having calculated ranking weight of each EPC under marine accident cause, normalization is performed for all EPCs which are accumulated corresponding HFACS level in order to adjust of EPC values. Table 3.33 gives the cumulative results of 692 marine accident causes classified under relevant HFACS sub-level and their normalized values. In the table, the first row shows the total accumulated EPC weight whilst second row gives their normalized value. In order to achieve that, the accumulated EPC weights inserted in first row is divided into total accident causes accumulated under resource management (73). For example, the ranking weight of EPC11 is 25.92 among the resource management and its normalized value is 0.36 among the all accident causes in resource management.

Step 6. Calculating validation weights: In this step, normalized each EPC column is summed vertically to find out total EPC effect at the end. In Table 3.34, last row shows the findings. The outcomes reveals that there are slight differences between the derived EPC values and validated EPC values for marine industry. Therefore, it is necessary to verify the findings that have been calculated in derivation section. To achieve this purposes, independence T test is used. The next step gives explanation as well as outcomes of t-test.

Step 7. Applying independent T-test: In this step, independent T-test is applied to verify whether results of derived marine-specific EPCs are matching with results of validated EPCs. The independent t-test, was presented in 1908, provides to compare average values of two different groups statistically (Box, 1987; Mankiewicz, 2004). The t-test compares the difference among two independent sample and the expectation that there is no big difference in the outcomes.

Table 3.33 : Cumulative results of 692 marine accident causes classified under relevant HFACS and their normalized values.

EPC38										
EPC37		0.29	12.00							
EPC36										
EPC35										
EPC34										
EPC33										
EPC32										
EPC31										
EPC30										
EPC29										
EPC28				0.04	3.88	0.19	10.46			
EPC27										
EPC26				0.06	5.30	0.22	11.84			
EPC25										
EPC24										
EPC23	0.23	16.70								
EPC22	0.07	5.14			0.10	5.39				
EPC21				0.07	6.67					
EPC20	0.08	6.05			0.14	7.57				
EPC19	0.10	7.39								
EPC18			0.19	7.91			0.09	2.85		
EPC17										
EPC16	0.16	11.73		0.05	4.87	0.08	3.94	0.18	5.84	
EPC15										
EPC14								0.11	3.46	
EPC13						0.27	14.73			
EPC12				0.14	13.71					
EPC11	0.36	25.92		0.09	8.47					
EPC10										
EPC9										
EPC8			0.52	21.27				0.31	9.78	
EPC7					0.04	3.90				
EPC6										
EPC5										
EPC4				0.19	17.67					
EPC3										
EPC2				0.32	30.90			0.31	10.07	
EPC1										
	73	1	42	1	95	1	54	1	32	1
	Resource	Organisational	Organisational	Organisational	Inadequate	Planned				

Table 3.33 (continued): Cumulative results of 692 marine accident causes classified under relevant HFACS and their normalized values.

	Adverse		Physical/mental		Crew resource		Personal		Decision error	
	12	1	4	1	51	1	4	1	56	1
EPC38										
EPC37					0,08	4.28				
EPC36										
EPC35	0.44	5.26					0.24	0.96		
EPC34			0.12	0.48						
EPC33									0.36	20.18
EPC32										
EPC31	0.22	2.63								
EPC30	0.09	1.05								
EPC29	0.15	1.75								
EPC28										
EPC27	0.11	1.31	0.16	0.64			0.12	0.48		
EPC26										
EPC25					0.11	5.53			0.18	10.18
EPC24										
EPC23										
EPC22										
EPC21										
EPC20					0,05	2.58				
EPC19										
EPC18										
EPC17										
EPC16					0,09	4.73				
EPC15			0.48	1.92	0,35	17.76				
EPC14					0,07	3.76				
EPC13					0,10	5.09				
EPC12										
EPC11							0.16	0.64		
EPC10					0,15	7.70				
EPC9										
EPC8										
EPC7										
EPC6										
EPC5			0.24	0.96						
EPC4									0.46	25.86
EPC3										
EPC2										
EPC1										

Table 3.33 (continued): Cumulative results of 692 marine accident causes classified under relevant HFACS and their normalized values.

EPC38	0.13	11.87	0.15	2.42			0.28
EPC37							0.37
EPC36						0.06	0.30
EPC35						1.75	0.92
EPC34							0.24
EPC33							0.79
EPC32							0.76
EPC31							0.22
EPC30							0.09
EPC29							0.15
EPC28							0.23
EPC27							0.39
EPC26							0.27
EPC25							0.11
EPC24							0.18
EPC23	0.21	18.65					0.44
EPC22							0.17
EPC21				0.17	9.77	0.05	1.57
EPC20							0.29
EPC19							0.27
EPC18							0.23
EPC17				0.09	5.40	0.04	1.19
EPC16				0.14	8.03	0.09	2.64
EPC15							0.66
EPC14	0.08	7.09				0.05	1.60
EPC13				0.31	18.01		0.83
EPC12			0.41	6.68			0.61
EPC11						0.09	2.71
EPC10	0.25	22.93		0.27	16.20	0.19	5.66
EPC9	0.07	6.63	0.13	2.15			0.87
EPC8							0.46
EPC7							1.20
EPC6			0.20	3.25			0.22
EPC5			0.10	0.64			0.20
EPC4							0.49
EPC3						0.16	0.65
EPC2						4.84	0.29
EPC1	0.23	20.89				0.28	1.13
	90	1	16	1	59	30	1.37
	Skill-based		Perceptual		Routine violations		TOTAL

The independent t-test can be calculated with following equations. In the equation (3.8), t denotes t-test.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad (3.8)$$

where

$$S_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}} \quad (3.9)$$

$$df = n_1 + n_2 - 2 \quad (3.10)$$

where

$\bar{x}_1$ denotes means of first sample $\bar{x}_2$ denotes means of second sample. Respectively;

S_p =pooled standard deviation,

n_1 = sample size of first sample,

n_2 = sample size of second sample,

s_1 =standard deviation of first sample,

s_2 =standard deviation of second sample,

df = degree of freedom,

In accordance with the equations (3.8), (3.9) and (3.10), Table 3.34 illustrates the independent t-test results driven by SPSS. In addition, Table 3.35 gives the statistical data information with respect to the samples. According to Levene's test, which is used prior a comparison of means, the variances of the data obtained from AHP and analysis of marine accident case are almost equal since significant level is larger than test value 0.05. The two-tailed value of p is 0.987, which is greater than 0.05, and it means that there is no significant difference between the means of two samples. In terms of the experiment, it can be inferred that the outcomes gathered from analysis of marine accident case is the same with the outcomes obtained from AHP in 98 % confidence interval.

Table 3.34 : Independent t-test results.

Independent Samples Test										
		Levene's Test for Equality of Variances		T-test for Equality of Means						
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference	
									Lower	Upper
Test	Equal variances assumed	0.198	0.658	0.016	74	0.987	0.00132	0.08123	-.21344	.21607
	Equal variances not assumed			0.016	73.746	0.987	0.00132	0.08123	-.21346	.21609

Table 3.35 : Statistical data information with respect to the samples.

Group Statistics					
	Groups	N	Mean	Std. Deviation	Std. Error Mean
Test	Data from AHP	38	0.4989	0.36430	0.05910
	Data from analysis of marine accident cases	38	0.4976	0.34351	0.05573

Step 8. Interpolation of EPCs: In this step, the validated EPC values are converted to acceptable limits by interpolating. The validated rough EPC with the highest value is compared with the highest EPC value in conventional HEART method to obtain interpolation ratio. In this context, equation (3.11) is used.

$$I_r = \frac{x_{max.}}{y_{max.}} \quad (3.11)$$

where ;

I_r : interpolation ratio

$x_{max.}$: the maximum EPC value in conventional HEART approach,

$y_{max.}$: the maximum validated rough EPC value in MAHRA approach,

Then, interpolation ratio is determined and applied through values of validated rough EPC at the same rate. To accomplish this, each validated rough EPC values is multiplied with interpolation ratio (I_r) respectively (equation 3.12). Thus, the effects of single EPC can be revealed in acceptable limits.

$$EPC_d = I_r \times EPC_\theta \quad (3.12)$$

where EPC_d denotes values of marine-specific EPC for MAHRA approach, EPC_θ denotes validated rough EPC values which is provided in Table 3.25. Accordingly, Table 3.36 shows the marine-specific EPC values for MAHRA approach. Since EPC is a simple multiplication factor for GEP value and affects human performance negatively, the EPC value which is less than 1.0 has no great influence on HEP value. Therefore, EPC30 have no considerable effects upon MAHRA concept.

Table 3.36 : Marine-specific EPC values for MAHRA approach.

Code	Error producing condition	Maximum affect
EPC1	Unfamiliarity	17.00
EPC2	Time shortage	14.01
EPC3	Low signal-noise ratio	3.31
EPC4	Features over-ride allowed	8.72
EPC5	Spatial and functional incompatibility	5.76
EPC6	Model mismatch	2.64
EPC7	Irreversibility	2.23
EPC8	Channel overload	14.45
EPC9	Technique unlearning	5.29
EPC10	Knowledge transfer	11.00
EPC11	Performance ambiguity	8.60
EPC12	Misperception of risk	12.51
EPC13	Poor feedback	12.55
EPC14	Delayed/incomplete feedback	6.72
EPC15	Operator inexperience	10.03
EPC16	Impoverished information	8.42
EPC17	Inadequate checking	2.79
EPC18	Objectives conflict	2.15
EPC19	No diversity	2.74
EPC20	Educational mismatch	2.88
EPC21	Dangerous incentives	3.62
EPC22	Lack of exercise	1.64
EPC23	Unreliable instruments	5.69
EPC24	Absolute judgements required	1.17
EPC25	Unclear allocation of function	1.22
EPC26	Progress tracking lack	3.28
EPC27	Physical capabilities	4.35
EPC28	Low meaning	2.56
EPC29	Emotional stress	1.59
EPC30	ill-health	0.89
EPC31	Low morale	3.00
EPC32	Inconsistency of displays	9.43
EPC33	Poor environment	9.90
EPC34	Low mental workload	2.63
EPC35	Sleep cycles disruption	10.30
EPC36	Task pacing	3.85
EPC37	Supernumeraries	4.14
EPC38	Age	3.61

3.3.3 Findings

In the light of table 3.36, EPC1 (Unfamiliarity) has the highest value since most of shipboard operations require specific task knowledge and familiarity. Therefore, ship crew/seafarers are requested to be familiar with situation and have knowledge of the

tasks. EPC8 (channel overload) has the second highest value (14.45) among the whole error producing conditions since heavy work load may lead confusion of the crew during specific task being performed. The third most important one is EPC2 (time shortage) while its value (14.01) ranks third place among the entire EPCs. Time shortage is one of the most critical factors on-board ships since it may result in pressure on ship crew and lead to make error during critical shipboard operations.

On the other hand, EPC30 (ill-health) has the lowest value (0.89) since ship crew are not allowed to work on critical shipboard operations until he/she is recovered. The second lowest ones are EPC24 (absolute judgement required) and EPC25 (unclear allocation of function) respectively. Absolute judgement is not required while performing a critical operation since shipboard cooperation and advisory is highly appreciated. Likewise, unclear allocation of function is prevented by organisations adopting safety management system which provides procedure and work allocation instruction on-board ship. EPC29 (high-level emotional stress) has the third lowest value in the whole assessment. If the high-level emotional stress is observed on ship crew, he will be repatriated in the next available port of call and is not allowed to attempt undertaking work requiring high reliability in ship environment.

In this context, provisional list of quantified EPCs developed for MAHRA is compared with the other methods which are based on tailoring the basic principle of the HEART. Table 3.37 depicts the comparison of maximum EPC effects in MAHRA, HEART, NARA, CARA and RARA methods. The outcomes of the comparison show that the effects of a single EPC can be seen clearly in MAHRA approach. The review of marine-specific EPCs has resulted that numerous EPCs are modified (either decreasing or increasing their maximum effect). For instance, the maximum effect of EPC2 (time shortage) or EPC33 (poor environment) are increased since those are quite important conditions in shipboard environment. On the other hand, the maximum effect of EPC3 and EPC6 are decreased sharply as those factors do not have significant impact in shipboard environment. In addition, the maximum effect of EPC 35 is considerably increased compared with conventional HEART as well as other similar methods. The reason of that sleep cycle is vital for crew member on-board ship as it directly impacts mental and physical conditions. Moreover, crew on-board ship without proper sleep are likely to make more mistakes particularly during critical shipboard operations due to fatigue.

Table 3.37 : Comparison of EPC in MAHRA, HEART, NARA, CARA and RARA.

Code	Maximum EPC effect				
	MAHRA	HEART	NARA	CARA	RARA
EPC1	17.00	17.00	20.00	20.00	17.00
EPC2	14.01	11.00	11.00	11.00	11.00
EPC3	3.31	10.00	10.00	N/A	10.00
EPC4	8.72	9.00	9.00	N/A	9.00
EPC5	5.76	8.00	N/A	N/A	8.00
EPC6	2.64	8.00	N/A	N/A	8.00
EPC7	2.23	8.00	9.00	N/A	8.00
EPC8	14.45	6.00	6.00	6.00	6.00
EPC9	5.29	6.00	24.00	24.00	8.00
EPC10	11.00	5.50	N/A	N/A	5.50
EPC11	8.60	5.00	N/A	N/A	5.00
EPC12	12.51	4.00	N/A	N/A	4.00
EPC13	12.55	4.00	4.00	5.00	4.00
EPC14	6.72	4.00	N/A	N/A	N/A
EPC15	10.03	3.00	8.00	N/A	3.00
EPC16	8.42	3.00	3.00	5.00	3.00
EPC17	2.79	3.00	10.00	3.00	3.00
EPC18	2.15	2.50	2.50	N/A	2.50
EPC19	2.74	2.50	N/A	N/A	N/A
EPC20	2.88	2.00	N/A	N/A	N/A
EPC21	3.62	2.00	2.00	N/A	N/A
EPC22	1.64	1.80	N/A	N/A	1.80
EPC23	5.69	1.60	N/A	1.60	N/A
EPC24	1.17	1.60	N/A	N/A	N/A
EPC25	1.22	1.60	N/A	N/A	1.60
EPC26	3.28	1.40	2.00	N/A	N/A
EPC27	4.35	1.40	N/A	N/A	1.40
EPC28	2.56	1.40	N/A	N/A	1.40
EPC29	1.59	1.30	2.00	5.00	2.00
EPC30	0.89	1.20	N/A	N/A	N/A
EPC31	3.00	1.20	2.00	2.00	1.20
EPC32	9.43	1.20	N/A	N/A	N/A
EPC33	9.90	1.15	8.00	N/A	8.00
EPC34	2.63	1.10	N/A	N/A	1.10
EPC35	10.30	1.10	N/A	N/A	N/A
EPC36	3.85	1.06	N/A	N/A	N/A
EPC37	4.14	1.03	N/A	N/A	N/A
EPC38	3.61	1.02	N/A	N/A	N/A

3.3.4 Proportion affect assessment

The assessed proportion of affect is one for the critical point during HEP calculation. The significant point in calculating APOA should be an assessment of the impact of EPC upon the reliability of the task. In conventional HEART approach, if there are more than one EPCs, the experts assign a proportion of the effect which is weighted (prioritised) for each EPC based on its importance. Instead of conducting traditional APOA assessment, this thesis proposes to apply smart solution utilising the AHP technique to weight the importance of each EPC since they are weighted from 0 to 1. So that, the methodological extension improves the consistency of the calculation during HEP calculation. In order to apply APOA calculation in MAHRA, equations (3.2), (3.3), (3.4), (3.5) and (3.6) will be conducted respectively. The APOA calculation will be applied for each sub-task being assessed, if there are more than one EPCs are assigned.

3.4 System Application

This section explains the system application to establish MAHRA approach. A flow diagram of MAHRA concept is illustrated in Figure 3.6. The system includes marine-specific EPCs and APOA calculation as innovation. The main steps of the MAHRA are briefly explained as follows.

3.4.1 Task analysis

The aim of this stage is to define the relevant task in accordance with the scenario which is including main and sub-tasks on-board ship. The task or activity is the definition of steps which crew must complete during shipboard operation. This is performed in line of hierarchical task analysis (HTA) where main tasks are divided into sub-tasks (Shepherd, 2001). In accordance with scenario, HTA may include pre-activities, activities and post-activities. Each sub-tasks/activities can give detail about the main tasks. The HEP value for each sub-tasks can be calculated one by one and combination of them can give final HEP value with respect to correlation between the sub-tasks. Thus, human error probability (respectively human reliability) can be estimated.

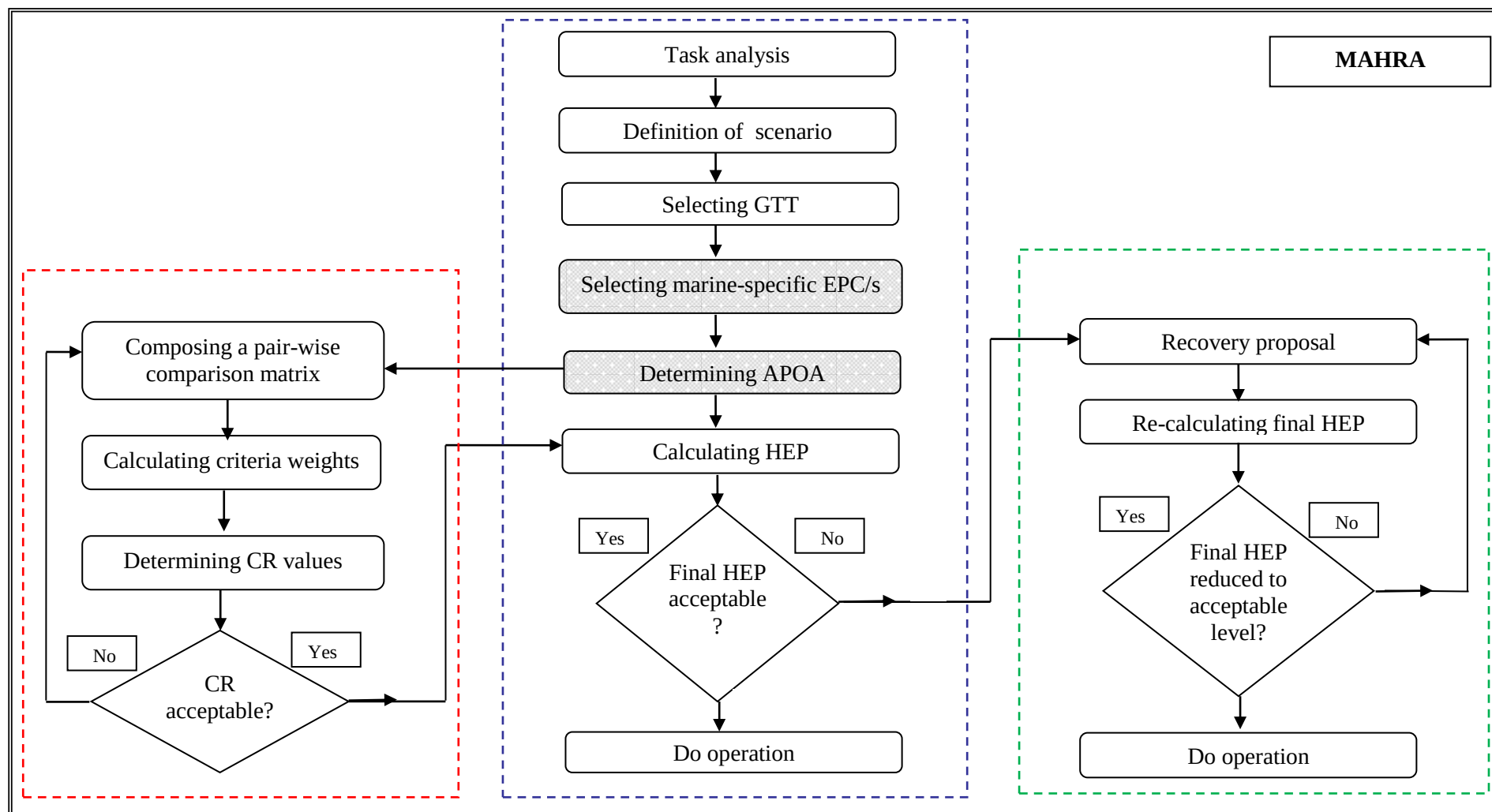


Figure 3.6 : Flow diagram of MAHRA.

3.4.2 Definition of scenario

After having completed task analysis, various scenarios representing in a broad sense will be defined. These scenarios include numerous conditions such as working environment, operator/crew experiences, noise level, stress, operator/crew workforce morale, disruption, available time for task, time of day or organisation quality, etc. In accordance with scenario developed by the shipboard environment, the marine experts will obtain the corresponding EPCs. The relevant scenario will be either developed in real shipboard case or simulation. For instance, shipboard working environment is one of the substantial condition during the executing of the operation. A poor or hostile working environment on-board ship may induce to human error and increase HEP during critical shipboard operations. Another critical condition is time of day that task is being since numerous crew on-board ship may suffer from the disrupted sleep cycle particularly at night shifts. If the tasks such as manoeuvring, bunkering, cargo loading or discharging perform at night hours, sleeplessness and fatigue will show up as lack of attention. This could cause human error and increase HEP as well.

3.4.3 Selecting generic task type

This section provides user to select relevant generic task type in accordance with sub-tasks. The relevant generic task type is determined in accordance with the eight qualitative descriptions of actions through A to M (William, 1988). Then, quantitative GEP value is assigned for each sub-step in conjunction with generic task type. The experts will nominate the corresponding GTT and GEP values. Table 3.38 illustrates the generic task and nominal human unreliability (or GEP value) (William, 1988). In MAHRA approach, similar GEP values are adopted as presented in traditional HEART since they are generic and extracted from a variety of sources including petrochemical and off-shore. For example, if crew is fairly experienced and has satisfactory skill for the sub-task that is being applied, the experts will probably select general task type “G” which best matches the specific task being assessed (Kirwan and Gibson, 2008). If the crew member does not understand the process completely and he has not enough knowledge for the process, the experts will assign GTT “C” which is most fitted for specific task.

Table 3.38 : Generic task type and nominal human unreliability (William, 1988).

Generic task type		Nominal human unreliability (5 th -95 th Percentile bounds)
A	Totally unfamiliar; performed at speed with no real idea of likely consequences.	0.55 (0.35 - 0.97)
B	Shift or restore system to a new or original state on a single attempt without supervision or procedures.	0.26 (0.14 – 0.42)
C	Complex task requiring high level of comprehension and skill.	0.16 (0.12 – 0.28)
D	Fairly simple task performed rapidly or given scant attention.	0.09 (0.06 – 0.13)
E	Routine, highly practiced, rapid task involving relatively low level of skill.	0.02 (0.07 – 0.045)
F	Restore or shift a system to original or new state following procedures with some checking.	0.003 (0.0008 – 0.007)
G	Completely familiar, well-designed, highly practiced, routine task occurring several times per day, performed to highest possible standards by highly motivated, highly trained, and experienced personnel, with time to correct potential error, but without the benefit of significant job aid.	0.0004 (0.00008 – 0.009)
H	Respond correctly to system command even when there is an augment or automated supervisory system providing accurate interpretation of system state.	0.00002 (0.000006 – 0.0009)
M	Miscellaneous task for which no description can be found.	0.03 (0.008 – 0.11)

3.4.4 Selecting marine-specific EPC/s

After having determined GEP values as per generic task type, relevant marine-specific EPC/s are nominated by experts. The EPC is considered to affect human performance negatively therefore it may increase the GEP value. The experts will utilise table 3.36 during EPC nomination. The EPC/s are assigned for each sub-steps

depend on the condition of operator/crew. There would be more than one EPCs for each sub-task. For instance, if the crew/operator has little experience for the sub-task being performed or there is not enough time for this job, the experts will select EPC15 and EPC2 respectively.

3.4.5 Determining APOA

This step provides to assess proportion effect of each EPC if there are more than one EPCs selected for relevant sub-task. This thesis proposes smart solution to distribute weight of each EPC reasonably (Akyuz and Celik, 2015a).

3.4.5.1 Composing a pair-wise comparison matrix

If there are more than one EPCs, a pair-wise comparison matrix is established by using relative importance scale. In this context, equation (3.2) will be applied. The experts are asked to compare each criteria with respect to Saat's linguistic scale which is provided in Table 3.1.

3.4.5.2 Calculating criteria weights

This step provides weight prioritization for each EPC by using equation (3.3). Thus, relative importance of EPCs will be weighted accordingly.

3.4.5.3 Determining CR values

In order to make sure that pair-wise comparison matrix is consistent and reasonable during EPCs relative weight calculation, CR values are calculated in accordance with equation (3.4), (3.5) and (3.6). If the CR values are found more than 0.10, the judgements inserted by experts are considered as inconsistent. In this case, the judgement inserted into the pair-wise comparison matrix shall be revised and re-calculated once again. If the CR values are equal or less than 0.10, the experts' judgements are considered consistent and reasonable.

3.4.6 Calculating HEP value

This stage enables user to calculate HEP value for each sub-task and main tasks. To achieve this purpose, equation (3.1) will be used. The equation simply multiply GEP value with EPC value. For instance, if the user selects EPC1 (unfamiliarity) with maximum effect of 17.0 and GTT E (Routine, highly practiced, rapid task involving relatively low level of skill) with a human error probability of 0.02, the total HEP affect will be 0.02×17.0 and HEP value is 0.34. This means that the reliability of operator/crew for the sub-task has been made 17 times worse. If there are more than one EPC selected, the multiplicative rule will be applied (Gibson et al., 2012). In the formula, 1 is subtracted from the maximum effect of selected EPC and added again at the end of calculation. The aim of this is to make sure that calculated APOA does not generate a value smaller than one.

After having calculated HEP for each sub-task, dependency can be addressed by ensuring that integration of human errors combined together in a HTA PSA. Since main task is divided into sub-tasks to obtain final HEP, the correlation between the sub-tasks will be provided accordingly. Thus, dependency between the main and sub-tasks HEP values will be provided. Table 3.39 shows the notations for dependency rule to find out the final HEP values (Akyuz and Celik, 2015a; He et al., 2008).

Table 3.39 : Notations for dependency rule (He et al., 2008).

System description	System sub-task dependency	Notation for HEP
Parallel system	High dependency	$HEP_{Task} = Min\{HEP_{Sub-task\ i}\}$
	Low or no dependency	$HEP_{Task} = \prod(HEP_{Sub-task\ i})$
Serial system	High dependency	$HEP_{Task} = Max\{HEP_{Sub-task\ i}\}$
	Low or no dependency	$HEP_{Task} = \sum(HEP_{Sub-task\ i})$

In the HTA PSA, the following rules are used to decide whether the system is parallel or serial. If the failure of part induces the system becoming inoperable, then system is considered as serial. In other words, the entire system will fail in case any one of the system parts fails. In the serial system, it is necessary to success of every individual part. On the contrary, the system is considered as parallel where entire system works as long as not all the system parts fail.

In the light of above, if two tasks in the system are serial then in case failure one of them induce the system inoperable. If two tasks in the system are parallel then entire system works as long as not all of the tasks fail.

3.4.7 Recovery proposal

In case final HEP value is found higher than desired level (DiMattia et al., 2005), recovery proposal will be recommended in order to reduce probability of human error. In this step, appropriate mitigation measures are taken for EPCs which may cause to increase HEP values.

Before taking appropriate mitigation measures, it is checked whether final HEP value is acceptable level or not. To accomplish this, DiMattia et al.(2005) risk matrix is used. In the matrix, illustrated in Figure 3.7, the probability of human failure is combined with the consequence of severity. The colour of each block indicates the level of immediate recovery action needed. In the risk matrix, the HEP value is categorized into four different level of $1.00E+00$ to $1.00E-01$, $1.00E-01$ to $1.00E-02$, $1.00E-02$ to $1.00E-03$, and $1.00E-03$ to $1.00E-04$ (DiMattia et al., 2005; Akyuz and Celik, 2015a).

HEP value	Consequences severity				
	Critical	High	Medium	Low	Warning
$1.00E+00$ to $1.00E-01$					
$1.00E-01$ to $1.00E-02$					
$1.00E-02$ to $1.00E-03$					
$1.00E-03$ to $1.00E-04$					

*High risk

*Lower risk

*Lowest risk

Figure 3.7 : Risk matrix (DiMattia et al., 2005).

If the final HEP value is placed inside the red boxes, then recovery proposal is needed to mitigate human error probability into desired level (lower risk level- yellow blocks). In this context, error reduction measures for relevant EPCs are proposed to remove the impacts of error producing conditions.

3.4.8 Re-calculating final HEP

After having proposed recovery measures, the EPCs which have the maximum effect on HEP can be removed. Thereafter, re-calculation will take a place whether final HEP value is reduced to acceptable level or not. Within this context, equation (3.1) is applied. In case re-calculated final HEP value is not decreased into desired level (lower risk level- yellow blocks), the recovery measure shall be revised and final HEP re-calculated once again.

4. DEMONSTRATION

In this part, an illustrative example involving cargo discharging operation on-board chemical tanker is presented to demonstrate the MAHRA approach since cargo discharging operation has always potential risk in chemical tankers in terms of marine environment, human life and property. In this context, the next step defines the carriage of chemical cargo in tanker ships.

4.1 Carriage of Chemical Cargo in Tanker Ship

Carriages of chemical commodities have been increasing substantially in recent years. In order to meet this demand, special types of vessels are designed- chemical tankers which are able to carry numerous different cargoes of different characteristics and inherent hazards. Some of the chemical cargoes are petrochemicals including products of crude oil, natural gas and coal; alcohols and carbohydrates; acids and inorganic chemicals and vegetable, animal oil. The chemical cargoes transportation is different from any other dry or liquid bulk cargo carriage since a variety of different properties and characteristics hazards might be carried.

The IBC Code is introduced by IMO and describes standards for chemical tankers involved in the carriage of chemical products. It comprises more than 600 chemical cargoes, addressing pollution category, hazard characteristics and specific requirements. Chemical tankers are generally designed with the highest specification and they are capable of transporting a variety of chemical products. Moreover, most of chemical tankers have fully segregated cargo handling system to enable safe and efficient transportation of products. While various dangerous chemical products are carried in the world seas, the following special types of chemical tankers are designed complying with the IBC Code (Akyuz and Celik, 2015a; IBC Code, 2007).

IMO Type I: This type of chemical tankers are designed to transport very severe environmental and hazards cargoes such as acid, phenol, phosphorous,

chlorosulphonic acid, phosphate, etc. Therefore, these types of tankers are required maximum preventive measures since the cargoes are very dangerous (IBC Code, 2007).

IMO Type II: This type of chemical tankers are built to carry less severe environmental and hazards cargoes than IMO Type I. For example, alcohols, benzyl acetate, cyclohexanol, phenol, palm oil, which may cause still substantial damage, are transported by this type of tankers. Therefore, significant preventive measures are still required. (IBC Code, 2007).

IMO Type III: This type of chemical tankers are designed to transport chemical cargoes such as hexanol, ethanol, methyl alcohol, propylene, sulphuric acid which may cause minor damage to the crew, marine environment and ship. Therefore, moderate preventive measures are required. (IBC Code, 2007).

In the light of above, IMO type I tanker ships are designed for the greatest hazardous chemical cargoes. Therefore, the cargo tanks of the IMO type I shall be robust to resist the most dangerous cargoes. According to the IBC Code (2007), four types of cargo tanks are designed for chemical tankers. These are independent, integral, gravity and pressure tanks. The most common cargo tank is used on-board chemical tankers is independent type which is able to eliminate stress to ship structure to minimise the risk to the ship. The independent type of cargo tanks can be either stainless steel or coated steel. The stainless steel tanks are the most resistant for aggressive cargoes and acids which are broadly carried by IMO type I chemical tankers. The chemical tanker installed with stainless steel provides easier tank cleaning.

4.2 Problem Description

The chemical tanker is special type of ships designed to carry petrochemical products in liquid form. Since the petrochemical products shipping has been increasing in marine industry, their carriage requires utmost attention due to the inherently hazardous content such as being explosive, poisonous and corrosive as well as toxic (IMDG Code, 1996). These hazardous products may have potential damage for crew on-board ship, environment and property. Therefore, the carriage of the chemical product by chemical tanker ships is quite critical process involving serious tasks for

responsible crew on-board ship (Akyuz and Celik, 2015a). Moreover, particular attention is given by crew on-board ship during critical shipboard operations such as cargo loading or discharging, gas inerting, tank cleaning, purging. Since most of cargoes carried by chemical tanker ship represent utmost hazards (may be flammable, corrosive or toxic) for marine environment, human life and properties, chemical tanker fleets require qualified crew who understand the characteristics of the chemicals and be aware of the potential hazards involved. The expectation from the crew is to perform system-required task without any misperception or violations which might cause an operational failure. So that, chemical tanker organisations should proactively control and prevent the possible catastrophe using advance techniques. In this context, crew/human reliability on-board ship has been a serious concern in marine industry in particular during the critical shipboard operations such as cargo loading or discharging (Akyuz and Celik, 2015b).

Cargo discharging operation in chemical tankers can pose potential harm to human life and marine environment if the cargo being discharged is extremely flammable or toxic. A catastrophic problem can arise at the operational level of the chemical tankers. During the discharging operation, it is necessary to comply with the requirements of the SOLAS and MARPOL conventions to prevent loss of life and environment pollution. Particular attention shall be paid in order to prevent contamination of next cargo, ignition or toxic. Therefore, it is imperative that all precautionary steps are taken to avoid any leakage and to limit all source of ignition. At this stage, human reliability and awareness play a critical role in sustainable maritime transportation with the highest level of safety and loss prevention sensitiveness. Thus, crew reliability shall be analyse to mitigate potential operational human failure while performing cargo discharging operations on-board chemical tanker ships (ICS, 2014).

4.3 Cargo Discharging Operation in Chemical Tanker Ship

Carriage of chemical products can be divided into three stage; cargo loading, transportation and cargo discharging. Since one of the main objectives of this thesis is to systematically predict human error for designated task and to ascertain the required safety control levels on-board chemical tanker ships, the cargo discharging operation is selected as illustrative case study. As the chemical tankers are designed

with completely independent cargo systems, each cargo tank has an independent pumping and venting system. Discharging operation should be therefore pre-planned and if the different cargo parcels are discharged, then it will be performed according to the plan. Furthermore, all cargo pumps valves and equipment are tested prior to discharging operation. The discharging operation is performed by vessel own cargo pumps. The process can be divided into three section; pre-action, action and post-action. To demonstrated the MAHRA approach, cargo discharging process in chemical tanker ship is applied into a real-time case study on-board ship. The cargo is propylene oxide (Annex II, cat.Y) which is carried with IMO type-II chemical tankers. The propylene oxide is one of the hazardous cargoes that is being transported on the high seas. If it contacts with combustible materials or water, this may cause fire or explosion. It can pose potential harm to the human body. During storage at cargo tanks, it is not stowed near the combustible materials as well as reacting with heat (IBC Code, 2007). The comprehensive information about the cargo is provided in Appendix A. In this context, Table 4.1 shows the discharging process of propylene oxide in chemical tanker ships.

Table 4.1 : Discharging process of propylene oxide cargo.

Step	Operational process
PRE-ACTION	1. Prepare deck for discharging operation
	1.1 Make sure that proper cargo discharging plan is ready
	1.2 Ensure that terminal re-confirm the discharging plan
	1.3 Calculate cargo quantity to be discharged
	1.4 Get confirmation for discharging quantity and discharging procedure from the terminal
	1.5 Make sure that ship/shore safety check is completed
	1.6 Connect the bonding cable
	1.7 Ensure all crew on-deck has personnel protective equipment
	1.8 Check if emergency shower and eye washer is ready
	1.9 Arrange sponge, rags and saw dust , ect (SMPEP) on deck in case of pollution
	1.10 Make sure that necessary samples have been taken from cargo tanks
	1.11 Separate unused cargo lines and cargo hoses
	1.12 Make sure that all drain plugs are in position
	1.13 Check if the cargo temperature is available
	1.14 Re-calculate ship stability as per harbour condition in terms of SF/BM
	1.15 Make sure that no source of ignition around the manifold area
	2. Prepare engine room for discharging operation
	2.1 Ensure that power packs are ready
	2.2 Check if the cargo tank cofferdam blown with nitrogen properly
	2.3 Make sure that generators are ready

Table 4.1 (continued) : Discharging process of propylene oxide cargo.

Step Operational process	
	2.4 Make sure that no steam to be injected into the tanks unless otherwise instructed
	2.5 Maintain discharge heat for efficient cargo pumping
ACTION	3. Check out valves and alarms
	3.1 Make sure that all warning signs are displayed
	3.2 Check if the status of open/shut valves are displayed at cargo control room as well as on deck
	3.3 Set P/V valves in manual /automatic open position in accordance with IBC Code
	3.4 Make sure that all cargo lines, hoses and valves are re-checked by duty officer
	3.5 Ensure HL / HHL alarm is run
	4. Prepare manifold area
	4.1 Make sure that all cargo lines are clean
	4.2 Check if all cargo lines and hoses are connected properly and ready for use
	4.3 Ensure unused manifold fully blinded
ACTION	4.4 Make sure that all plugs are removed and drain cocks shut.
	4.5 Make sure that manifold is connected to the marine loading arm properly
	4.6 Test the manifold connection with air and soap water
	4.7 Re-check maximum discharge rate and get confirmation from terminal
	4.8 Make sure that internal stripping of tanks is discharged against high back pressure
	4.9 Check if vapour return hoses and valves are ready
	5. Commence cargo discharging process
	5.1 Open manifold valve
	5.2 Start cargo discharging pumps with slow rate
	5.3 Inform terminal to commencement of discharging
ACTION	5.4 Check level gauges and UTI tapes
	5.5 Set the pressure gauge on the manifold
	5.6 Make sure that necessary samples have been taken from manifold drain
	6. Check stability of ship
	6.1 Check vessel stability condition frequently in particular SF/BM
	6.2 Arrange ballast condition of vessel
	6.3 Calculate discharged cargo quantity frequently
	7. Monitor cargo discharging process
	7.1 Make sure that duty officer is in cargo control room and monitoring the operation
	7.2 Provide good communication between CCR, manifold area and terminal
POST-ACTION	7.3 Monitor cargo discharging sequence
	7.4 Monitor manifold pressure and cargo flow rate
	7.5 Make sure that stripping of cargo tanks are commenced
	8. Complete cargo discharging process
	8.1 Get confirmation from the terminal for completion of discharging
	8.2 Stop cargo pumps and inform engine room
	8.3 Calculate final cargo quantity to be discharged
	8.4 Obtain the tank dry certificate
	8.5 Make sure that line blowing is conducted properly
	8.6 Check if all cargo valves are shut off
	8.7 Disconnect marine loading arm from the ship manifold

As it is seen on the table, task analysis of propylene oxide cargo discharging process has mainly eight steps; i)prepare deck for discharging operation, ii)prepare engine room for discharging operation, iii)check out valves and alarms, iv)prepare manifold area, v) commence cargo discharging process, vi)check stability of ship, vii)monitor cargo discharging process, viii)complete cargo discharging process and fifty-five sub-steps.

Prior discharging operation, deck preparation will take a place. This step includes sub-steps 1.1 to 1.15. The second step is preparing engine room. It includes sub-step 2.1 to 2.5. Thereafter, valves and alarms are checked in accordance with sub-steps 3.1 to 3.5. Manifold area preparation includes sub-steps 4.1 to 4.9 respectively. Then, the next step is commencement of cargo discharging process which consists of six sub-steps from 5.1 to 5.6. Checking ship stability involves three sub-steps from 6.1 to 6.3. The next step is monitoring cargo discharging process which is having five sub-steps as well. It is 7.1 to 7.5. The last step is completion of cargo discharging process covering sub-steps 8.1 to 8.7.

4.4 Analysis of Respondents

In order to demonstrate the approach, a real-shipboard cargo discharging operation has been selected in reputed and reliable chemical shipping company. The ship capacity is about 10,450 dwt. It is chemical/oil tanker ships sailing on the high seas. The comprehensive survey/assessment has been performed with Master of vessel, who has been working as an ocean going master for a long years in chemical tanker ships, during discharge of propylene oxide cargo at Port of Zhangjiagang, China. Appendix A shows the comprehensive survey/assessment result carried out by Master of vessel. Totally, 3,500 mts cargo was discharged. At the time of discharging operation, Master of vessel are asked to select the most appropriate generic task type for each sub-step as well as relevant EPC/s.

4.5 Definition of Scenario

In order to apply proposed model, the real-shipboard cargo discharging operation has performed for discharging of propylene oxide cargo. The availability of time, crew mental state or stress, working environment, crew collaborations, fatigue, noise level and ability of crew, time of day during operation, task familiarity,etc. are evaluated

by the Master of vessel at the time of cargo discharging process. Discharge operation commenced at day time (15:00 lt) and completed early morning of following day (04:00 lt). The weather was calm and sea was smooth. Wind speed was around 8 knots/hr. Tide is +5 meters at high tide, +0,5 m at low tide. Chief officer, second officer, third officer, bosun, pumper and able seamen participated discharging operation at different sub-tasks. They were rested enough before commence operation. The Master decided the most available generic task type as well as EPC/s for each sub-step in the light of environmental condition.

In order to demonstrate the MAHRA approach, step 5 (commence cargo discharging process) is selected as a sample of process since there are totally eight main step and fifty-five sub-steps.

4.6 Selecting Generic Task

Generic task is defined with the Master of vessel. The crew is fairly experienced and has satisfactory skill during commencement of cargo discharging process. The crew (pumper), who is in charge of opening manifold valve, is totally familiar to perform this task. In addition, he/she is highly practiced. Likewise, duty officer (2/O) in CCR has enough experience to start cargo discharging pumps with slow rate since it is routine task at the beginning of discharging operation. The communication between the ship and terminal in order to exchange information about commencement of discharging operation is very routine task for duty officer (3/O). Therefore, officer in charge can respond it correctly. Checking level gauges and UTI tapes are also routine task and nominated crew (A/B) has enough knowledge to perform it. Furthermore, adjusting the pressure gauge on the manifold is carried out by A/B who is completely familiar to perform this task. Likewise, taking samples from manifold drain is carried out by chief officer and surveyors. Chief officer has enough experience and knowledge for this task. In accordance with above assessment, the Master selected the generic task for commencement cargo discharging process as illustrated in Table 4.2.

4.7 Selecting Marine-specific EPCs

The marine-specific EPC/s were nominated by Master. Since EPC affects the human performance negatively and leads to increase GEP value, relevant marine-specific EPC is chosen from the list of 38 possible statements. Table 4.2 shows the selected EPC/s for step 5 (commence cargo discharging process).

Table 4.2 : Generic tasks and marine-specific EPC/s for step 5.

Sub-step	Selected generic task	GEP value	Nominated EPC
5. Commence cargo discharging process			
5.1 Open manifold valve	G	4.00E-04	EPC2, EPC23
5.2 Start cargo discharging pumps with slow rate	E	2.00E-02	EPC17, EPC22, EPC23
5.3 Inform terminal to commencement of discharging	H	2.00E-05	EPC8, EPC11, EPC13 EPC14
5.4 Check level gauges and UTI tapes	E	2.00E-02	EPC22
5.5 Set the pressure gauge on the manifold	G	4.00E-04	EPC2, EPC17, EPC33
5.6 Make sure that necessary samples have been taken from manifold drain	G	4.00E-04	EPC2, EPC15

4.8 Determining APOA

In order to assess proportion of affect for each marine-specific EPC, the AHP technique is used to execute sensitive calculation. As it is seen in table 4.1, except sub-step 5.4 the rest of sub-steps have more than one marine-specific EPC. Therefore, sensitive weighting calculation is required to calculate HEP value. Within this context, the next part provides comparison matrices for each sub-steps from 5.1 to 5.6 sequentially.

4.9 Composing a Pair-wise Comparison Matrix

A pair-wise comparison matrix is established in accordance with equation (3.2) using a relative importance scale. The Master of vessel is asked to assess importance level of each marine-specific EPC as per Saaty's relative importance scale. Accordingly, Table 4.3 provides the comparison matrix of nominated marine-specific EPCs for sub-step 5.1 (open manifold valve). Table 4.4 shows the comparison matrix of nominated marine-specific EPCs for sub-step 5.2 (start cargo discharging pumps with slow rate). Table 4.5 gives the comparison matrix of nominated marine-specific

EPCs for sub-step 5.3 (inform terminal to commencement of discharging). Table 4.6 gives the comparison matrix of nominated marine-specific EPCs for sub-step 5.5 (set the pressure gauge on the manifold). Finally, Table 4.7 gives the comparison matrix of nominated marine-specific EPCs for sub-step 5.6 (make sure that necessary samples have been taken from manifold drain).

Table 4.3 : Comparison matrix of selected marine-specific EPCs for step 5.1.

	EPC2	EPC23
EPC2	1	5
EPC23	1/5	1

Table 4.4 : Comparison matrix of selected marine-specific EPCs for step 5.2.

	EPC17	EPC22	EPC23
EPC17	1	1/2	3
EPC22	2	1	3
EPC23	1/3	1/3	1

Table 4.5 : Comparison matrix of selected marine-specific EPCs for step 5.3.

	EPC8	EPC11	EPC13	EPC14
EPC8	1	4	2	1/2
EPC11	1/4	1	1/2	1/3
EPC13	1/2	2	1	1/2
EPC14	2	3	2	1

Table 4.6 : Comparison matrix of selected marine-specific EPCs for step 5.5.

	EPC2	EPC17	EPC33
EPC2	1	1/2	3
EPC17	2	1	4
EPC33	1/3	1/4	1

Table 4.7 : Comparison matrix of selected marine-specific EPCs for step 5.6.

	EPC2	EPC15
EPC2	1	3
EPC15	1/3	1

4.10 Calculating Criteria Weights

The priority weights of each marine-specific EPC can be calculated in accordance with equation (3.3). Thus, consistency in APOA calculation is obtained. In this

context, Table 4.8 shows the marine-specific EPC prioritization weights for commence cargo discharging process (step 5) accordingly.

4.11 Determining CR Values

The CR value can be found by using equations (3.4), (3.5) and (3.6). Whilst the CR value is less than 0.10, the judgements inserted in pair-wise comparison matrix by Master are considered as reasonable and consistent. Table 4.8 gives the CR values along with prioritization weights of EPCs.

Table 4.8 : EPC prioritization weights and CR values.

Sub-step	EPC	Priority weight	CR value
5.1	EPC2	0.817	0.001
	EPC23	0.183	
5.2	EPC17	0.334	0.046
	EPC22	0.525	
	EPC23	0.142	
5.3	EPC8	0.311	0.035
	EPC11	0.100	
	EPC13	0.182	
	EPC14	0.406	
5.4	EPC22	1.000	0.015
5.5	EPC2	0.320	
	EPC17	0.557	
	EPC33	0.123	
5.6	EPC2	0.750	0.001
	EPC15	0.250	

4.12 Calculating HEP

HEP value can be calculated by using equation (3.1) for discharging process of propylene oxide cargo in chemical tanker ships. In this context, Table 4.9 shows HEP calculation for step 5 (commence cargo discharging process). In the light of above illustration, the HEP calculation is conducted for discharging process of propylene oxide cargo in chemical tanker ship. Table 4.10 shows the results. Moreover, Appendix B illustrates the comprehensive results of whole discharging process involving GEP values, maximum affects of EPCs, APAO calculations as well as HEP values.

Table 4.9 : HEP calculation for step 5 (commence cargo discharging process).

Step 5 (commence cargo discharging process)	GEP value	EPC	EPC max. affect	EPC APOA	HEP value
5.1 Open manifold valve	4.00E-04	*Time shortage	14.01	0.817	8.64E-03
		*Unreliable instruments	5.69	0.183	
5.2 Start cargo discharging pumps with slow rate	2.00E-02	*Inadequate checking	2.79	0.334	7.11E-02
		*Lack of exercise	1.64	0.525	
		*Unreliable instruments	5.69	0.142	
5.3 Inform terminal to commencement of discharging	2.00E-05	*Channel overload	14.45	0.311	1.88E-03
		*Performance ambiguity	8.60	0.100	
		*Poor feedback	12.55	0.182	
		*Delayed/incomplete feedback	6.72	0.406	
5.4 Check level gauges and UTI tapes	2.00E-02	*Lack of exercise	1.64	1.000	3.28E-02
5.5 Set the pressure gauge on the manifold	4.00E-04	*Time shortage	14.01	0.320	8.64E-03
		*Inadequate checking	2.79	0.557	
		*Poor environment	9.90	0.123	
5.6 Make sure that necessary samples have been taken from manifold drain	4.00E-04	*Time shortage	14.01	0.750	1.40E-02
		*Operator inexperience	10.03	0.250	

Table 4.10 : HEP calculation for discharging process of propylene oxide cargo.

Step	Sub-step	EPC	HEP value
1.	1.1	EPC2, EPC38	7.24E-03
	1.2	EPC8, EPC14, EPC18	3.18E-04
	1.3	EPC2, EPC11, EPC35	2.32E-02
	1.4	EPC5, EPC13,EPC15, EPC22	7.12E-03
	1.5	EPC2, EPC11, EPC17	7.77E-02
	1.6	EPC12, EPC13, EPC33	1.72E-03
	1.7	EPC2, EPC17, EPC26	2.88E-04
	1.8	EPC1, EPC10, EPC17	1.96E-02
	1.9	EPC2, EPC11,EPC17	1.15E-02
	1.10	EPC17, EPC33	1.89E-04
	1.11	EPC2, EPC14, EPC15	1.64E-01
	1.12	EPC17, EPC33	1.51E-04
	1.13	EPC2, EPC14, EPC17	1.04E-02
	1.14	EPC2, EPC12, EPC23	1.24E-03
	1.15	EPC17	5.58E-02
2.	2.1	EPC1, EPC13, EPC16	1.84E-03
	2.2	EPC15, EPC17	2.21E-02
	2.3	EPC2, EPC14	5.71E-04
	2.4	EPC12, EPC15	1.32E-02
	2.5	EPC11, EPC15	8.89E-03
3.	3.1	EPC2, EPC18, EPC32	4.90E-04
	3.2	EPC2, EPC17	3.63E-02
	3.3	EPC17	5.58E-02
	3.4	EPC17, EPC27,EPC33, EPC36	4.56E-03
	3.5	EPC17, EPC34	6.62E-05
4.	4.1	EPC13, EPC27	4.41E-02
	4.2	EPC17	5.58E-02
	4.3	EPC1, EPC15,EPC22	6.88E-03
	4.4	EPC17, EPC22	6.90E-03
	4.5	EPC27, EPC38	2.38E-03
	4.6	EPC2	4.20E-02
	4.7	EPC8, EPC14, EPC36	9.35E-03
	4.8	EPC15, EPC17	2.29E-02
	4.9	EPC2	5.60E-03
5.	5.1	EPC2, EPC23	8.64E-03
	5.2	EPC17, EPC22, EPC23	7.11E-02
	5.3	EPC8, EPC11,EPC13 EPC14	1.88E-03
	5.4	EPC22	3.28E-02
	5.5	EPC2, EPC17, EPC33	8.64E-03
	5.6	EPC2, EPC15	1.40E-02
6.	6.1	EPC22, EPC29	1.53E-01
	6.2	EPC12, EPC22, EPC32	7.67E-03
	6.3	EPC17, EPC38	8.71E-05
7.	7.1	EPC2, EPC32	1.37E-02
	7.2	EPC14, EPC27, EPC36	2.33E-04
	7.3	EPC2, EPC10	8.67E-04
	7.4	EPC23, EPC33	6.28E-03

Table 4.10 (continued) : HEP calculation for discharging process of propylene cargo.

Step	Sub-step	EPC	HEP value
8.	7.5	EPC15, EPC25, EPC38	1.39E-04
	8.1	EPC10, EPC13, EPC17	1.45E-02
	8.2	EPC8, EPC14	5.50E-04
	8.3	EPC2, EPC15, EPC22	3.59E-03
	8.4	EPC17	1.12E-03
	8.5	EPC11, EPC14, EPC32	6.64E-04
	8.6	EPC17	5.58E-02
	8.7	EPC1, EPC2, EPC27, EPC38	1.69E-03

As the cargo discharging process of propylene oxide in chemical tanker consists of eight main steps and fifty-five sub-steps in HTA, the final HEP values should be determined in order to assess human reliability. In this context, correlation between the main steps and sub-steps in accordance with PSA HTA are addressed. Namely, fifteen sub-steps shall be completed properly to success step 1 (prepare deck for discharging operation) successfully. This refers a serial system where the step 1 will fail if any of fifteen sub-step fails to complete. Therefore, the overall HEP value is found 3.80E-01 since fifteen sub-steps have a low dependency. Likewise, step 2 (prepare engine room for discharging operation) will fail in case any of five sub-steps fail (serial system-low dependency). Therefore, the HEP value is 4.66E-02 for step 2. Accordingly, the overall HEP value is found 1.00E-04 for step 3 (check out valves and alarms) as there is a high dependency (parallel system) between five sub-steps. Respectively, the overall HEP value is found as 5.60E-02 (serial system- high dependency) for step 4; 7.11E-02 (serial system-high dependency) for step 5; 1.00E-04 (parallel system-high dependency) for step 6; 2.13E-02 (serial system-low dependency) for step 7 and 7.79E-02 (serial system-low dependency) for step 8.

In order to calculate final HEP value for propylene oxide cargo discharging operation on-board ship, eight main steps should be completed without any error. In this context, if any of these steps fail, cargo discharging operation will not be carried out. Therefore, the final HEP value is found 3.80E-01 since there is high dependency between them.

4.13 Recovery Proposal

The relation between the failure and reliability can be defined with $R(t) = 1 - F(t)$ formula basically. In accordance with the sensitive calculation carried out, the human

reliability value of cargo discharging operation for propylene oxide has been found as $6.20\text{E-}01$ which is very low. Therefore, recovery action is needed to enhance performance reliability (Akyuz and Celik, 2015a).

Table 4.11 provides the detail of recovery proposal in order to mitigate the highest HEP values in accordance with DiMattia et al.(2005) risk matrix where the probability of failure combined with the consequence severity. In the matrix, the colour of each block shows the level of immediate recovery action that is needed. In the matrix, the HEP value is categorized into four different level of $1.00\text{E+}00$ to $1.00\text{E-}01$, $1.00\text{E-}01$ to $1.00\text{E-}02$, $1.00\text{E-}02$ to $1.00\text{E-}03$, and $1.00\text{E-}03$ to $1.00\text{E-}04$ (DiMattia et al., 2005). In this context, whilst cargo discharging operation of propylene oxide in chemical tanker is considerably critical aspect for maritime safety and environment protection, severities of consequence are considered as high level by Master of vessel. The calculated final HEP value ($3.80\text{E-}01$) is to be categorized into high risk (red blocks) since the value is placed the range of $1.00\text{E+}00$ to $1.00\text{E-}01$. In order to enhance reliability of operation, the final HEP value shall be reduced either into lower (yellow blocks) or lowest (green blocks) risk levels. Therefore, the recovery action is represented to reduce HEP value into desired level (lower or lowest risk levels) by mitigating the EPCs (Akyuz and Celik, 2015a).

4.14 Re-calculating HEP Value

According to the above recovery actions, the highest EPC values which cause to reduce human reliability can be avoided. In this sense, equation (1) is used again. Table 4.12 shows the results of re-calculated HEP values for discharging operation of propylene oxide cargo after mitigation measures. The re-calculated HEP values are found after remedial actions. The finding shows that the re-calculated HEP values are $8.47\text{E-}02$ for step 1, $4.66\text{E-}02$ for step 2, $1.00\text{E-}04$ for step 3, $4.20\text{E-}02$ for step 4, $3.28\text{E-}02$ for step 5, $1.00\text{E-}04$ for step 6, $2.13\text{E-}02$ for step 7 and $2.21\text{E-}02$ for step 8 respectively.

Table 4.11 : Recovery proposal.

Sub-step	EPC	Recovery action
1.5	EPC2	*Nominate experienced officer to carry out task timely *Prepare functional and efficient check-list to avoid waste of time
	EPC11	*Allocate of role and responsibility of officers clearly *Increase awareness about the importance of check list application
	EPC17	*Inspect each ship/shore check list before commencement of operation *Increase frequency of internal audit carried out by shore-based management company
1.11	EPC2	*Provide sufficient number of crew to perform task timely *Instruct duty crew to attend work place in advance
	EPC14	*Provide effective communication between the duty crew and officer for feedback *Instruct duty crew to inform officer properly right after the task completed
	EPC15	*Support inexperienced crew by experienced one and apply practical training accordingly *Provide practical training concerning how to do this task
1.15	EPC17	*Increase frequency of safety patrol around the manifold area *Instruct duty officer to monitor the deck, in particular manifold are, at regular intervals
3.3	EPC17	*Increase frequency of monitoring of P/V valve positioning *Enable available check list not to skip process
4.2	EPC17	*Instruct duty officer to conduct re-inspection for connection of all cargo lines and hoses *Provide safety checklist which includes monitoring and re-checking of the situation
5.2	EPC17	*Monitor pressure gauge on the manifold continuously whether discharging pumps run with slow rate *Keep continuous communication between CCR, manifold area and terminal
	EPC22	*Perform training programme for duty crew before they embark the ship *Apply theoretical and practical training on-board ship how to operate discharging pumps
	EPC23	*Make sure that pressure gauge are reliable and maintained regularly *Check if discharging pumps indicators are in order

Table 4.11 (continued) : Recovery proposal.

Sub-step	EPC	Recovery action
6.1	EPC22	*Perform training programme for officers before they embark the ship
		*Provide illustrated guidance for officer showing how to follow the process
	EPC29	*Enable appropriate social activities for crew on-board ship as much as possible *Enhance motivational situation of crew by providing high-standard of seafarer life
8.6	EPC17	*Provide safety checklist which includes monitoring and re-checking position of cargo valves
		*Request re-confirmation from the engine control room whether cargo valves are shut off

Since the system has high dependency, the final re-calculated HEP value is found 8.47E-02. Thus, the human error probability is reduced to lower risk (yellow blocks) and categorized in the range of 1.00E-01 to 1.00E-02 in accordance with the risk matrix.

Table 4.12 : Re-calculated HEP values.

Step	Sub-step	EPC	HEP value
1.	1.1	EPC2, EPC38	7.24E-03
	1.2	EPC8, EPC14,EPC18	3.18E-04
	1.3	EPC2, EPC11, EPC35	2.32E-02
	1.4	EPC5,EPC13,EPC15,EPC22	7.12E-03
	1.5	N/A	8.70E-04
	1.6	EPC12,EPC13,EPC33	1.72E-03
	1.7	EPC2,EPC17,EPC26	2.88E-04
	1.8	EPC1,EPC10,EPC17	1.96E-02
	1.9	EPC2,EPC11,EPC17	1.15E-02
	1.10	EPC17,EPC33	1.89E-04
	1.11	N/A	8.57E-04
	1.12	EPC17,EPC33	1.51E-04
	1.13	EPC2,EPC14,EPC17	1.04E-02
	1.14	EPC2,EPC12,EPC23	1.24E-03
	1.15	N/A	0.00E-00
2.	2.1	EPC1,EPC13,EPC16	1.84E-03
	2.2	EPC15,EPC17	2.21E-02
	2.3	EPC2,EPC14	5.71E-04
	2.4	EPC12,EPC15	1.32E-02
	2.5	EPC11,EPC15	8.89E-03
3.	3.1	EPC2,EPC18,EPC32	4.90E-04
	3.2	EPC2,EPC17	3.63E-02
	3.3	N/A	0.00E-00
	3.4	EPC17,EPC27,EPC33,EPC36	4.56E-03
	3.5	EPC17,EPC34	6.62E-05
4.	4.1	EPC13,EPC27	4.41E-02
	4.2	N/A	0.00E-00
	4.3	EPC1,EPC15,EPC22	6.88E-03
	4.4	EPC17,EPC22	6.90E-03
	4.5	EPC27,EPC38	2.38E-03
	4.6	EPC2	4.20E-02
	4.7	EPC8,EPC14,EPC36	9.35E-03
	4.8	EPC15,EPC17	2.29E-02
	4.9	EPC2	5.60E-03
5.	5.1	EPC2,EPC23	8.64E-03
	5.2	N/A	5.43E-03
	5.3	EPC8,EPC11,EPC13	1.88E-03

Table 4.12 (continued) : Re-calculated HEP values.

Step	Sub-step	EPC	HEP value
	5.4	EPC22	3.28E-02
	5.5	EPC2,EPC17,EPC33	8.64E-03
	5.6	EPC2,EPC15	1.40E-02
6.	6.1	N/A	2.09E-02
	6.2	EPC12,EPC22,EPC32	7.67E-03
	6.3	EPC17,EPC38	8.71E-05
7.	7.1	EPC2,EPC32	1.37E-02
	7.2	EPC14,EPC27,EPC36	2.33E-04
	7.3	EPC2,EPC10	8.67E-04
	7.4	EPC23,EPC33	6.28E-03
	7.5	EPC15,EPC25,EPC38	1.39E-04
8.	8.1	EPC10,EPC13,EPC17	1.45E-02
	8.2	EPC8,EPC14	5.50E-04

4.15 Extended Discussion

In the light of HEP values, findings show that crew error probability is very high (3.8E-01) and categorized into high risk level during propylene oxide cargo discharging operation in chemical tankers. Apparently, the reason of the high human error probability (i.e. lowest human reliability) is mainly caused by sub-tasks which have the highest HEP value. Particularly, sub-step 1.11 (separate unused cargo lines and cargo hoses) has the highest HEP value as the task requires utmost deck organisation and planning. It means that sub-step 1.11 has more impact on the entire process. Moreover, sub-step 6.1 (check vessel stability condition frequently in particular SF/BM) is the second highest HEP value during discharging process since it ranks second place among the all sub-steps. During cargo discharging process, it is very important to check vessel stability and stress frequently (in general hourly) since the stress limits of vessel are never exceeded. The third highest HEP value is sub-step 1.5 (make sure that ship/shore safety check is completed). The ship/shore safety check list involves various critical procedure to enable safer cargo handling operation. Therefore, it should be completed without any failure. The other highest HEP values are sub-steps 1.15 (make sure that no source of ignition around the manifold area), 3.3 (set P/V valves in manual /automatic open position in accordance with IBC Code), 4.2 (check if all cargo lines and hoses are connected properly and ready for use) and 8.6 (check if all cargo valves are shut off) respectively.

In the view of main steps, it appears that step 1 (Prepare deck for discharging operation) contains the highest HEP value. Chemical cargo discharging operation involves numerous critical safety factors which have to be taken into consideration. Therefore, it is quite important to take necessary measures prior to discharging operation, with particular attention being paid by crew during the cargo is severely hazardous for human life and marine environment. In order to minimize human errors, necessary remedial actions shall be taken for the EPCs which have the highest affect upon HEP value. The findings also indicates that each main step has dependency with each other. Therefore, each main step shall be completed without any failure. In this context, if any of these steps fail, cargo discharging operation will not be completed properly.

After having taken necessary remedial actions, the final HEP value is reduced to 8.47E-02 and categorised into lower risk level during propylene oxide cargo discharging operation. As mentioned before, reliability can be defined as probability of a part of equipment or service operating without failure. Basically, equation $R(t) = 1 - F(t)$ represents the relation between reliability and error. In this context, the finding shows that performance reliability of crew (operator) typically follows planned procedures and it is acceptable level. The demonstration results clearly show that critical tasks within an operation can be completed with higher reliability if operator (crew) complies with remedial actions. Therefore, the performance reliability result is satisfactory and it leads an improvement in the overall levels of safety in cargo discharging operation.

In the context of reliability interval, the human error probability value is fluctuating from 1.64E-01 to 6.62E-05. The means of HEP value is found 2.03E-02. In the light of outcomes, fifteen HEP values are higher than mean of human unreliability. This reveals that most of sub-tasks are performed within acceptable limits.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusive Remarks

Human factor has been becoming the prominent cause of marine incidents in the recent years. Therefore, human element is one of the most significant concerns in marine industry. In last decades, safety and risk practitioners attempted to extend the use of proactive methods in the analysis of human failures to enhance safety and prevent environment at sea. In this context, there are a variety of safety and risk-based studies presented by safety researchers as proactive tools. However, maritime safety has not raised to the desired level. In order to remedy that, this thesis provides a novel approach, namely called MAHRA, to analyse human reliability on-board ship. The proposed approach is robust marine-specific tool whose aim is to mitigate the human error during critical shipboard operations. The thesis also discusses and analyses human error probability particularly critical shipboard operation in chemical tanker ships since they have a potential risk for human and environment due to hazardous cargo content. Therefore, crew on-board chemical tanker ship should be fully aware of potential hazards. At this point, crew reliability plays substantial role on-board ship.

The thesis proposes an empirical human reliability analysis which has marine-specific parameters for critical operations on-board ship to enhance safety and operational reliability in marine industry by integrating HEART and AHP as well as HFACS technique. The study quantifies and validates the EPC parameter since obtaining historical data with respect to human error on the nature of maritime industry is very challenging and mostly unknown due to scarce of data. In this context, HFACS methodology is used to derive and validate marine-specific EPC. The AHP method is utilised during derivation process as well as APOA calculation. HEART approach is used to calculate HEP value. Thus, MAHRA approach improves the overall accuracy on which the consistency of proportion affect in HEP

calculation is increased. In addition, dependency is provided as practice of the reliability estimation with the serial or parallel systems to calculate final HEP.

The modification along with the suggested approach is demonstrated with cargo discharging operation which is involving relatively high level of risk when compared to other shipboard operations. In this sense, a real-shipboard cargo discharging operation is presented as demonstration. At the end of HRA assessment, the initial HEP value is found $3.8\text{E-}01$ which is considerably high. It means that human reliability is very low. After having taken necessary preventive measures for relevant EPC which may cause to increase HEP values, the final HEP value is reduced $8.47\text{E-}02$ which is acceptable since it is categorized in lower risk area. In the light of above, the thesis reached the following solid targets;

- Minimizing the error risk by assessing human reliability in shipboard operations,
- Applying proposed approach into critical shipboard operations,
- Creating available solutions for shipboard operational concept by developing a valid approach to human error assessment,
- Recommending preventive measures against pivotal factors that cause errors in shipboard operations,
- Contribute to ship safety management system practices,

5.2 Contributions to Academic Literature

In the view of methodological background of the MAHRA, the research has serious contributions to academic literature. The following items can be highlighted as contribution to academic literature.

- A new robust tool presentation, namely called MAHRA, is provided
- Marine-specific EPC values are generated
- Comprehensive marine incidents investigation and causes identification are provided
- AHP integration into HEART approach, which is a relatively new hybrid decision-making method, is introduced
- HFACS integration into HEART method, which is a hybrid decision-making model

- A wide range of literature review along with the human reliability assessment in marine industry is completed. This provides a valuable source to the safety and risk researchers
- Quantitative and qualitative data in maritime safety is provided,

5.3 Contributions to Marine Industry

Since most of accident on-board ship is due to human error, it is vital for ship management company to reduce human failure on-board ship. Otherwise, operational or technical failure of crew can pose potential harm to ship, commodity, human life and environment. Therefore, shore-based shipping companies are eager to take benefits of academic researches that may introduce proactive methods reducing human error on-board ship. At this point, the need for a marine-specific HRA technique, capable of systematically predict human error potentials for designated tasks and determine the required safety control levels on-board ship, is required. In order to remedy this issue, the proposed MAHRA approach is introduced as a contribution to marine industry. The followings contributions are made with respect to the thesis into maritime sector.

- A novel HRA technique based on decision-making model is developed to enhance safety at sea
- The proposed approach contributes to evaluate human reliability on-board ship
- It contribute to ship safety management system practices
- The proposed approach compensates shortfalls of human reliability enhancement in maritime industry
- The proposed approach can assist ship management companies, safety engineers and reliability researchers to give their full attention on the most critical human error factor whilst giving them the top priority
- It allows monitoring as well as controlling human performance on-board ships
- Enhancement in ship operational safety procedures
- A comprehensive and robust tool can assist shore-based shipping company as well as shipboard organisation to estimate and predict human error likelihood in critical operations

5.4 Research Limitations

Some of limitations can be understood and planned for before the research process starts, while others become apparent during or after the thesis research process. During research of this thesis, it was difficult to get sufficient support from the marine experts since they were very busy. Particularly, the experts had no enough time to establish relation matrix as well as rank-weighting rules at the time of EPC derivation process. Hopefully, necessary judgements were gathered timely and transformed into useful information. Another important limitation of this thesis is that the method mainly based on expert judgements data which are relatively subjective data even though marine experts have adequate seafarer experiences. On the other hand, obtaining technical or operational data on the nature of marine domain is very challenging and mostly unknown. Therefore, it seems quite reasonable that the method based on expert judgements.

One of the fundamental limitation with quantitative HRA methods is scarce of data. Therefore, empirical method is an alternative solution to deal with scarcity of data, in particular marine industry. The MAHRA approach, marine-specific method, provides satisfactory result since it based on real-marine accident causes.

The main aim of this research is to mitigate human error in ship operation level. Thus, enhancement of maritime safety, prevention loss of life as well as environment pollution prevention is achieved. The research encourages the shore-based maritime managers as well as safety practitioners in the maritime domain. However, it should be user-friendly for shipboard organisation and shore-based executives. Therefore, it is necessary to design a smart knowledge-based software for practical use. This thesis provides to establish a theoretical background for MAHRA approach. The next important step will be design a knowledge-based programming in the system in order to transform operational task scenarios in database into meaningful information. A H-RAMS (Human Reliability Analysis and Monitoring System Proposal in Shipboard Operations) software will provide users a proactive user-friendly solution prior commencement of any critical shipboard operations. Figure 4.1 and Figure 4.2 show demo versions of H-RAMS software. In this concept, the followings further research proposal are made with respect to the thesis.

- Design knowledge-based technological solution (H-RAMS software) to operate MAHRA approach
- Develop marine-specific GTT and GEP values
- Apply proposed approach into different case application
- Test proposed approach on vessel fleets such as container, crude carrier, LGP and LNG tanker, bulk carrier, general cargo ships.
- Extend proposed approach into similar sectors such as off-shoring, shipyard, port and terminal operations, etc.
- Design ship crew reliability index concept

Generic Task Types				
Selection	Code	Explanation	Value	5th -95th Percentile b...
☐	A	Totally unfamiliar; performed at speed with no real idea of likely consequences.	0.55	(0.35 - 0.97)
☐	B	Shift or restore system to a new or original state on a single attempt without supervision or procedures.	0.26	(0.14 - 0.42)
☐	C	Complex task requiring high level of comprehension and skill.	0.16	(0.12 - 0.28)
☐	D	Fairly simple task performed rapidly or given scant attention.	0.09	(0.06 - 0.13)
☐	E	Routine, highly practiced, rapid task involving relatively low level of skill.	0.02	(0.07 - 0.045)
☐	F	Restore or shift a system to original or new state following procedures with some checking.	0.003	(0.0008 - 0.007)
☒	G	Completely familiar, well-designed, highly practiced, routine task occurring several times per day, performed to highest possible standards by highly motivated, highly trained, and experienced personnel...	0.0004	(0.00008 - 0.009)
☐	H	Respond correctly to system command even when there is an augment or automated supervisory system providing accurate interpretation of system state.	0.00002	(0.000006 - 0.0009)
☐	M	Miscellaneous task for which no description can be found.	0.03	(0.008 - 0.11)
Error Producing Condition				
Selection	Code	Explanation	Value	APOA
☒	EPC2	Time shortage	14.01	0.817
☐	EPC3	Low signal-noise ratio	3.31	
☐	EPC4	Features over-ride allowed	8.72	
☐	EPC5	Spatial and functional incompatibility	5.76	
☐	EPC6	Model mismatch	2.64	
☐	EPC7	Irreversibility	2.23	
☐	EPC8	Channel overload	14.45	
☐	EPC9	Technique unlearning	5.29	
☐	EPC10	Knowledge transfer	11	
☐	EPC11	Performance ambiguity	8.6	
☐	EPC12	Misperception of risk	12.51	
☐	EPC13	Poor feedback	12.55	
☐	EPC14	Delayed/incomplete feedback	6.72	
☐	EPC15	Operator inexperience	10.03	
☐	EPC16	Impoverished information	8.42	
☐	EPC17	Inadequate checking	2.79	
☐	EPC18	Objectives conflict	2.15	
☐	EPC19	No diversity	2.74	
☐	EPC20	Educational mismatch	2.88	
☐	EPC21	Dangerous incentives	3.62	
☐	EPC22	Lack of exercise	1.64	
☒	EPC23	Unreliable instruments	5.69	0.183

Figure 4.1 : H-RAMS software demo sample.

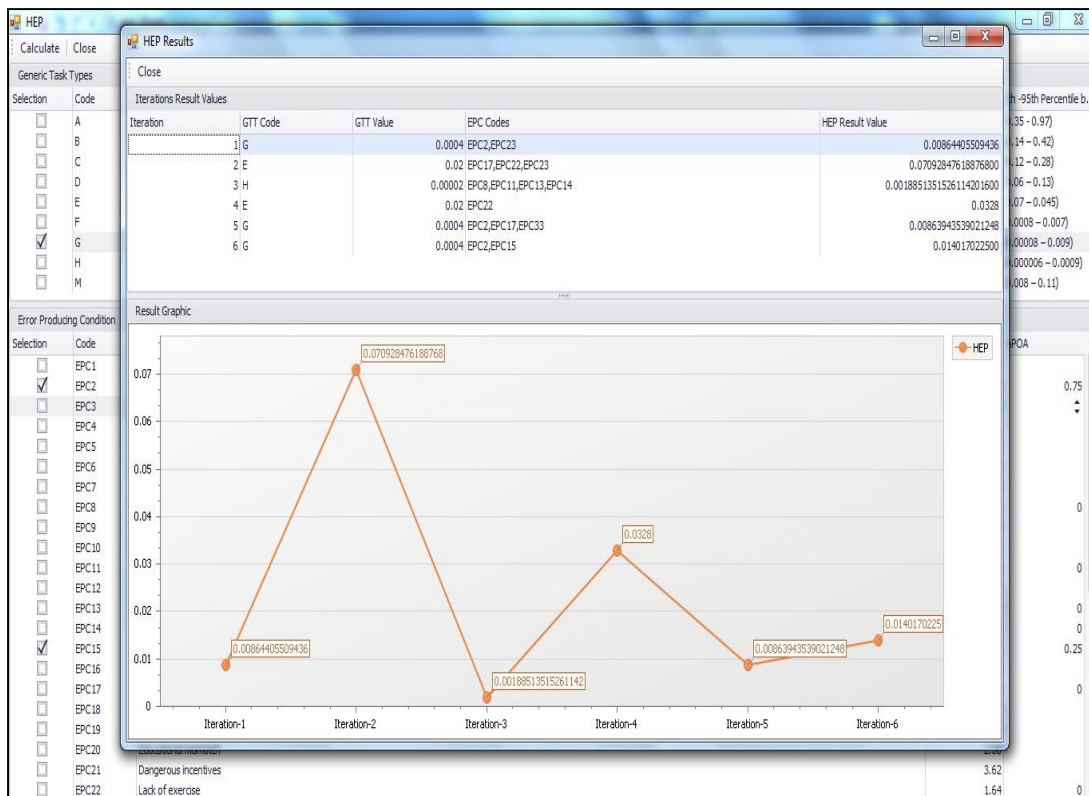


Figure 4.2 : H-RAMS software demo sample.

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APPENDICES

APPENDIX A : Figures

APPENDIX B : Tables

APPENDIX A: Figures

[illegible]

Figure A.1 : HFACS-EPC relation matrix established by the consensus of marine experts for chemical tankers.

[illegible]

[illegible]

Figure A.3 : HFACS-EPC relation matrix established by the consensus of marine experts for container ships.

[illegible]

		CARGO INFORMATION SHEET	
Ship: CESTENI		Customer: EASTPORT MARITIME PTE LTD	
Voy.No:039		Prewash Requirement: NO	
Loading Port : MAP TAP HUT		Disch.Port : TAICHUNG-ZJG DOW-NINGBO	
Cargo: PROPYLENE OXIDE		Cargo Tanks No.: 3W-4W-5W-6W	
Description Of Product			
Un No.	1280	Fire Extinguishing Agent: DP, CO2, Foam, Water Spray	
Imdg Class	3	Loading Temp.	Contracted
Cargo Miscibility	40.5 %		Actual
Poll/Cat	CAT Y	Heat Instruct.	Min. N/A
Uscg Compability Group	16		Max. N/A
Mfag	Page 100-101	Intended Disch. Temp.	
Ems	F-E,S-D	Allowed Temp. Rate Of Increase	
Tlv	2 - 100 ppm	Heating Required	YES ☐ NO ☒
Odour Treshold	N/A	Polymerization Possibility	YES ☒ NO ☐
Test (Drager) Tubes	Ethyleneoxide 25/A	Cargo Inhibited	YES ☒ NO ☐
Specific Gravity	0.825	Nitrogen Cover	YES ☒ NO ☐
Correction Factor	-----	Closed Loading Required	YES ☒ NO ☐
Flash Point	-37.2 °C	Vapour Return Required	YES ☒ NO ☐
Melting/Freezing Point	111.9 °C	Compability To Tank	YES ☒ NO ☐
Viscosity	0.4 cps @ 20 °C	Coating & Material	MARINE LINE
Cargo Vapour Pressure	440.7 mmHg @ 20 °C	Cooling Requirments	YES ☒ NO ☐
Cargo Liquid Density	0.829 - 0.831 g/cm3 @ 20 °C	Corgo Vapour Density	YES ☒ NO ☐
Cargo Tank Filling Limits	%93,2 at 15C	Other Informations :	
Health Hazard Data			
General Hazards	Causes severe eye burns. Harmful if inhaled. Harmful if swallowed. May be harmful if absorbed through skin. Aspiration hazard. Can enter lungs and cause damage to body systems. Possible cancer hazard. May cause cancer based on animal data.		
Skin Or Eye Contact (Symptoms & Treatment)	Wash immediately and with flowing water for at least 30 minutes. Remove contact lenses after the first 5 minutes and continue washing. Obtain prompt medical consultation,preferably from an ophthalmologist. Immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Obtain medical attention without delay. Wash clothing before reuse.Properly dispose of contaminated leather items, such as shoes, belts, and watchbands.		
Inhalation Of Vapour (Symptoms & Treatment)	Move person to fresh air. If not breathing, give artificial respiration; if by mouth to mouth use rescuer protection (pocket mask, etc). If breathing is difficult, oxygen should be administered by qualified personnel. Call a physician or transport to a medical facility.		
Swallow Of Product (Symptoms & Treatment)	Do not induce vomiting. Call a physician and/or transport to emergency facility immediately. Seek medical attention immediately		

Figure A.6 : Cargo information sheet.

Protective Equipment To Be Use During Handling					
Helmet	YES ☒	NO ☐	Rubber Gloves	YES ☒	NO ☐
Goggles	YES ☒	NO ☐	Full Chemical Protection	YES ☒	NO ☐
Face Mask	YES ☐	NO ☒	Safety Shoes	YES ☒	NO ☐
PVC Gloves	YES ☐	NO ☒	Rubber Boots	YES ☒	NO ☐
Other					
Emergency Procedures					
Fire And Explosion	Keep people away. Isolate fire and deny unnecessary entry. Stay upwind. Keep out of low areas where gases (fumes) can accumulate. Water may not be effective inextinguishing fire. Use water spray to cool fire exposed containers and fire affected zone until fire is out and danger of reignition has passed. Fight fire from protected location or safe distance. Consider the use of unmanned hose holders or monitor nozzles. Immediately withdraw all personnel from the area in case of rising sound from venting safety device or discoloration of the container. Burning liquids may be extinguished by dilution with water. Do not use direct water stream. May spread fire. Eliminate ignition sources.				
Leakage	If available, use foam to smother or suppress vapors. Do not use absorbents. Small spills: Wash the spill site with large quantities of water. Large spills: Dike area to contain spill. Dilute with large quantities of water. Ground and bond all containers and handling equipment. Pump with explosion-proof equipment. If available, use foam to smother or suppress. Collect in suitable and properly labeled containers. Contact Dow for clean-up assistance				
Reactivity	Avoid contact with oxidizing materials. Avoid contact with: Acids. Amines. Bases. Avoid contact with absorbent materials such as: Clay-based absorbents. Hazardous Polymerization Can occur. Elevated temperatures can cause hazardous polymerization. Polymerization can be catalyzed by: Acidic pH. Alkali metal hydroxides. Aluminum chloride. Basic pH. Ferric chlorides. Highly active catalytic surfaces. Iron chloride				

Signature of Duty Officer(s): 2ND OFF. 3RD OFF.

Signature of Chief Officer : :

Signature of Master : :

Figure A.6 (continued) : Cargo information sheet.

	Generic task type	EPC																																							
		Unfamiliarity (EPC1)	Time shortage(EPC2)	Low signal ratio (EPC3)	Features over-ride allow (EPC4)	Spatial and functional incompatibility (EPC5)	Model mismatch (EPC6)	Irreversibility (EPC7)	Channel overload (EPC8)	Technique unlearning (EPC9)	Knowledge transfer (EPC10)	Performance ambiguity (EPC11)	Misperception of risk (EPC12)	Poor feedback (EPC13)	Delayed/incomplete feedback (EPC14)	Inexperience operator (EPC15)	Impoverished information (EPC16)	Inadequate checking (EPC17)	Objectives conflict (EPC18)	No diversity (EPC19)	Educational mismatch(EPC20)	Dangerous incentives (EPC21)	Lack of exercise (EPC22)	Unreliable instruments (EPC23)	Absolute judgement required (EPC24)	Unclear allocation of function (EPC25)	Progress tracking lack (EPC26)	Physical capabilities (EPC27)	Low meaning (EPC28)	Emotional stress (EPC29)	Ill-health (EPC30)	Low morale (EPC31)	Inconsistency of displays (EPC32)	Poor environment (EPC33)	Low mental workload (EPC34)	Sleep cycle disruption(EPC35)	Task pacing (EPC36)	Supernumeraries:EPC37	Operator age (EPC38)		
1. Prepare deck for discharging operation																																									
1.1 Make sure that proper cargo discharging plan is ready	G		X																																						X
1.2 Ensure that terminal re-confirm the discharging plan	H							X							X				X																						
1.3 Calculate cargo quantity to be discharged	G		X									X																									X				
1.4 Get confirmation for discharging quantity and discharging procedure from the terminal	G					X							X		X								X																		
1.5 Make sure that ship/shore safety check is completed	F		X									X							X																						
1.6 Connect the bonding cable	H												X	X																						X					
1.7 Ensure all crew on-deck has personnel protective equipment	H		X																X									X													
1.8 Check if emergency shower and eye washer is ready	G	X									X								X																						
1.9 Arrange sponge, rags and saw dust , etc (SMPEP)on deck in case of pollution risk	G		X									X							X																						
1.10 Make sure that necessary samples have been taken from cargo tanks	H																		X																	X					
1.11 Separate unused cargo lines and cargo hoses	F		X												X	X																									
1.12 Make sure that all drain plugs are in position	H																		X																	X					
1.13 Check if the cargo temperature is available	G		X												X				X																						
1.14 Re-calculate ship stability as per harbour condition in terms of SF/BM	G		X										X											X																	

Figure A.7 : Comprehensive survey/assessment result carried out by Master of vessel.

[illegible]

[illegible]

APPENDIX B: Tables

Table B.1: Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
Collision/ Contact	MV Paula C & MV Darya Gayatri (MAIB)	C1	Ineffectively using the electronic aids during watch
		C2	Inappropriate and not timely intervention on VHF radio
		C3	Inexperienced OOW and insufficient competency to keep a bridge watch in constrain waters
		C4	OOW was the sole lookout on bridge
		C5	Not calling Master although clear instruction was given by ship management company
		C6	Unaware of both the capabilities and limitations of the electronic systems (AIS, ARPA, ECDIS,etc..)
		C7	Not giving any sound signals when manoeuvring during the vessels were in close proximity
		C8	Poor watchkeeping standards
	MV Seagate & MV Timor Stream (MAIB)	C9	OOW on both vessels failed to keep a proper lookout
		C10	Lack of taking appropriate action stiuplated by COLREG to avoid collision
		C11	Not to assess the risk of collision sufficiently
		C12	Failed to comply with some of the most fundamental elements of the COLREG
		C13	Failed to comply with the written navigational procedures issued by ship management company
		C14	The OOW did not assess the situation correctly initially
		C15	Watch alarm (Deadman alarm) was not set by the Master
		C16	OOW was distracted by other tasks rather than keeping a lookout
		C17	Lack of maintaining high standards of watchkeeping at all times
	MV Antonis (MAIB)	C18	Poor fendering and lightering by port authority
		C19	Lack of protection for the exposed bridge aft

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
		C20	No formal risk assessment was conducted
		C21	Limited time for manoeuvring
		C22	Lack of safety meeting between port authority and vessel
	MV Alam Pintar (MAIB)	C23	The bridge was manned by an inexperienced officer and an unqualified deck cadet.
		C24	Ineffective alterations of course to avoid collision
		C25	Ill considered decision taken to resume shooting pots
		C26	Inexperienced bridge team
		C27	Not to comply with the requirement to keep a look out
		C28	Inappropriate actions of many vessels in the area of the distress
		C29	VHf radio volume was reduced and became inaudible
		C30	Fishing vessel not fitted with AIS
		C31	SMS non-conformities were not identified during internal audit by management company
		C32	Ship management company did not have a system of formal appraisal for the Master
	MV Global Mariner (MAIB)	C33	No voyage data recorder fitted to the vessel
		C34	The positions of the vessels were not fixed on the chart
		C35	Improper documents were used
		C36	Inadequate anchor watch was being maintained
		C37	Improperly rigged anchor ball against the aft side of the jackstay
		C38	No attempt was made to use the available binoculars to monitor other vessel's manoeuvring
		C39	Time limitation induced to take effective avoiding action
		C40	Master did not receive close navigational support from the chief officer
		C41	Master or chief officer did not receive specific bridge teamwork training before
		C42	Increased levels of stress during the immediacy of risk of collision

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MV Xuchanghai (MAIB)	C43	Vessel's speed was insufficient to maintain steerage in the prevailing conditions
		C44	Master and OOW did not have an adequate knowledge of the English for safe operation
		C45	Lack of information exchanging between the pilot and master
		C46	Initially steerage was lost when speed reduced
		C47	The master was unable to confirm his tow was made fast
		C48	Late corrective action was performed
		C49	Improper pilot card available on bridge containing the information
	MV Kinsale (MAIB)	C50	The bridge team was unaware of the approach of other vessel
		C51	A proper lookout astern was not being kept
		C52	Operational radar had a shadow sector astern
		C53	A sole watchkeeper on bridge
		C54	Inappropriate construction/mast visually impeded the officer's line of sight
	MV Nordheim (MAIB)	C55	Execution of the manoeuvre was not best carried out in accordance with COLREG
		C56	The master did not make proper voyage plan
		C57	Negligence of vicinity control
		C58	Incorrect assumption made by Master
		C59	The chart was not marked with no-go areas
		C60	Relaying only electronic information than the chart
		C61	Look out had not reported properly
	MV Nikkei Tiger (JTSB)	C62	Incorrect assumption on the basis of scanty radar information
		C63	OOW did not assess the situation of approaching and determine the necessity of actions to avoid collision
		C64	Improper bridge watchkeeping procedure manual to avoid collision in ample time
		C65	Improper adjustment were made by OOW

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MV Western Winner (MAIB)	C66	OOW hesitated to use whistles or engines
		C67	Insufficient boards poster showing the vessel manoeuvring characteristic
		C68	Failure to comply with COLREG properly
		C69	Not to proceed with safe speed
		C70	Not to have made proper use of radar given the conditions of restricted visibility
		C71	Master unfamiliar with the situation
		C72	Ship not to have prepared passage plan
		C73	Physical and mental stress
		C74	Main fire pumps had not been started
		C75	The vessel did not participate the VTS
	MV Zulfikar (MAIB)	C76	Inadequate rest of seafarers before incident
		C77	Incorrect assumption on the basis of scanty radar information
		C78	Improper radar watch to obtain early warning of the risk of collision
		C79	The bridge was not properly manned when the vessel navigating in thick fog
		C80	Unreliable equipment used (EPIRB did not transmit the signal)
		C81	Negligence of environmental control
		C82	Certifacate of competency did not comply with the requirement
		C83	Failure to use the urgency PAN PAN prefix
		C84	Failure to proceed at a safe speed.
		C85	Failure to navigate with particular caution near the termination of the traffic lane
		C86	Failure to have the engines ready for immediate manoeuvre

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
		C87	Series of assumptions based on limited information instead of following a systematic approach
		C88	Watchkeeper was not keeping a proper lookout
		C89	An absence of early and appropriate action to avoid the collision
		C90	The other ship was not equipped with a radar reflector
		C91	Faigue
		C92	Low signal sound from AIS
	MV Grandi Rodosi (ATSB)	C93	Insufficient time for starting air to stop the ahead running engine
		C94	The ship's main engine did not run astern ontime due to organisation failure
		C95	Lack of bridge resource management principles
		C96	Engineer's mistake was not identified by anyone on the ship's bridge
		C97	No audible alarm to indicate when it was running the 'wrong way'
		C98	No impenetation or procedures was given by ship management company in case of wrong way
		C99	The master/pilot exchange did not cover the essential details required under the port regulation
		C100	Ship management compnay did not develop contingency plans for specific manouvering
	MV Silver Yang (ATSB)	C101	Ineffective bridge resource management principles followed on board
		C102	OOW was involved non-work related conversation during the period of time leading up to the collision
		C103	Insufficient course alteration made by OOW
		C104	Not to do all available means appropriate in the prevailing circumstances
		C105	Active radar reflector was turned off by the Master of ship
		C106	Performance detetiorated due to fatigue and a minor seasickness
		C107	OOW could not effectively use the IMO's Standard Marine Communication Phrases (SMCP)
		C108	Ineffectively implemetation of UNCLOS law onboard ship

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MV F&K (ATSB)	C109	AIS transmissions may not be reliably onboard ship
		C110	Maintain improper lookout
		C111	Master took no action to avoid the collision
		C112	Inappropriate means to determine whether a risk of collision existed
		C113	Radar was not turned on by OOW
		C114	There were no other electronic collision avoidance or warning aids on board
	MV Ormiston (ATSB)	C115	The wheelhouse and afterdeck working lights were on
		C116	Obscuring much of the view out to either side of the fishing vessel
		C117	Adverse weather condition
		C118	Bridge team made assumptions about the developing situation
		C119	Inappropriate action to avoid the collision
		C120	Bridge team members had not effectively implemented bridge resource management principles
		C121	Lost situational awareness
		C122	Lack of effective radio communication between the vessel
		C123	Failure to keep went checked
	MV Silky Ocean (ATSB)	C124	Failure to keep an effective lookout
		C125	Inadequate passage plan prepared by OOW
		C126	Failure to keep an effective lookout
		C127	OOW did not appropriately consider the information provided by the navigational charts and publication
		C128	Inappropriately using all means available, in particular the radar
		C129	Inadequately managed the crew's work/rest periods

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MV Mary Ann Hudon & Mv Star (NTSB)	C131	Superficially training planning
		C132	No effective lookout being maintained
		C133	Ineffective handling of rudder command
		C134	Ineffective use of the two tugboats to manoeuvre
		C135	Not comply with the COLREG
		C136	Stress on crew due to commercial pressure
		C137	Lack of coordination with port authorities
		C138	Improper physical environment
		C139	Lack of operational knowledge upon ECDIS
Grounding	MV Beaumont (MAIB)	C140	OOW was asleep due to fatigue
		C141	No lookout on the bridge
		C142	Master did not exercise his overriding authority for the safety of the vessel
		C143	Navigational aids were not used effectively by OOW
		C144	BNWAS was seldom used
		C145	Inefficient implementation of SMS by shore-based management company
	MV Amber (MAIB)	C146	Bridge equipment tests are not carried out before departure as per SOLAS
		C147	Watchkeeping officers are not completely familiar with all navigational equipment on board
		C148	Master/pilot information exchanges were not completed properly
		C149	Poor communications among the bridge team member
		C150	Failure at the briefing stage to assign appropriate roles and responsibilities within the bridge team
		C151	Failing to report defects as required by the COLREG
		C152	Loss of situational awareness within the bridge team
		C153	OOW do not keep a proper visual lookout

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MV CSL Thames (MAIB)	C154	Not to comply with passage plan
		C155	OOW did not detect activation of the anti-grounding warning zone visual alarm
		C156	OOW was not monitoring the ECDIS properly
		C157	Audible ant-grounding alarm did not function
		C158	Lack of understanding of the equipment's safety features and/or their value
		C159	OOW lacked experience
		C160	Bridge team did not use the available grounding checklist
		C161	Bridge team did not record the times of follow-up actions
	MV CFL Performer (MAIB)	C162	No risk assessment was undertaken
		C163	Navarea system warnings were not received
		C164	Route plan was not cross-checked by the Master
		C165	The officers had not been trained in the use of ECDIS
		C166	No procedures on the system's use were included in the vessel's SMS
		C167	Undue reliance on the ECDIS
	MV Harvest Caroline (MAIB)	C168	Vessel did not have proper emergency response procedures
		C169	Safety management of the vessel was not meeting the objectives of the ISM Code
		C170	Insufficient anchor cable was deployed
		C171	Dragging of the anchor was not detected because the OOW due to fatigue
		C172	Insufficient Master judgement and attitude to risk due to consumption of alcohol
		C173	The DPA did not possess the necessary experience and knowledge
		C174	Insufficient instructions for anchoring in its safety management manual
		C175	Lack of fitted a watch alarm on the bridge
		C176	Lack of internal audit

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MV Thunder (MAIB)	C177	Appropriate chart was not available on board.
		C178	Fundamental misunderstanding of the principles of anchoring
		C179	Lack of amendment upon the sailing direction
		C180	OOW did not call the master on time
		C181	The master failed to report the grounding to either a national or local authority
		C182	Insufficient emergency response plan prepared by ship management company
	MV Lerrix (MAIB)	C183	Master was asleep due to fatigue
		C184	Improper lookouts
		C185	Watch alarm (BNWAS) were off
		C186	Not comply with ILO and STCW crew rest hours
		C187	Inappropriate use of personal electronic navigation equipment carried by crew
		C188	Poor work performance
	MV Dumun (ATSB)	C189	The bridge team had no way of knowing the position of the rudder
		C190	The ship's rudder angle indicator transmitter and tiller link-arm were not fitted
		C191	Incorrect installation at shipyard
		C192	Inappropriate comprehensive safety management system implemented
		C193	Communication error between the Master and pilot
		C194	Lack of good seamanship practice during manouvering
	MV Shen Neng 1 (ATSB)	C195	OOW did not alter the ship's course at the designated course alteration position
		C196	Ineffective monitoring of the ship's position due to fatigue
		C197	No effective fatigue management system in place
		C198	Insufficient guidance in relation to the proper use of passage plans
		C199	Amendments upon passage plan were not entered into the ship's GPS unit

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MV Iron King (ATSB)	C200	Improper look out carried out by OOW
		C201	Hours of work recorded by the chief mate did not accurately reflect the actual working hours
		C202	Steering system hydraulic pressure was limited by a leaking actuator relief valve
		C203	SMS did not include procedures during emergency steering failure
		C204	Inappropriate crew training carried out by ship management company before embarking ship
		C205	Insufficient risk management strategy
		C206	Lack of awareness of emergency procedures
	MV Atlantic Eagle (ATSB)	C207	Superficially internal audit carried out by DPA
		C208	The ship's position was not established by any member of the bridge team
		C209	Poor situational awareness
		C210	Ambiguous and inconsistent instruction against the passage plan
		C211	Improper monitoring the ship's progress
		C212	Effectively made the bridge watch inadequate
		C213	SMS procedures for record keeping were not effectively implemented on board the ship
Fire/Explosion	MV Yeoman Bontrup (MAIB)	C214	Failure to follow company instruction with regards to hot work repair
		C215	Lack of suitable smoke detector inserted on-board ship
		C216	Relevant compartment was not equipped with a fixed fire-fighting system
		C217	Storing some chemicals in the steering gear room
		C218	Lack of risk assessment conducted by shore-based management company
		C219	Lack of emergency fire drill training on-board ship
	MV Rosebank (MAIB)	C220	Using improper fire extinguisher
		C221	Not follow up the situation after extinguished the first fire

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MV Saldanha (ATSB)	C222	Lack of communication between the bridge and fire fighting team
		C223	Negligence of environmental control before fire
		C224	Communication problem among the crew due to poor English
		C225	Not follow up the instruction during emergency situation
		C226	Crew were not aware of any similar previous flashbacks involving Volcano VJ type burners
		C227	Duty engineer was not aware of all of the hazards associated with operating and maintaining the burner
		C228	Master and crew were not aware of the appropriate first aid treatment required for
		C229	Lack of post accident notice to ship
	MV Jin Hui (ATSB)	C230	Inadequate safety meeting
		C231	Lack of approval in boiler equipment modification
		C232	The fumigation contractor did not adequately consider the risks associated with burying
		C233	Master was not supplied with sufficient information for cargo inherent
		C234	Ineffective supervise the application of the aluminium phosphide fumigant
		C235	Insufficient fire extinguish technique performed by crew
	MV Baltimar Boreas (ATSB)	C236	Lack of understanding cargo guidance
		C237	Failure of a flexible fuel hose due to negligence
		C238	The maintenance of the generator flexible fuel hoses was inadequate
		C239	Inappropriate temporary repairs had been made
		C240	Improper equipment used (hoses longer than specified)
		C241	Poor hoses were not found during surveys, audits or inspections
		C242	SMS provides no guidance for the maintenance or routine replacement of the flexible fuel hoses
		C243	Flexible fuel hoses was not in accordance with SOLAS requirement
		C244	Necessary fire extinguisher located incorrect place

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
Machinery damage	MV Blue Note (MAIB)	C245	The crew were not aware of the guidance and entered the engine room after CO2 release
		C246	The closing arrangement did not comply with the requirement of SOLAS
		C247	Insufficiently re-tightened the bolts in accordance with the manufacturer's maintenance schedule
		C248	Improperly engaged in the hatch-lid sockets
		C249	Improper equipment used (length of the ends of the lifting hooks)
		C250	Lack of crew training with respect to crane functions
		C251	Incompetent crew operating the crane
		C252	Maintenance instructions had not been followed properly by crew
		C253	Necessary lifting test inspection for crane was not carried out
		C254	Poor record keeping induced to track the history of the crane
		C255	Lack of risk assessment conducted by shore-based management company
	MV Love Letter (MAIB)	C256	Absence of suitable markings
		C257	Insufficient maintenance planning
		C258	Inadequate assessment of risk
		C259	Limited monitoring of operations
		C260	Incorrect modification
	MV HC Rubina (ATSB)	C261	Improper planned maintenance system carried out
		C262	Manufacturer's requirements for the shaft alternator flexible coupling were not follow up
		C263	Ineffective systems for the defective control system for the CPPreported to the relevant authority
		C264	The pilot and master did not identify an increase in risk
		C265	The bridge team did not confirm that the predetermined passage plan
		C266	Communication error between the Master and pilot

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
Listing/Capsizing	MV Flying Phantom (MAIB)	C267	No defined limits for tug towing operations in restricted visibility
		C268	Bridge ergonomics of vessel were not suited to conducting blind pilotage operations
		C269	No checklist prepared for pre-towing operation
		C270	No effective system for assessing the risk of fog
		C271	Ineffective SMS with regard to operation in restricted visibility
		C272	Previous accident were not followed up properly
		C273	A number of inconsistencies and conflicts within ship's SMS documentation
		C274	ISO 9001 (quality) audits were not effective at highlighting any gaps in safety procedure
Flooding	MV Sonia (MAIB)	C275	Fitting of internal plugs were not successfully completed
		C276	Late announcement of flooding to port authority by Master
		C277	There was no evidence of any protective coating applied either inside or outside the stub pipe
		C278	Severe corrosion into valve flange were not ascertained properly during last dry dock
		C279	Owners failed to response emergency due to commercial considerations
		C280	There was confusion as to what repair work was likely to be required by vessel
		C281	Insurance underwriters and other sources was made more difficult due to no “out of hours” telephone numbers
	MV Great Majesty (ATSB)	C282	When the ballast pump was disassembled for repair, the suction pipe was not blanked off properly
		C283	The suction valves were not isolated correctly by crew
		C284	No work permit was completed for the pump maintenance

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
Others(FFO&cargo handling damage, weather damage, etc.)	MV Dutch Navigator (MAIB)	C285	No appropriate poster were placed on the ballast valve remote control panel
		C286	The ballast operations procedure did not provide a sufficient level of guidance for crew
		C287	The work permit system had not been effectively implemented on board the ship
		C288	The communications between officers on board ship were not effective
		C289	Chief engineer did not pay neccessary attention for ballast pump repairing
	MV Wah Shan (MAIB)	C290	The Master and owner were not aware of the regulations covering the dangerous good transportation
		C291	Overstowage of the tank container was not in compliance with the requirement of IMDG code
		C292	Container stack massess were in excess of the recommendations of vessel' cargo sec manuel
		C293	Excessive racking load
		C294	Poorly executed and monitored repairs performed onboard ship
		C295	The absence of a report from the Master that dangerous goods were involved with the cargo shift
		C296	Insufficant risk assessment made by ship management company
		C297	The aft mooring team did not use the equipment that was available to them effectively
		C298	Duty officer demonstrated very poor leadership
		C299	Duty officer did not understand or assess the risks involved effectively
		C300	The aft mooring team of ship did not work effectively as a team
		C301	The instructions set out in ship’s SMS were not followed effectively
		C302	The arrangement of the equipment of ship did not provide an obvious safe method of using a winch
C303	Lack of emergency response plan		
C304	Lack of crew training with respect to correct mooring and towing operations		
Collision/Contact	MT Saetta and MV Conger (MAIB)	C305	During main engine failure to stop, no procedure in place for the crew to follow
		C306	Communication error between the ships

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
		C308	Over-reliance upon checklists
		C309	The hours of work and rest were not monitored properly by superintendents
		C310	Wide-ranging and time-consuming responsibilities given to officers
		C311	No occupational standards defined for superintendents or masters
		C312	Inadequate contingency plan for STS transfer
	MT Vallermosa (MAIB)	C313	Unnecessary anxiety induced to distraction of pilot and master
		C314	Late notice given by Master
		C315	Weak bridge team management
		C316	Principles of BTM would not be applied during the pilotage
		C317	Master totally reliance and trust on the Pilot's ability to control the vessel
		C318	The weak link in the safety chain
		C319	Lack of complete understanding of HMRC's requirements
	MT Sicheam Melbourne (MAIB)	C320	The master and pilot pre-departure exchange of information was inadequate
		C321	Diagrams or sketches were not used in the master pilot exchange.
		C322	Communication error between the bridge team and pilot
		C323	Planned manoeuvring based on assumption
		C324	Bow thruster was used indiscriminately by the master without instruction
		C325	Lack of review the terminal's risk assessment
		C326	Insufficient training for ship handling was provided by ship management company to Master
	MT Audacity (MAIB)	C327	Inefficient briefing conducted between the pilot and bridge team
		C328	Unreliable radar equipment used
		C329	Inadequate risk analysis made by ship

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
		C330	Lack of trafik information provided to ship by VTS
		C331	Lack of taking appropriate action situplated by COLREG to avoid collision
		C332	ARPA was not used effectively on either vessel to assess risk of collision
		C333	No-one held the con on the bridge of ship
		C334	The bridge was insufficiently manned in the circumstances and condition
		C335	The communication between all parties involved was unclear
	MT Amenity (MAIB)	C336	Master made a quick decision based on scanty information
		C337	Master of vessel had no other officer present on the bridge to assist him
		C338	Master of ship did not use his lookout to best effect
		C339	Master's PEC training and examination did not include a formally assessed act of pilotage
		C340	Master's poor practical pilotage abilities
		C341	Improper bridge team procedure implemented
	MT Gudermes (MAIB)	C342	OOW did not have an adequate knowledge of the English for safe operation
		C343	Guard zones were not set on any of the three radar displays available
		C344	OOW did not hear the warning broadcast from VHF
		C345	Ship did not report the collision to authorities
		C346	Ship track lane was not in accordance with COLREG regulations
		C347	Collision regulation was a lesser consideration than commercial interests by ship
		C348	Assessment of the CPA of other vessel was inaccurate
		C349	An effective lookout was not maintained
		C350	Fatigue and inexperienced caused the OOW to fail to switch from autopilot ot manual
		C351	OOW did not call the master on time

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MT Barents Sea (ATSB)	C352	Lack of taking appropriate action stipulated by COLREG to avoid collision
		C353	Unreliable radar equipment used
		C354	Lookout did not maintain properly
		C355	OOW did not hear the warning broadcast from VHF
		C356	Safety management of the vessel was not meeting the objectives of the ISM Code
	MT Olympic Symphony (ATSB)	C357	The ‘helm off midships alarm’ was not approved by the manufacturers
		C358	The communication by the bridge team to the pilot was deficient
		C359	The master did not try the other steering system or change to the non-followup mode.
		C360	Insufficient procedures available to the bridge team to be taken following the failure
		C361	The ship’s bridge team was not familiar with the steering systems
		C362	Insufficient consideration was given to the risks and possible consequences
		C363	Insufficient information exchanges made between bridge team and pilot
	MT Unisina (ATSB)	C364	Proper lookout was not maintained on the bridge
		C365	Proper appraisal of the situation was not carried out by OOW
		C366	Reduced alertness on the part of the OOW due to fatigue
		C367	The absence of any guidelines to owners and operators on rest period requirement
		C368	Inappropriate display of signal lights
		C369	Lack of giving report to relevant authorities
	MT Sampet Hope (ATSB)	C370	Insufficient risk assessment in particularly wind strenght
		C371	Ambiguity on positions plotted on the chart
		C372	Lack of decision to move the ship another anchorage position
		C373	The anchors of ship were not arranged properly
		C374	The anchor was not designed to hold or stop ship

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MT Naticina (NTSB)	C375	Master did not report mechanical problems during transit passage
		C376	Decision error during manoeuvring
		C377	Inappropriate bridge watchkeeping hand over between officers
		C378	Insufficient training upon collision
		C379	Insufficient internal audit performed by ship management company
		C380	Not to comply with COLREG regulation
	MT Song Lin Wan (JTSB)	C381	Proper lookout was not maintained on the bridge
		C382	Lack of BTM training for officers and Masters
		C383	Poor VHF communication
		C384	Inadequate assumption upon risk of collision
		C385	Inadequate collision avoidance manoeuvring
	MV Seeb (MSIU)	C386	Communication was not established by either vessel
		C387	Ship did not monitor the developing situation
		C388	OOW overshot the alteration point
		C389	Master did not have accurate situation awareness
		C390	Ineffective radar usage
Grounding	MT Patriot (NTSB)	C391	Management company in place a shoreside multidisciplinary team specifically responsible for assisting
		C392	Master did not understand the operational limitations of this size of vessel
		C393	Inexperienced officer deployed in specific trading zone
		C394	Master did not make good and timely decision due to fatigue
		C395	Ineffective management of the movements of its vessel
		C396	Inadequate shore side support for critical shipboard decisions affecting vessel safety
		C397	Insufficient contingency plan preparedness

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MT British Enterprise (MAIB)	C398	Seabad topography was inaccuretaly charted
		C399	The echo sounder alarm was not active
		C400	The master did not inform the port state as soon as the vessel ran aground
		C401	No information concerning the nature of the seabed was gathered
		C402	No reports of its existence had been received by ship management company
		C403	A formal task risk assessment was not carried out by the vessel
		C404	Master was not aware of the importance of the chart source data
	MT Stolt Tern (MAIB)	C405	The ship's turn to starboard could not be checked properly by OOW
		C406	Master reduced to ship speed without asking Pilot
		C407	Inadequate communication and bridge teamwork
		C408	The master ignored the pilot's advice to put the engine astern
		C409	The lack of tide tables on bridge
		C410	The lack of experience of bridge team and pilot
		C411	The ship manager's safety management system did not identify the deficiencies
		C412	Ineffective risk assessment conducted by ship management company
	MT Willy (MAIB)	C413	Insufficient cable given the prevailing weather condition by Master
		C414	Anchor dragging position was not being accurately determined by OOW
		C415	The swinging circle was not calculated or plotted correctly
		C416	GPS guard zone was set at distance almost three times the radius of swinging circle
		C417	OOW did not call the master timely
		C418	The engine was not started and made available in sufficient time
		C419	Inadequate emergency response plan

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MT Atlantic Blue (ATSB)	C420	Inadequate manouvering performed by bridge team
		C421	The passage plan did not define any off-track limits
		C422	The bridge team did not discuss limits, define roles and responsibilities
		C423	The position fixing and track monitoring methods used by the bridge team were not consistently accurate
		C424	Ineffective and inappropriate use of the radar and GPS
		C425	Bridge resource management was ineffective
		C426	Inadequate communication between members of the bridge team
		C427	Safety management system procedures did not require specific off-track limit
		C428	The bridge equipment did not provide a failure indication
	MT Breakthrough (ATSB)	C429	The ship's engineers did not make preparations for using the intermediate fuel oil
		C430	Intermediate fuel oil had not been tested by marine engineers
		C431	Ship's senior officers did not adequately manage the risks
		C432	Passage plan was based on incomplete information
		C433	Ship owner did not provide the necessary support to vessel
		C434	The ship's safety management system was inadequate.
		C435	Officers did not have sufficient relevant knowledge and experience to safely undertake ship voyage
		C436	Ineffective inspections of the ship or audits conducted
	MT Desh Rakshak (ATSB)	C437	Inadequately considered the ship's speed through the water
		C438	The ship's under keel clearance was less than had been anticipated
		C439	Ineffective procedures and guidelines provided by port authority
		C440	Inadequate application of bridge resource management principles
		C441	Lack of time available
		C442	The bridge team did not effectively use the echo sounder to monitor the depth

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
Fire/Explosion	MT Conus (ATSB)	C443	The pilot did not plan the undocking
		C444	The bridge team did not take full account of the wind and current strength
		C445	Insufficient decision making upon increasing ship speed
		C446	Inappropriate action taken during course alteration
		C447	No accurate assessment could be made of the tidal stream
		C448	Ineffective radar monitoring performed by OOW
	M/V Hilli (MAIB)	C449	Crew misunderstand regarding with the circulation of the water/acid mixture
		C450	Negligence of checking the ventilation installation
		C451	Improper equipment usage during boiler cleaning operation
		C452	Proper ventilation did not provide by crew
		C453	No consideration was given to testing the steam drum atmosphere
		C454	Lack of risk assessment conducted by responsible officer
		C455	Lack of detail crew responsibilities inserted in company SMS in accordance with ISM Code
	M/T Qian Chi (ATSB)	C456	Incorrectly assembled equipment after maintenance
		C457	The design error in equipment
		C458	Maintenance manual did not provide sufficient guidance
		C459	Incorrect first aid applied to the injured crew
		C460	Improper checklist provided by ship management company
		C461	Not to use personnel protective equipment
	MT Tasman (ATSB)	C462	The source of ignition of the fire could not be determined with certainty by crew
		C463	Fuel oil temperature was not sufficiently screened against spray from the engine hot box by operator
		C464	Fuel leakage alarm was ineffective
		C465	Screws was not sufficiently tightened during previous assembly of the pipework

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MT Helix (ATSB)	C466	The crew was using the incorrect torque
		C467	The response to the fire by the ship's staff was prompt and ineffective
		C468	The design of the hot box was incorrect
		C469	Insufficient preload (torque) upon assembly
		C470	The failure of the supporting bracket was caused by inadequate design
		C471	Fire was not extinguished properly
		C472	Emergency procedures for calling the fireman were ineffective
		C473	The failure of the bolts securing conducted by crew
		C474	The windlass appears to have exploded due to overpressure
		C475	Equipment's design limitations being exceeded
Machinery Damage	MT Stellar Voyager (MAIB)	C476	Crew were not aware of the limitations of anchor windlass systems
		C477	Crew were not aware of risk when the windlass work under excessive load
		C478	Technical data provided by manufacturer was insufficient
		C479	Information provided on guidance was inadequate for operation
		C480	Duty crew did not follow the master's instructions for heaving up the anchor
		C481	Duty crew had poor practice upon anchor handling
		C482	Ballast discharging operation performed under closed venting conditions
	MT Mobil Petrel (MAIB)	C483	The ballast valve was closed incorrectly
		C484	Crew made no attempt to repair or replace defective valve
		C485	The officers did not take appropriate precautions
		C486	Unsafe practices in the operation of the IG system become acceptable to the ship's officers
		C487	Ineffective practice upon ballast operation

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
Listing/Capsizing	MT Aquila (MAIB)	C488	Insufficient risk assessment
		C489	OOW was not aware of the critic stability condition of vessel
		C490	Lack of traning performed on-board ship
		C491	Commercial pressure
		C492	Chain of command error
		C493	Improper physical environment
Flooding	MT Seiyo (JTSB)	C494	Air vent pipes did not work properly becuse no countermeasures had been taken by crew
		C495	The operation of ballast lines were changed without getting permission from class society
		C496	Deficiency of operation management plan
		C497	Poor record keeping
		C498	Negligence of environmental control
Others(FFO&cargo handling damage, weather damage, etc.)	MT Young Lady (MAIB)	C499	Master decision making error
		C500	Insufficient shackles of cable was let go seabad
		C501	Inadequate contingency plan
		C502	Failure to follow up on the events detected by VTS radar,
		C503	The absence of a formal requirement for the early reporting of the incident to authorities
		C504	The absence of an effective action response plan
Collision/Contact	MV CMA CGM Florida & MV Chou Shan (MAIB)	C505	The absence of agreed procedures between pipeline operators and terminal
		C506	OOW lacked situational awareness and precautionary though
		C507	Inappropriate use of VHF radio channel for collision avoidance
		C508	Communication problem among the crew due to poor English
		C509	Misunderstanding the content of master standing orders
		C510	Master's standing orders lacked specific metrics and provided ambiguous instruction

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MV ACX Hibiscus & MV Hyundai Discovery (MAIB)	C513	High power-distance hierarchy affected the OOW
		C514	Most emergency drills conducted on ship did not provide for a practical simulation
		C515	Incorrect manouvering performed by OOW
		C516	Bridge teams did not comply fully with the applicable COLREGS for restricted visibility
		C517	Chief officer's performance was adversely affected by fatigue
		C518	The standard of watchkeeping on the vessel at the time of the accident was very poor
		C519	Master's lack of oversight of the passage plan
		C520	Fundamental weakness in that administration's application of the IMO Casualty
	MV Bai Chay Bridge (JTSB)	C521	Master did not take appropriate action to avoid collision
		C522	OOW was not keeping a proper look out
		C523	OOW did not listen communication in VHF radio
		C524	OOW did not properly monitor the maneuvers of other ship
		C525	Incorrect manouvering performed by OOW
		C526	Incorrect assumption on the basis of scanty radar information
	MV Ocean Odyssey & MV P&O Nedlloyd Taranaki (ATSB)	C527	OOW was falling a sleep due to fatigue
		C528	Inappropriate physical environment on the bridge
		C529	Unsuccessfully to alert the other vessel by sounding the ship's whistles
		C530	No attempt was made to use the available VHF channel for communication
		C531	Lack of risk assessment strategies
		C532	Master made a quick decision based on scanty information
		C534	The lack of communications between the bridge and engine room teams

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MV Lykes Voyager & MV Washington Senator (MAIB)	C535	Bridge team not keeping the engine room team informed of progress
		C536	The lack of Bridge Resource Management principles on board
		C537	The ship did not inform the authorities about the engine response
		C538	The absence of a safety assessment
		C539	Inappropriate contingency planning on board ship
		C540	Inexperienced third officer on the bridge
		C541	Fatigue due to cargo delay
		C542	Late VHF communication attempt made by Master
		C543	Misunderstanding between the master and third officer regarding who had the con
		C544	Useless AIS information
		C545	Inefficient bridge team management training provided by ship management company
		C546	Not to keep a good listening watch on VHF radio channel 16
Grounding	MV New Delhi Express (NTSB)	C547	Ineffective bridge team management
		C548	Ineffective use of resources on bridge
		C549	Responsibilities between bridge team and pilot did not distribute properly
		C550	Ineffective communication between the bridge team and pilot
		C551	Careless passage plan prepared
	MV Coastal Isle (MAIB)	C552	No one on the bridge to correct the vessel's heading properly
		C553	No watch alarms on the bridge have been switched on
		C554	Absence of the bridge watchkeepers
		C555	Not to comply with maritime authorities
		C556	OOW did not inform the Master timely
		C557	The VDR was kept switched off by the crew

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MV MSC Basel (MAIB)	C559	Steering was not tested in accordance with SOLAS requirements before departure
		C560	Preliminary inspections and tests of steering gear system did not performed properly
		C561	Intermittent steering fault has not been rectified properly before
		C562	Relevant checklist regarding prior to departure did not complete by officers
		C563	Communication between engine room and bridge team was very poor
		C564	Inadequate internal audit performed by ship management company
Machinery Damage	MV Maersk Doha (MAIB)	C565	Loss of feed water in the auxiliary boiler led to failure of temperature increase
		C566	Soot deposits accumulated in the EGE were not cleaned properly
		C567	Keep to main engine running
		C568	Lack of risk assessment in engine control room
		C569	Delays in reporting the problem to the bridge
		C570	Lack of advice given to the master
		C571	Unsuitable techniques were used to attack the fire by crew
		C572	Ineffective maintenance planning
		C573	Fuel quick closure valves not functioning correctly
		C574	Quality and Safety Management System did not contain sufficient detail about emergency operation procedures
		C575	Difficulties with language and poor communication
		C577	Winch brake was not fully applied
		C578	Hawse pipe covers had not been fitted to position
		C579	No heavy weather precautions were taken by Master

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
Collision/Contact	MV Key Bora (MAIB)	C581	Flammable clothing was left in the vicinity of the acetylene gas bottles
		C582	No gas leak tests were carried out by the manufacturer
		C583	Hot work permission was not followed by crew
		C584	The “in use” bottles were co-located with the storage bottles
		C585	Poor communications between the technical management and the ship
		C586	Safety watchman was not equipped with a portable VHF radio
		C587	The VDR information was not saved.
	MV Apollo (KAIK)	C588	OOW did not develop sufficient astern thrust in time to stop the shipvessel
		C589	Poor CPP astern response was introduced at the time the system
		C590	Ineffecitve fault findings were performed by crew
		C591	Duty engineer did not test the propulsion system prior to manouvering
		C592	The master’s lack of familiarity with the backup control system
		C593	Poor measure effectiveness of the safety management systems on board the ship
		C594	Lack of periodic drill to practice the correct response
		C595	The master had not received 6 consecutive hours of rest during the 24 hour period
		C596	No reliable source of vessel information provided to pilots
		C597	Ship SMS did not include responsibility distribution properly
		C598	Lack of traning performed on-board ship
		C599	Inadequate bridge procedures manuel on bridge

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MV Spring Bok and MV gas Artic (MAIB)	C600	OOW was not keeping a proper lookout
		C601	Scanty radar monitoring provided only
		C602	No restricted visibility poster provided on bridge against ship's SMS
		C603	Master became distracted by various personnel for non-operational reasons
		C604	Master was fatigued due to cumulative effects of his work hours
		C605	Insufficient bridge team management
	MV Namhae Gas (ATSB)	C606	OOW did not immediately report the collision to the ship's Master
		C607	Master did not make a proper appraisal of the risk of collision
		C608	Lack of radar reflector fitted to ship
		C609	Chart corrections were not performed properly in line of notice to mariners
		C610	BNWAS was seldom used
Grounding	MV Navigator Scorpio (MAIB)	C611	The ship was underway without a complete berth-to-berth passage plan
		C612	Passage plan was not thoroughly checked by the Master
		C613	Master did not take effective action to mitigate the danger
		C614	Sole bridge watchkeeper was assigned
		C615	OOW was distracted by undertaking chart corrections and passage plan
		C616	OOW did not follow the master's instruction to fix position at 5 min interval
		C617	Bridge manning was insufficient for the restricted passage
		C618	The course alteration was ineffective to avoid collision
		C619	Incorrect information was inserted to the chart

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
	MV Ovit (MAIB)	C621	Passage plan prepared by inexperienced and unsupervised officer
		C622	The passage plan was not properly checked by Master
		C623	The OOW did not check the ship's intended track when taking over the watch
		C624	OOW situational awareness was poor
		C625	The officers were unable to safely navigate using the vessel's ECDIS
		C626	Route was not properly checked by OOW
		C627	Master and deck officers did not implement the ship manager's policies for safe navigation and bridge watchkepg
		C628	Master provided insufficient leadership
		C629	No specific training in the alerting system was given
	MV Attilio Levoli (MAIB)	C630	Poor team work
		C631	No pre-sailing briefing was given to bridge team
		C632	Contrary to company instructions, the echo sounder alarm was set to zero
		C633	The vessel did not report the grounding to the coastguard
		C634	There is a lack of navigational buoys
		C635	The passage plan did not follow company instructions
		C636	A parallel indexing technique was not in use
		C637	The bridge team did not comply with the specific requirements of the company SMS
		C638	The responsibility of bridge team was not defined clearly by ship management company
		C639	The vessel was not fitted with an electronic chart system

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
Fire/Explosion	M/T Esso Mersey (MAIB)	C640	Inadequate quality control standarts caused absence of the two locking grub screws
		C641	Lack of required standart of the Classification Society
		C642	Purchasing substandard equipment for pump
		C643	Lack of communication between the ship and spare parts supplier
		C644	Failure of the intermediate bush resulting from vibration
		C645	Not to fulfill requirements of planned maintenance system on-board ship
Machinery Damage	MV Hawkong (MAIB)	C646	Inadequate emergency response plan
		C647	Training programme did not adequately take into consideration shift patterns
		C648	Shortcomings in the communication and exchange of information between ship and terminal
		C649	No system of sharing alarms existed in ship
		C650	Inadequately monitor the arrangements made to ensure safety at the terminal during loading operation
	MV Kenos Athena (KMST)	C651	Inadequate inspection performed by superintendets for cargo tank inner walls
		C652	Incorrect maintainenca method applied to cargo tanks' inner walls against corrosion
		C653	Lack of crew training
		C654	Bilge PPI alarm was not active
		C655	Regular safety patrol were not carried out by duty engineer
		C656	Deficiency in ship's safety management system
	MV Forum Samoa II (ATSB)	C657	The OOW was not keeping a proper lookout
		C658	OOW was distracted by his radio conversation with friend
		C659	Unjustified assumption was made by OOW
		C660	OOW did not check the ARPA or take compass bearing properly

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
		C661	Inadequate handover performed by duty officers
		C662	OOW did not call the Master
	MV Scot Isles & MV Wadi Halfa (MAIB)	C663	No night orders left by the master to alert the watchkeeper about risk of collision
		C664	ARPA was not used to acquire and plot targets
		C665	Positions were not plotted on the chart
		C666	The AIS was not monitored properly
		C667	The bridge watch alarm was not activated
		C668	Available navigational equipment was not used effectively
		C669	SMS non-conformities were not identified during internal audit by management company
		C670	General alarm was not included in the SMS post collision checklist
		C671	Checklist carried out on vessel were not sufficient to identify the major damage to the hull
Grounding	MV Bohai Challenge (JTSB)	C672	Checklists was not completely completed by OOW before leaving port
		C673	No weather information and navigational aids were received properly by Master
		C674	Utmost attention should not be paid to bad weather
		C675	A comprehensive anchoring plan and navigation plan did not develop
		C676	Carelessness navigational information including port of call, pilot, radio signal, etc. were received
		C677	Inadequate implement ongoing risk assessment procedures
		C678	Anchor lights were not switched on in accordance with COLREG

Table B.1 (continued) : Marine accident causes, type of accidents and vessel names.

Type of accident	Vessel name	Cause code	Marine accident causes
Fire/Explosion	MV Celtic Carrier (MAIB)	C679	Failure to comply with any of the safety rules renders by company
		C680	Improper use of equipment
		C681	Ill-prepared for the emergency situation
		C682	Chain of command error
		C683	Sub-standard fire-fighting techniques applied by crew
		C684	Lack of emergency fire drill training on-board ship
		C685	Negligence of SMS by shore-based management company
		C686	Inadequate audits performed by shore-based management company
Listing/Capsizing	MV Maritime Lady (MAIB)	C687	Master's poor judgement and decision-making error
		C688	Master was alone on the bridge therefore did not have the resources to operate
		C689	Vessel's bridge team was diluted during a crucial part of the river
		C690	Unreasonable workload undertaken as the vessel manoeuvred into the river
		C691	Master had not properly used the manpower available
		C692	There were fundamental VHF procedural errors made by the master

Table B.2 : Distribution of 692 marine accident causes into HFACS.

Cause	HFACS level	Times	Cause	HFACS level	Times
C1	Skill-based error	2	C48	Failed to correct problem	1
C2	Skill-based error	2	C49	Resource management	1
C3	Crew resource man	8	C50	Skill-based error	1
C4	Resource management	4	C52	Inadequate supervision	1
C5	Routine violation	2	C54	Resource management	1
C6	Skill-based error	1	C56	Organisational process	5
C7	Decision error	1	C57	Physical environment	4
C8	Organisational process	4	C58	Perceptual error	4
C9	Skill-based error	18	C59	Failed to correct problem	1
C10	Routine violation	12	C60	Routine violation	1
C11	Organisational process	2	C61	Skill-based error	9
C12	Planned inappropriate op	6	C62	Decision error	3
C13	Routine violation	1	C64	Organisational process	1
C14	Decision error	2	C65	Skill-based error	1
C15	Routine violation	8	C66	Decision error	1
C16	Adverse mental state	4	C67	Organisational process	1
C18	Organisational climate	1	C69	Routine violation	2
C19	Organisational process	1	C70	Routine violation	6
C20	Organisational process	7	C71	Skill-based error	2
C21	Organisational process	4	C73	Physical/mental limitation	1
C22	Crew resource man	2	C74	Skill-based error	1
C25	Decision error	1	C75	Exceptional violation	1
C27	Organisational climate	1	C76	Planned inappropriate op	2
C28	Decision error	1	C79	Planned inappropriate op	2
C29	Exceptional violation	2	C80	Resource management	4
C30	Resource management	6	C82	Organisational process	1
C31	Inadequate supervision	2	C83	Exceptional violation	1
C32	Organisational climate	1	C85	Failed to correct problem	1
C34	Skill-based error	2	C86	Decision error	2
C35	Organisational process	1	C87	Perceptual error	1
C37	Decision error	1	C91	Adverse physiological state	12
C38	Decision error	1	C92	Technological environment	1
C40	Crew resource man	3	C94	Organisational climate	1
C41	Resource management	3	C95	Resource management	5
C42	Adverse mental state	1	C96	Inadequate supervision	1
C43	Skill-based error	1	C97	Technological environment	2
C44	Crew resource man	6	C98	Organisational process	1
C45	Crew resource man	6	C100	Organisational process	1
C46	Decision error	1	C102	Routine violation	1
C47	Adverse mental state	1	C103	Decision error	1

Table B.2 (continued) : Distribution of 692 marine accident into HFACS.

Cause	HFACS level	Times	Cause	HFACS level	Times
C104	Crew resource man	1	C182	Organisational process	1
C105	Exceptional violation	2	C186	Personal readiness	2
C107	Crew resource man	1	C187	Resource management	2
C108	Planned inappropriate op	1	C188	Organisational process	2
C114	Resource management	1	C189	Skill-based error	1
C115	Failed to correct problem	1	C191	Resource management	1
C116	Physical environment	1	C192	Organisational process	3
C117	Physical environment	1	C194	Decision error	4
C118	Organisational climate	1	C195	Decision error	1
C121	Adverse mental state	3	C197	Organisational process	1
C122	Crew resource man	3	C199	Skill-based error	1
C123	Skill-based error	1	C201	Routine violation	1
C127	Decision error	1	C202	Skill-based error	1
C129	Personal readiness	1	C203	Organisational process	1
C130	Organisational process	3	C204	Inadequate supervision	5
C131	Inadequate supervision	1	C205	Organisational process	1
C133	Skill-based error	1	C206	Organisational process	1
C134	Skill-based error	1	C207	Inadequate supervision	2
C136	Resource management	2	C208	Organisational climate	1
C137	Organisational climate	1	C209	Adverse mental state	3
C138	Physical environment	3	C210	Crew resource man	1
C139	Skill-based error	1	C214	Exceptional violation	7
C142	Failed to correct problem	1	C215	Resource management	1
C144	Organisational climate	1	C216	Planned inappropriate op	1
C145	Organisational process	3	C217	Physical environment	2
C146	Routine violation	2	C219	Inadequate supervision	7
C147	Skill-based error	3	C220	Failed to correct problem	2
C149	Organisational climate	12	C221	Inadequate supervision	1
C150	Inadequate supervision	3	C226	Crew resource man	1
C154	Exceptional violation	1	C227	Decision error	1
C155	Failed to correct problem	1	C228	Organisational process	2
C156	Routine violation	4	C229	Crew resource man	1
C158	Skill-based error	1	C231	Organisational process	1
C160	Skill-based error	2	C232	Failed to correct problem	1
C161	Organisational climate	1	C233	Inadequate supervision	1
C163	Resource management	1	C234	Inadequate supervision	1
C164	Inadequate supervision	4	C235	Skill-based error	2
C165	Resource management	1	C236	Perceptual error	1
C166	Organisational process	1	C237	Physical environment	2
C167	Routine violation	1	C238	Skill-based error	1
C168	Organisational process	5	C239	Skill-based error	1
C169	Inadequate supervision	2	C240	Resource management	5
C170	Decision error	3	C241	Inadequate supervision	1
C172	Decision error	2	C242	Organisational climate	1
C173	Crew resource man	1	C243	Resource management	5
C174	Organisational process	1	C245	Organisational process	1
C176	Inadequate supervision	3	C246	Resource management	2
C177	Routine violation	1	C247	Failed to correct problem	4
C178	Resource management	1	C248	Skill-based error	1
C179	Routine violation	1	C251	Crew resource man	1
C180	Decision error	3	C253	Planned inappropriate op	1

Table B.2 (continued) : Distribution of 692 marine accident into HFACS.

Cause	HFACS level	Times	Cause	HFACS level	Times
C256	Inadequate supervision	1	C321	Exceptional violation	1
C257	Organisational process	3	C323	Organisational process	1
C258	Planned inappropriate op	9	C324	Exceptional violation	1
C259	Technological environment	1	C325	Organisational process	1
C260	Decision error	1	C330	Planned inappropriate op	1
C261	Organisational process	1	C332	Skill-based error	2
C264	Skill-based error	1	C333	Organisational climate	1
C265	Organisational climate	1	C336	Decision error	3
C267	Physical environment	1	C337	Resource management	1
C268	Resource management	1	C340	Skill-based error	1
C269	Skill-based error	1	C343	Failed to correct problem	1
C270	Planned inappropriate op	1	C344	Technological environment	2
C272	Crew resource man	1	C347	Resource management	1
C273	Organisational process	2	C348	Skill-based error	1
C274	Organisational process	1	C359	Failed to correct problem	1
C276	Decision error	1	C360	Organisational process	1
C277	Failed to correct problem	1	C365	Routine violation	2
C278	Inadequate supervision	1	C367	Personal readiness	1
C279	Resource management	1	C368	Technological environment	1
C280	Organisational climate	1	C371	Decision error	1
C281	Routine violation	1	C372	Decision error	1
C282	Skill-based error	1	C373	Failed to correct problem	1
C283	Routine violation	1	C374	Resource management	1
C284	Planned inappropriate op	2	C376	Decision error	2
C285	Organisational process	2	C377	Crew resource man	2
C286	Inadequate supervision	3	C384	Perceptual error	1
C289	Routine violation	1	C387	Skill-based error	1
C290	Organisational climate	1	C388	Decision error	1
C292	Skill-based error	1	C391	Organisational climate	1
C293	Skill-based error	1	C395	Organisational climate	1
C294	Inadequate supervision	1	C398	Planned inappropriate op	1
C297	Exceptional violation	1	C400	Failed to correct problem	2
C298	Crew resource man	2	C401	Inadequate supervision	2
C299	Perceptual error	2	C404	Perceptual error	1
C300	Organisational climate	1	C405	Decision error	1
C302	Resource management	1	C406	Exceptional violation	1
C305	Failed to correct problem	1	C408	Exceptional violation	1
C306	Organisational climate	3	C409	Organisational process	1
C307	Organisational process	1	C410	Physical/mental limitation	2
C308	Skill-based error	1	C411	Organisational process	1
C310	Decision error	1	C414	Skill-based error	1
C311	Organisational process	1	C415	Skill-based error	1
C312	Organisational process	4	C416	Decision error	1
C313	Adverse mental state	1	C421	Organisational process	1
C314	Decision error	1	C422	Organisational climate	2
C315	Resource management	5	C423	Failed to correct problem	1
C316	Exceptional violation	2	C427	Organisational process	1
C317	Decision error	1	C428	Planned inappropriate op	1
C318	Organisational climate	1	C429	Exceptional violation	1
C319	Perceptual error	1	C430	Inadequate supervision	2

Table B.2 (continued) : Distribution of 692 marine accident into HFACS.

Cause	HFACS level	Times	Cause	HFACS level	Times
C431	Organisational process	1	C533	Skill-based error	1
C436	Supervisory violations	3	C535	Crew resource man	1
C437	Decision error	1	C538	Organisational process	1
C438	Perceptual error	1	C543	Perceptual error	1
C439	Organisational process	1	C544	Resource management	1
C442	Planned inappropriate op	2	C548	Resource management	1
C443	Organisational process	1	C551	Routine violation	1
C444	Routine violation	1	C552	Decision error	1
C445	Decision error	1	C554	Organisational process	1
C447	Decision error	1	C555	Exceptional violation	1
C449	Perceptual error	1	C556	Failed to correct problem	1
C452	Skill-based error	1	C557	Exceptional violation	1
C453	Technological environment	1	C558	Inadequate supervision	1
C456	Skill-based error	1	C561	Resource management	1
C457	Resource management	3	C562	Skill-based error	2
C460	Organisational process	1	C565	Technological environment	1
C461	Routine violation	1	C566	Inadequate supervision	1
C462	Failed to correct problem	1	C567	Decision error	1
C463	Skill-based error	1	C569	Crew resource man	2
C465	Exceptional violation	1	C570	Resource management	1
C467	Crew resource man	1	C573	Inadequate supervision	1
C469	Skill-based error	1	C574	Organisational process	1
C471	Failed to correct problem	1	C577	Skill-based error	1
C472	Organisational process	2	C578	Resource management	1
C473	Skill-based error	1	C582	Routine violation	1
C474	Physical environment	1	C584	Supervisory violations	2
C475	Resource management	1	C585	Organisational climate	2
C476	Crew resource man	1	C586	Crew resource man	1
C478	Resource management	1	C587	Exceptional violation	1
C481	Inadequate supervision	1	C588	Decision error	1
C482	Physcial environment	1	C589	Skill-based error	1
C483	Skill-based error	1	C590	Adverse mental state	1
C484	Routine violation	1	C593	Organisational process	1
C485	Decision error	2	C594	Inadequate supervision	1
C486	Skill-based error	1	C596	Exceptional violation	1
C487	Inadequate supervision	1	C599	Resource management	1
C492	Organisational climate	2	C609	Inadequate supervision	1
C494	Crew resource man	1	C610	Resource management	1
C495	Exceptional violation	1	C611	Organisational process	1
C496	Organisational climate	1	C613	Failed to correct problem	1
C504	Organisational process	1	C619	Skill-based error	1
C505	Crew resource man	1	C620	Organisational process	1
C509	Perceptual error	1	C623	Skill-based error	1
C510	Organisational process	1	C625	Physical/mental limitation	1
C511	Failed to correct problem	1	C626	Decision error	1
C513	Crew resource man	1	C627	Routine violation	1
C514	Inadequate supervision	1	C631	Crew resource man	1
C520	Organisational climate	1	C634	Organisational climate	1
C523	Routine violation	2	C635	Exceptional violation	1
C529	Physical environment	1	C636	Skill-based error	1
C530	Exceptional violation	1	C637	Routine violation	2

Table B.2 (continued) : Distribution of 692 marine accident into HFACS.

Cause	HFACS level	Times	Cause	HFACS level	Times
C640	Resource management	1	C660	Skill-based error	1
C641	Planned inappropriate op	1	C663	Adverse mental state	1
C642	Resource management	1	C670	Organisational process	1
C644	Physcial environment	1	C671	Skill-based error	1
C645	Organisational process	1	C674	Perceptual error	1
C647	Inadequate supervision	1	C675	Organisational process	1
C649	Resource management	1	C683	Crew resource man	1
C650	Skill-based error	1	C689	Adverse mental state	1
C652	Skill-based error	1	C690	Planned inappropriate op	1
C655	Routine violation	1	C691	Resource management	1
C659	Decision error	1	C692	Decision error	1

Table B.3 : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking, and weigting									
C1	2	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		3	5	1	6	2	4				
		0.136	0.082	0.408	0.068	0.204	0.102				
C2	2	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		4	5	1	6	3	2				
		0.102	0.082	0.408	0.068	0.136	0.204				
C3	8	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37		
		3	8	5	1	4	7	2	6		
		0.123	0.046	0.074	0.368	0.092	0.053	0.184	0.061		
C4	4	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	2	4	5	6	3				
		0.408	0.204	0.102	0.082	0.068	0.136				
C5	2	EPC10	EPC13	EPC16	EPC17	EPC21					
		1	4	3	5	2					
		0.438	0.109	0.146	0.088	0.219					
C6	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		3	5	4	6	1	2				
		0.136	0.082	0.102	0.068	0.408	0.204				
C7	1	EPC4	EPC24	EPC32							
		2	3	1							
		0.273	0.182	0.545							
C8	4	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		2	1	8	4	3	7	5	6	9	
		0.177	0.353	0.044	0.088	0.118	0.05	0.071	0.059	0.039	
C9	18	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		3	6	2	5	1	4				
		0.136	0.068	0.204	0.082	0.408	0.102				
C10	12	EPC10	EPC13	EPC16	EPC17	EPC21					
		1	4	3	5	2					
		0.438	0.109	0.146	0.088	0.219					
C11	2	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	2	8	4	3	7	5	6	9	
		0.353	0.177	0.044	0.088	0.118	0.05	0.071	0.059	0.039	
C12	6	EPC2	EPC8	EPC14	EPC16	EPC18					
		1	3	4	2	5					
		0.438	0.146	0.109	0.219	0.088					
C13	1	EPC10	EPC13	EPC16	EPC17	EPC21					
		1	2	3	5	4					
		0.438	0.219	0.146	0.088	0.109					
C14	2	EPC4	EPC24	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C15	8	EPC10	EPC13	EPC16	EPC17	EPC21					
		2	1	3	5	4					
		0.219	0.438	0.146	0.088	0.109					
C16	4	EPC8	EPC9	EPC34	EPC35						
		3	1	4	2						
		0.160	0.480	0.120	0.240						
C18	1	EPC8	EPC18	EPC37							
		1	3	2							
		0.545	0.182	0.273							
C19	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	2	8	3	4	7	6	5	9	
		0.353	0.177	0.044	0.118	0.088	0.05	0.059	0.071	0.039	
C20	7	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	2	9	4	3	7	5	6	8	
		0.353	0.177	0.039	0.088	0.118	0.05	0.071	0.059	0.044	
C21	4	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	8	4	2	7	5	6	9	
		0.353	0.044	0.044	0.088	0.177	0.05	0.071	0.059	0.039	

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking, and weigting								
C21	4	0.353	0.177	0.039	0.088	0.118	0.05	0.071	0.059	0.044
		EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
C22	2	1	3	8	4	2	7	5	6	9
		0.353	0.044	0.044	0.088	0.177	0.05	0.071	0.059	0.039
C25	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37	
		4	8	5	2	3	7	1	6	
C27	1	0.092	0.046	0.082	0.204	0.123	0.053	0.368	0.061	
		EPC4	EPC24	EPC32						
C28	1	1	3	2						
		0.545	0.182	0.273						
C29	2	EPC8	EPC18	EPC37						
		1	3	2						
C30	6	0.545	0.182	0.273						
		EPC4	EPC24	EPC32						
C31	2	1	3	2						
		0.545	0.182	0.273						
C32	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36
		1	3	2	8	5	4	9	7	6
C33	6	0.353	0.118	0.177	0.044	0.071	0.088	0.039	0.05	0.059
		EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
C34	2	2	3	5	4	6	1			
		0.204	0.136	0.082	0.102	0.068	0.408			
C35	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28			
		3	6	5	4	2	1			
C36	1	0.136	0.068	0.082	0.102	0.204	0.408			
		EPC8	EPC18	EPC37						
C37	2	2	3	1						
		0.273	0.182	0.545						
C38	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		2	5	4	6	1	3			
C39	1	0.204	0.082	0.102	0.068	0.408	0.136			
		EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
C40	1	1	2	9	4	3	7	5	6	8
		0.353	0.177	0.039	0.088	0.118	0.05	0.071	0.059	0.044
C41	1	EPC4	EPC24	EPC32						
		1	3	2						
C42	1	0.545	0.182	0.273						
		EPC4	EPC24	EPC32						
C43	3	1	3	2						
		0.545	0.182	0.273						
C44	3	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37	
		3	8	5	1	4	7	2	6	
C45	3	0.123	0.046	0.074	0.368	0.092	0.053	0.184	0.061	
		EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
C46	1	2	3	5	4	6	1			
		0.204	0.136	0.082	0.102	0.068	0.408			
C47	1	EPC8	EPC9	EPC34	EPC35					
		1	3	4	2					
C48	1	0.48	0.16	0.12	0.24					
		EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
C49	6	4	6	1	5	3	2			
		0.102	0.068	0.408	0.082	0.136	0.204			
C50	6	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37	
		2	3	5	1	4	7	8	6	
C51	6	0.184	0.123	0.074	0.368	0.092	0.053	0.046	0.061	
		EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37	
C52	1	3	2	5	1	4	8	7	6	
		0.123	0.184	0.074	0.368	0.092	0.046	0.053	0.061	
C53	1	EPC4	EPC24	EPC32						
		1	3	2						

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking, and weighting									
C47	1	EPC8	EPC9	EPC34	EPC35						
		3	1	4	2						
		0.160	0.480	0.120	0.240						
C48	1	EPC2	EPC7	EPC32							
		2	3	1							
		0.273	0.182	0.545							
C49	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		2	3	5	4	6	1				
		0.204	0.136	0.082	0.102	0.068	0.408				
C50	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		3	6	1	5	2	4				
		0.136	0.068	0.408	0.082	0.204	0.102				
C52	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		4	6	2	5	3	1				
		0.102	0.068	0.204	0.082	0.136	0.408				
C54	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		2	3	4	5	6	1				
		0.204	0.136	0.102	0.082	0.068	0.408				
C56	5	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	2	8	3	4	7	6	5	9	
		0.353	0.177	0.044	0.118	0.088	0.05	0.059	0.071	0.039	
C57	4	EPC5	EPC19	EPC33	EPC36						
		3	4	1	2						
		0.160	0.120	0.480	0.240						
C58	4	EPC5	EPC6	EPC9	EPC12	EPC38					
		5	2	3	1	4					
		0.088	0.219	0.146	0.438	0.109					
C59	1	EPC2	EPC7	EPC32							
		2	3	1							
		0.273	0.182	0.545							
C60	1	EPC10	EPC13	EPC16	EPC17	EPC21					
		2	1	3	5	4					
		0.219	0.438	0.146	0.088	0.109					
C61	9	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		3	6	1	5	2	4				
		0.136	0.068	0.408	0.082	0.204	0.102				
C62	3	EPC4	EPC24	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C64	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	8	4	2	7	6	5	9	
		0.353	0.353	0.044	0.088	0.177	0.05	0.059	0.071	0.039	
C65	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	5	4	6	2	3				
		0.408	0.082	0.102	0.068	0.204	0.136				
C66	1	EPC4	EPC24	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C67	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	2	9	3	4	7	5	6	8	
		0.353	0.177	0.039	0.118	0.088	0.05	0.071	0.059	0.044	
C69	2	EPC10	EPC13	EPC16	EPC17	EPC21					
		2	1	3	4	5					
		0.219	0.438	0.146	0.109	0.088					
C70	6	EPC10	EPC13	EPC16	EPC17	EPC21					
		2	1	3	5	4					
		0.219	0.438	0.146	0.088	0.109					
C71	2	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		2	6	1	5	3	4				
		0.204	0.068	0.408	0.082	0.136	0.102				

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking, and weigting									
C73	1	EPC5	EPC15	EPC27	EPC34						
		2	1	3	4						
		0.240	0.480	0.160	0.120						
C74	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	5	2	6	3	4				
		0.408	0.082	0.204	0.068	0.136	0.102				
C75	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		1	3	2	9	5	4	8	6	7	
		0.353	0.118	0.177	0.039	0.071	0.088	0.044	0.059	0.05	
C76	2	EPC2	EPC8	EPC14	EPC16	EPC18					
		1	3	4	2	5					
		0.438	0.146	0.109	0.219	0.088					
C79	2	EPC2	EPC8	EPC14	EPC16	EPC18					
		2	3	4	1	5					
		0.219	0.146	0.109	0.438	0.088					
C80	4	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		2	3	4	5	6	1				
		0.204	0.136	0.102	0.082	0.068	0.408				
C82	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	2	8	5	3	6	7	4	9	
		0.353	0.177	0.044	0.071	0.118	0.059	0.05	0.088	0.039	
C83	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		3	1	2	8	6	4	9	7	5	
		0.118	0.353	0.177	0.044	0.059	0.088	0.039	0.05	0.071	
C85	1	EPC2	EPC7	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C86	2	EPC4	EPC24	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C87	1	EPC5	EPC6	EPC9	EPC12	EPC38					
		4	2	3	1	5					
		0.109	0.219	0.146	0.438	0.088					
C91	12	EPC27	EPC29	EPC30	EPC31	EPC35					
		4	3	5	2	1					
		0.109	0.146	0.088	0.219	0.438					
C92	1	EPC3	EPC13	EPC14	EPC32	EPC33					
		5	2	4	3	1					
		0.088	0.219	0.109	0.146	0.438					
C94	1	EPC8	EPC18	EPC37							
		1	3	2							
		0.545	0.182	0.273							
C95	5	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	3	4	5	6	2				
		0.408	0.136	0.102	0.082	0.068	0.204				
C96	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		2	6	4	5	3	1				
		0.204	0.068	0.102	0.082	0.136	0.408				
C97	2	EPC3	EPC13	EPC14	EPC32	EPC33					
		5	2	3	4	1					
		0.088	0.219	0.146	0.109	0.438					
C98	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	9	4	2	6	5	6	8	
		0.353	0.118	0.039	0.088	0.177	0.059	0.071	0.059	0.044	
C100	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	2	8	5	3	9	7	4	6	
		0.353	0.177	0.044	0.071	0.118	0.039	0.05	0.088	0.059	
C102	1	EPC10	EPC13	EPC16	EPC17	EPC21					
		2	1	3	5	4					
		0.219	0.438	0.146	0.088	0.109					

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking, and weighting								
C103	1	EPC4	EPC24	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C104	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37	
		2	3	5	1	4	7	8	6	
		0.184	0.123	0.074	0.368	0.092	0.053	0.046	0.061	
C105	2	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36
		1	3	2	8	5	4	9	6	7
		0.353	0.118	0.177	0.044	0.071	0.088	0.039	0.059	0.05
C107	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37	
		2	3	5	1	4	8	7	6	
		0.184	0.123	0.074	0.368	0.092	0.046	0.053	0.061	
C108	1	EPC2	EPC8	EPC14	EPC16	EPC18				
		1	2	4	3	5				
		0.438	0.219	0.109	0.146	0.088				
C114	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	3	4	6	5	2			
		0.408	0.136	0.102	0.068	0.082	0.204			
C115	1	EPC2	EPC7	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C116	2	EPC5	EPC19	EPC33	EPC36					
		3	4	1	2					
		0.160	0.120	0.480	0.240					
C118	1	EPC8	EPC18	EPC37						
		1	3	2						
		0.545	0.182	0.273						
C121	3	EPC8	EPC9	EPC34	EPC35					
		1	3	4	2					
		0.480	0.160	0.120	0.240					
C122	3	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37	
		2	3	6	1	4	7	8	5	
		0.184	0.123	0.061	0.368	0.092	0.053	0.046	0.074	
C123	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	6	2	4	3	5			
		0.408	0.068	0.204	0.102	0.136	0.082			
C127	1	EPC4	EPC24	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C129	1	EPC1	EPC11	EPC27	EPC35					
		1	3	4	2					
		0.480	0.160	0.120	0.240					
C130	3	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		2	1	9	4	3	7	5	6	8
		0.177	0.353	0.039	0.088	0.118	0.05	0.071	0.059	0.044
C131	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28			
		3	5	6	4	2	1			
		0.136	0.082	0.068	0.102	0.204	0.408			
C133	2	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		3	5	2	6	4	1			
		0.136	0.082	0.204	0.068	0.102	0.408			
C136	2	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	2	4	6	5	3			
		0.408	0.204	0.102	0.068	0.082	0.136			
C137	1	EPC8	EPC18	EPC37						
		2	3	1						
		0.273	0.182	0.545						
C138	3	EPC5	EPC19	EPC33	EPC36					
		3	4	1	2					
		0.16	0.12	0.48	0.24					

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking, and weigting								
C139	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		4	6	2	6	3	1			
		0.102	0.068	0.204	0.068	0.136	0.408			
C142	1	EPC2	EPC7	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C144	1	EPC8	EPC18	EPC37						
		1	3	2						
		0.545	0.182	0.273						
C145	3	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		2	1	8	4	3	6	5	7	9
		0.177	0.353	0.044	0.088	0.118	0.059	0.071	0.05	0.039
C146	2	EPC10	EPC13	EPC16	EPC17	EPC21				
		2	4	3	5	1				
		0.219	0.109	0.146	0.088	0.438				
C147	3	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		4	6	1	5	2	3			
		0.102	0.068	0.408	0.082	0.204	0.136			
C149	12	EPC8	EPC18	EPC37						
		1	3	2						
		0.545	0.182	0.273						
C150	3	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28			
		3	5	4	6	2	1			
		0.136	0.082	0.102	0.068	0.204	0.408			
C154	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36
		1	3	2	5	8	4	9	7	6
		0.353	0.118	0.177	0.071	0.044	0.088	0.039	0.05	0.059
C155	1	EPC2	EPC7	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C156	4	EPC10	EPC13	EPC16	EPC17	EPC21				
		2	5	3	4	1				
		0.219	0.088	0.146	0.109	0.438				
C158	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	6	2	5	3	4			
		0.408	0.068	0.204	0.082	0.136	0.102			
C160	2	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		4	5	1	6	3	2			
		0.102	0.082	0.408	0.068	0.136	0.204			
C161	1	EPC8	EPC18	EPC37						
		1	3	2						
		0.545	0.182	0.273						
C163	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	2	3	5	6	4			
		0.408	0.204	0.136	0.082	0.068	0.102			
C164	4	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28			
		3	6	5	4	2	1			
		0.136	0.068	0.082	0.102	0.204	0.408			
C165	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	2	4	5	6	3			
		0.408	0.204	0.102	0.082	0.068	0.136			
C166	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		2	3	9	4	1	7	5	6	8
		0.177	0.118	0.039	0.088	0.353	0.05	0.071	0.059	0.044
C167	1	EPC10	EPC13	EPC16	EPC17	EPC21				
		2	1	3	5	4				
		0.219	0.438	0.146	0.088	0.109				
C168	5	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		1	2	9	4	3	7	5	6	8
		0.353	0.177	0.039	0.088	0.118	0.05	0.071	0.059	0.044

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking, and weighting								
C169	2	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28			
		3	4	6	5	2	1			
		0.136	0.102	0.068	0.082	0.204	0.408			
C170	3	EPC4	EPC24	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C172	2	EPC4	EPC24	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C173	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37	
		2	3	5	1	4	8	7	6	
		0.184	0.123	0.074	0.368	0.092	0.046	0.053	0.061	
C174	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		1	2	8	4	3	9	5	6	7
		0.353	0.177	0.044	0.088	0.118	0.039	0.071	0.059	0.05
C176	3	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28			
		3	6	5	4	2	1			
		0.136	0.068	0.082	0.102	0.204	0.408			
C177	1	EPC10	EPC13	EPC16	EPC17	EPC21				
		2	1	3	4	5				
		0.219	0.438	0.146	0.109	0.088				
C178	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	2	3	6	5	4			
		0.408	0.204	0.136	0.068	0.082	0.102			
C179	1	EPC10	EPC13	EPC16	EPC17	EPC21				
		2	1	4	3	5				
		0.219	0.438	0.109	0.146	0.088				
C180	3	EPC4	EPC24	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C182	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		2	3	8	4	1	9	5	6	7
		0.177	0.118	0.044	0.088	0.353	0.039	0.071	0.059	0.05
C186	2	EPC1	EPC11	EPC27	EPC35					
		1	3	4	2					
		0.480	0.160	0.120	0.240					
C187	2	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		2	3	4	5	6	1			
		0.204	0.136	0.102	0.082	0.068	0.408			
C188	2	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		1	2	9	4	3	7	5	6	8
		0.353	0.177	0.039	0.088	0.118	0.05	0.071	0.059	0.044
C189	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	6	2	5	4	3			
		0.408	0.068	0.204	0.082	0.102	0.136			
C191	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	2	4	6	5	3			
		0.408	0.204	0.102	0.068	0.082	0.136			
C192	3	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		1	3	8	4	2	6	5	7	9
		0.353	0.118	0.044	0.088	0.177	0.059	0.071	0.05	0.039
C194	4	EPC4	EPC24	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C195	1	EPC4	EPC24	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C197	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		2	1	9	4	3	7	5	6	8
		0.177	0.353	0.039	0.088	0.118	0.05	0.071	0.059	0.044

Table B.3 (continued) : Ranking and weighting result of each EPC in accident

Cause	Times	EPC, ranking and weighting									
C199	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		3	5	1	6	4	2				
C201	1	0.136	0.082	0.408	0.068	0.102	0.204				
		EPC10	EPC13	EPC16	EPC17	EPC21					
C202	1	2	1	3	5	4					
		0.219	0.438	0.146	0.088	0.109					
C203	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		4	6	1	5	2	3				
C203	1	0.102	0.068	0.408	0.082	0.204	0.136				
		EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
C204	5	3	1	8	4	2	6	5	7	9	
		0.118	0.353	0.044	0.088	0.177	0.059	0.071	0.05	0.039	
C205	2	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		5	6	3	4	1	2				
C207	2	0.082	0.068	0.136	0.102	0.408	0.204				
		EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
C208	1	3	1	9	4	2	6	5	7	8	
		0.118	0.353	0.039	0.088	0.177	0.059	0.071	0.05	0.044	
C209	3	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		1	5	3	4	2	6				
C210	1	0.408	0.082	0.136	0.102	0.204	0.068				
		EPC8	EPC18	EPC37							
C214	7	1	3	2							
		0.545	0.182	0.273							
C215	1	EPC8	EPC9	EPC34	EPC35						
		1	3	4	2						
C216	1	0.480	0.16	0.120	0.240						
		EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37		
C217	2	2	6	5	1	4	8	7	3		
		0.184	0.061	0.074	0.368	0.092	0.046	0.053	0.123		
C219	7	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		5	1	2	3	8	4	9	7	6	
C220	2	0.071	0.353	0.177	0.118	0.044	0.088	0.039	0.05	0.059	
		EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
C221	1	1	2	4	5	6	3				
		0.408	0.204	0.102	0.082	0.068	0.136				
C222	1	EPC2	EPC8	EPC14	EPC16	EPC18					
		1	2	4	3	5					
C223	2	0.438	0.219	0.109	0.146	0.088					
		EPC5	EPC19	EPC33	EPC36						
C224	7	4	3	1	2						
		0.12	0.16	0.48	0.24						
C225	2	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		1	6	3	4	2	5				
C226	1	0.408	0.068	0.136	0.102	0.204	0.082				
		EPC2	EPC7	EPC32							
C227	1	1	3	2							
		0.545	0.182	0.273							
C228	2	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		1	6	3	4	2	5				
C229	1	0.408	0.068	0.136	0.102	0.204	0.082				
		EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37		
C230	1	4	6	5	1	3	8	7	2		
		0.092	0.061	0.074	0.368	0.123	0.046	0.053	0.184		
C231	1	EPC4	EPC24	EPC32							
		2	3	1							
C232	2	0.273	0.182	0.545							
		EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
C233	2	1	2	9	4	3	7	5	6	8	
		0.353	0.177	0.039	0.088	0.118	0.05	0.071	0.059	0.044	

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking and weigting								
C229	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37	
		3	6	5	2	4	7	8	1	
		0.123	0.061	0.074	0.184	0.092	0.053	0.046	0.368	
C231	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		1	2	8	4	3	7	5	6	9
		0.353	0.177	0.044	0.088	0.118	0.05	0.071	0.059	0.039
C232	1	EPC2	EPC7	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C233	2	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28			
		1	6	3	4	2	5			
		0.408	0.068	0.136	0.102	0.204	0.082			
C235	2	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		5	3	1	6	3	2			
		0.082	0.136	0.408	0.068	0.136	0.204			
C236	1	EPC5	EPC6	EPC9	EPC12	EPC38				
		4	2	5	1	3				
		0.109	0.219	0.088	0.438	0.146				
C237	2	EPC5	EPC19	EPC33	EPC36					
		3	4	1	2					
		0.160	0.120	0.480	0.240					
C238	2	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	6	2	3	4	5			
		0.408	0.068	0.204	0.136	0.102	0.082			
C240	5	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	3	4	5	6	2			
		0.408	0.136	0.102	0.082	0.068	0.204			
C241	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28			
		1	6	4	3	2	5			
		0.408	0.068	0.102	0.136	0.204	0.082			
C242	1	EPC8	EPC18	EPC37						
		1	3	2						
		0.545	0.182	0.273						
C243	5	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	3	4	5	6	2			
		0.408	0.136	0.102	0.082	0.068	0.204			
C245	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		1	2	9	3	4	6	5	7	8
		0.353	0.177	0.039	0.118	0.088	0.059	0.071	0.05	0.044
C246	2	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		2	1	5	4	6	3			
		0.204	0.408	0.082	0.102	0.068	0.136			
C247	4	EPC2	EPC7	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C248	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	5	3	4	2	6			
		0.408	0.082	0.136	0.102	0.204	0.068			
C251	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37	
		2	6	4	3	5	8	7	1	
		0.184	0.061	0.092	0.123	0.074	0.046	0.053	0.368	
C253	1	EPC2	EPC8	EPC14	EPC16	EPC18				
		1	2	5	3	4				
		0.438	0.219	0.088	0.146	0.109				
C256	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28			
		1	6	3	4	2	5			
		0.408	0.068	0.136	0.102	0.204	0.082			
C257	3	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		1	2	9	4	3	7	5	6	8
		0.353	0.177	0.039	0.088	0.118	0.05	0.071	0.059	0.044

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking and weighting								
C258	9	EPC2	EPC8	EPC14	EPC16	EPC18				
		2	1	4	3	5				
		0.219	0.438	0.109	0.146	0.088				
C259	1	EPC3	EPC13	EPC14	EPC32	EPC33				
		3	2	4	5	1				
		0.146	0.219	0.109	0.088	0.438				
C260	1	EPC4	EPC24	EPC32						
		2	3	2						
		0.273	0.182	0.273						
C261	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		3	1	8	4	2	6	5	7	9
		0.118	0.353	0.044	0.088	0.177	0.059	0.071	0.05	0.039
C264	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	5	2	4	3	6			
		0.408	0.082	0.204	0.102	0.136	0.068			
C265	1	EPC8	EPC18	EPC37						
		1	3	2						
		0.545	0.182	0.273						
C267	1	EPC5	EPC19	EPC33	EPC36					
		4	3	1	2					
		0.120	0.160	0.480	0.240					
C268	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	2	4	5	6	3			
		0.408	0.204	0.102	0.082	0.068	0.136			
C269	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	4	3	2	5	6			
		0.408	0.102	0.136	0.204	0.082	0.068			
C270	1	EPC2	EPC8	EPC14	EPC16	EPC18				
		1	2	5	3	4				
		0.438	0.219	0.088	0.146	0.109				
C272	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37	
		2	5	4	3	6	7	8	1	
		0.184	0.074	0.092	0.123	0.061	0.053	0.046	0.368	
C273	3	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		1	2	9	4	3	7	5	6	8
		0.353	0.177	0.039	0.088	0.118	0.05	0.071	0.059	0.044
C276	1	EPC4	EPC24	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C277	1	EPC2	EPC7	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C278	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28			
		3	5	1	4	2	6			
		0.136	0.082	0.408	0.102	0.204	0.068			
C279	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	2	5	4	6	3			
		0.408	0.204	0.082	0.102	0.068	0.136			
C280	1	EPC8	EPC18	EPC37						
		1	3	2						
		0.545	0.182	0.273						
C281	1	EPC10	EPC13	EPC16	EPC17	EPC21				
		2	1	3	5	4				
		0.219	0.438	0.146	0.088	0.109				
C282	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	5	2	6	4	3			
		0.408	0.082	0.204	0.068	0.102	0.136			
C283	1	EPC10	EPC13	EPC16	EPC17	EPC21				
		2	1	4	5	3				
		0.219	0.438	0.109	0.088	0.146				

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking and weigting									
C284	2	EPC2	EPC8	EPC14	EPC16	EPC18					
		1	2	4	3	5					
		0.438	0.219	0.109	0.146	0.088					
C285	2	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	8	4	2	6	5	7	9	
		0.353	0.118	0.044	0.088	0.177	0.059	0.071	0.05	0.039	
C286	3	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		3	5	1	4	2	6				
		0.136	0.082	0.408	0.102	0.204	0.068				
C289	1	EPC10	EPC13	EPC16	EPC17	EPC21					
		2	3	1	5	4					
		0.219	0.146	0.438	0.088	0.109					
C290	1	EPC8	EPC18	EPC37							
		1	3	2							
		0.545	0.182	0.273							
C292	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		5	4	1	6	3	2				
		0.082	0.102	0.408	0.068	0.136	0.204				
C293	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		4	5	1	6	3	2				
		0.102	0.082	0.408	0.068	0.136	0.204				
C294	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		1	5	4	3	2	6				
		0.408	0.082	0.102	0.136	0.204	0.068				
C297	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		1	4	2	3	8	5	9	6	7	
		0.353	0.088	0.177	0.118	0.044	0.071	0.039	0.059	0.05	
C298	2	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37		
		3	8	5	1	4	7	1	6		
		0.123	0.046	0.074	0.368	0.092	0.053	0.368	0.061		
C299	2	EPC5	EPC6	EPC9	EPC12	EPC38					
		5	2	3	1	4					
		0.088	0.219	0.146	0.438	0.109					
C300	1	EPC8	EPC18	EPC37							
		1	2	3							
		0.545	0.273	0.182							
C302	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	2	5	4	6	3				
		0.408	0.204	0.082	0.102	0.068	0.136				
C305	1	EPC2	EPC7	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C306	3	EPC8	EPC18	EPC37							
		1	3	2							
		0.545	0.182	0.273							
C307	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	9	4	2	7	5	6	8	
		0.353	0.118	0.039	0.088	0.177	0.05	0.071	0.059	0.044	
C308	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	5	3	6	2	4				
		0.408	0.082	0.136	0.068	0.204	0.102				
C310	1	EPC4	EPC24	EPC32							
		2	3	1							
		0.273	0.182	0.545							
C311	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	8	4	2	7	5	6	9	
		0.353	0.118	0.044	0.088	0.177	0.05	0.071	0.059	0.039	
C312	4	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		3	1	9	4	2	7	5	6	8	
		0.118	0.353	0.039	0.088	0.177	0.05	0.071	0.059	0.044	

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking and weighting									
C313	1	EPC8	EPC9	EPC34	EPC35						
		1	3	4	2						
		0.480	0.160	0.120	0.240						
C314	1	EPC4	EPC24	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C315	5	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	3	4	5	6	2				
		0.408	0.136	0.102	0.082	0.068	0.204				
C316	2	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		1	3	2	8	5	4	9	7	6	
		0.353	0.118	0.177	0.044	0.071	0.088	0.039	0.05	0.059	
C317	1	EPC4	EPC24	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C318	1	EPC8	EPC18	EPC37							
		1	2	3							
		0.545	0.273	0.182							
C319	1	EPC5	EPC6	EPC9	EPC12	EPC38					
		5	3	4	1	2					
		0.088	0.146	0.109	0.438	0.219					
C321	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		1	6	2	4	8	3	9	7	5	
		0.353	0.059	0.177	0.088	0.044	0.118	0.039	0.05	0.071	
C323	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	8	5	2	7	4	6	9	
		0.353	0.118	0.044	0.071	0.177	0.05	0.088	0.059	0.039	
C324	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		1	4	2	9	7	3	8	6	5	
		0.353	0.088	0.177	0.039	0.05	0.118	0.044	0.059	0.071	
C325	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	9	4	2	7	5	6	8	
		0.353	0.118	0.039	0.088	0.177	0.05	0.071	0.059	0.044	
C330	1	EPC2	EPC8	EPC14	EPC16	EPC18					
		2	1	4	3	5					
		0.219	0.438	0.109	0.146	0.088					
C332	2	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	5	2	6	3	4				
		0.408	0.082	0.204	0.068	0.136	0.102				
C333	1	EPC8	EPC18	EPC37							
		1	3	2							
		0.545	0.182	0.273							
C336	3	EPC4	EPC24	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C337	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	3	4	6	5	2				
		0.408	0.136	0.102	0.068	0.082	0.204				
C340	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	5	2	6	3	4				
		0.408	0.082	0.204	0.068	0.136	0.102				
C343	1	EPC2	EPC7	EPC32							
		2	3	1							
		0.273	0.182	0.545							
C344	2	EPC3	EPC13	EPC14	EPC32	EPC33					
		3	1	4	5	2					
		0.146	0.438	0.109	0.088	0.219					
C347	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	3	4	5	6	2				
		0.408	0.136	0.102	0.082	0.068	0.204				

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking and weigting									
C348	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	4	3	6	2	5				
		0.408	0.102	0.136	0.068	0.204	0.082				
C359	1	EPC2	EPC7	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C360	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	2	9	3	4	6	5	7	8	
		0.353	0.177	0.039	0.118	0.088	0.059	0.071	0.05	0.044	
C365	2	EPC10	EPC13	EPC16	EPC17	EPC21					
		2	1	3	4	5					
		0.219	0.438	0.146	0.109	0.088					
C367	1	EPC1	EPC11	EPC27	EPC35						
		1	3	4	2						
		0.480	0.160	0.120	0.240						
C368	1	EPC3	EPC13	EPC14	EPC32	EPC33					
		3	1	4	5	2					
		0.146	0.438	0.109	0.088	0.219					
C371	2	EPC4	EPC24	EPC32							
		2	3	1							
		0.273	0.182	0.545							
C373	1	EPC2	EPC7	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C374	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	3	4	5	6	2				
		0.408	0.136	0.102	0.082	0.068	0.204				
C376	2	EPC4	EPC24	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C377	2	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37		
		3	8	5	1	4	7	2	6		
		0.123	0.046	0.074	0.368	0.092	0.053	0.184	0.061		
C384	1	EPC5	EPC6	EPC9	EPC12	EPC38					
		5	2	3	1	4					
		0.088	0.219	0.146	0.438	0.109					
C387	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	5	2	6	4	3				
		0.408	0.082	0.204	0.068	0.102	0.136				
C388	1	EPC4	EPC24	EPC32							
		2	3	1							
		0.273	0.182	0.545							
C391	1	EPC8	EPC18	EPC37							
		1	3	2							
		0.545	0.182	0.273							
C395	1	EPC8	EPC18	EPC37							
		2	3	1							
		0.273	0.182	0.545							
C398	1	EPC2	EPC8	EPC14	EPC16	EPC18					
		2	1	4	3	5					
		0.219	0.438	0.109	0.146	0.088					
C400	2	EPC2	EPC7	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C401	2	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		1	6	3	4	2	5				
		0.408	0.068	0.136	0.102	0.204	0.082				
C404	1	EPC5	EPC6	EPC9	EPC12	EPC38					
		5	2	3	1	4					
		0.088	0.219	0.146	0.438	0.109					

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking and weighting									
C405	1	EPC4	EPC24	EPC32							
		2	3	1							
		0.273	0.182	0.545							
C406	2	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		2	5	1	3	8	4	9	7	6	
		0.353	0.071	0.353	0.118	0.044	0.088	0.039	0.05	0.059	
C409	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	9	4	2	6	5	7	8	
		0.353	0.118	0.039	0.088	0.177	0.059	0.071	0.05	0.044	
C410	2	EPC5	EPC15	EPC27	EPC34						
		2	1	3	4						
		0.240	0.480	0.160	0.120						
C411	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	8	4	2	7	5	6	9	
		0.353	0.118	0.044	0.088	0.177	0.05	0.071	0.059	0.039	
C414	2	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		4	5	2	6	1	3				
		0.102	0.082	0.204	0.068	0.408	0.136				
C416	1	EPC4	EPC24	EPC32							
		2	3	1							
		0.273	0.182	0.545							
C421	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	7	3	5	8	4	6	9	
		0.353	0.118	0.05	0.118	0.071	0.044	0.088	0.059	0.039	
C422	2	EPC8	EPC18	EPC37							
		1	3	2							
		0.545	0.182	0.273							
C423	1	EPC2	EPC7	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C427	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	8	5	2	7	4	6	9	
		0.353	0.118	0.044	0.071	0.177	0.05	0.088	0.059	0.039	
C428	1	EPC2	EPC8	EPC14	EPC16	EPC18					
		2	1	4	3	5					
		0.219	0.438	0.109	0.146	0.088					
C429	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		1	5	2	3	8	4	9	7	6	
		0.353	0.071	0.177	0.118	0.044	0.088	0.039	0.05	0.059	
C430	2	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		1	6	3	4	2	5				
		0.408	0.068	0.136	0.102	0.204	0.082				
C431	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	9	5	2	7	4	6	8	
		0.353	0.118	0.039	0.071	0.177	0.05	0.088	0.059	0.044	
C436	3	EPC1	EPC12	EPC14							
		2	1	3							
		0.273	0.545	0.182							
C437	1	EPC4	EPC24	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C438	1	EPC5	EPC6	EPC9	EPC12	EPC38					
		5	3	4	1	2					
		0.088	0.146	0.109	0.438	0.219					
C439	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	9	5	2	7	4	6	8	
		0.353	0.118	0.039	0.071	0.177	0.05	0.088	0.059	0.044	
C442	2	EPC2	EPC8	EPC14	EPC16	EPC18					
		2	1	4	3	5					
		0.219	0.438	0.109	0.146	0.088					

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking and weigting								
C443	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		1	6	9	3	2	8	4	5	7
		0.353	0.059	0.039	0.118	0.177	0.044	0.088	0.071	0.05
C444	1	EPC10	EPC13	EPC16	EPC17	EPC21				
		2	1	3	4	5				
		0.219	0.438	0.146	0.109	0.088				
C445	2	EPC4	EPC24	EPC32						
		2	3	1						
		0.273	0.182	0.545						
C449	1	EPC5	EPC6	EPC9	EPC12	EPC38				
		5	2	3	1	4				
		0.088	0.219	0.146	0.438	0.109				
C452	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	6	2	5	4	3			
		0.408	0.068	0.204	0.082	0.102	0.136			
C453	1	EPC3	EPC13	EPC14	EPC32	EPC33				
		3	1	4	5	2				
		0.146	0.438	0.109	0.088	0.219				
C456	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	5	2	6	4	3			
		0.408	0.082	0.204	0.068	0.102	0.136			
C457	3	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	3	4	5	6	2			
		0.408	0.136	0.102	0.082	0.068	0.204			
C460	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		1	3	9	4	2	7	5	6	8
		0.353	0.118	0.039	0.088	0.177	0.05	0.071	0.059	0.044
C461	1	EPC10	EPC13	EPC16	EPC17	EPC21				
		2	1	3	5	4				
		0.219	0.438	0.146	0.088	0.109				
C462	1	EPC2	EPC7	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C463	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	6	2	5	4	3			
		0.408	0.068	0.204	0.082	0.102	0.136			
C465	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36
		1	4	2	3	8	5	9	6	7
		0.353	0.088	0.177	0.118	0.044	0.071	0.039	0.059	0.05
C467	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37	
		3	2	5	1	4	7	8	6	
		0.123	0.184	0.074	0.368	0.092	0.053	0.046	0.061	
C469	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	5	2	6	4	3			
		0.408	0.082	0.204	0.068	0.102	0.136			
C471	1	EPC2	EPC7	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C472	2	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		1	3	9	4	2	7	5	6	8
		0.353	0.118	0.039	0.088	0.177	0.05	0.071	0.059	0.044
C473	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	6	2	5	4	3			
		0.408	0.068	0.204	0.082	0.102	0.136			
C474	1	EPC5	EPC19	EPC33	EPC36					
		3	4	1	2					
		0.160	0.120	0.480	0.240					
C475	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	4	3	5	6	2			
		0.408	0.102	0.136	0.082	0.068	0.204			

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking and weigting									
C475	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	4	3	5	6	2				
		0.408	0.102	0.136	0.082	0.068	0.204				
C476	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37		
		2	3	5	1	4	8	7	6		
		0.184	0.123	0.074	0.368	0.092	0.046	0.053	0.061		
C478	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	3	2	5	6	4				
		0.408	0.136	0.204	0.082	0.068	0.102				
C481	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		1	5	4	3	2	6				
		0.408	0.082	0.102	0.136	0.204	0.068				
C482	1	EPC5	EPC19	EPC33	EPC36						
		4	3	1	2						
		0.120	0.160	0.480	0.240						
C483	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	5	2	6	4	3				
		0.408	0.082	0.204	0.068	0.102	0.136				
C484	1	EPC10	EPC13	EPC16	EPC17	EPC21					
		2	1	3	4	5					
		0.219	0.438	0.146	0.109	0.088					
C485	2	EPC4	EPC24	EPC32							
		2	3	1							
		0.273	0.182	0.545							
C486	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	5	3	6	4	2				
		0.408	0.082	0.136	0.068	0.102	0.204				
C487	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		1	6	3	4	2	5				
		0.408	0.068	0.136	0.102	0.204	0.082				
C492	2	EPC8	EPC18	EPC37							
		1	3	2							
		0.545	0.182	0.273							
C494	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37		
		2	3	5	1	4	8	7	6		
		0.184	0.123	0.074	0.368	0.092	0.046	0.053	0.061		
C495	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		1	4	2	8	3	5	9	7	6	
		0.353	0.088	0.177	0.044	0.118	0.071	0.039	0.05	0.059	
C496	1	EPC8	EPC18	EPC37							
		1	2	3							
		0.545	0.273	0.182							
C504	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	9	4	2	7	5	6	8	
		0.353	0.118	0.039	0.088	0.177	0.05	0.071	0.059	0.044	
C505	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37		
		2	3	5	1	4	7	8	6		
		0.184	0.123	0.074	0.368	0.092	0.053	0.046	0.061		
C509	1	EPC5	EPC6	EPC9	EPC12	EPC38					
		3	4	5	1	2					
		0.146	0.109	0.088	0.438	0.219					
C510	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	8	4	2	7	5	6	9	
		0.353	0.118	0.044	0.088	0.177	0.05	0.071	0.059	0.039	
C511	1	EPC2	EPC7	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C513	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37		
		2	3	5	1	4	8	7	6		
		0.184	0.123	0.074	0.368	0.092	0.046	0.053	0.061		

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking and weigting									
C514	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		1	6	2	4	3	5				
		0.408	0.068	0.204	0.102	0.136	0.082				
C520	1	EPC8	EPC18	EPC37							
		1	3	2							
		0.545	0.182	0.273							
C523	2	EPC10	EPC13	EPC16	EPC17	EPC21					
		2	1	3	5	4					
		0.219	0.438	0.146	0.088	0.109					
C529	1	EPC5	EPC19	EPC33	EPC36						
		3	4	1	2						
		0.160	0.120	0.480	0.240						
C530	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		1	5	2	3	8	4	9	7	6	
		0.353	0.071	0.177	0.118	0.044	0.088	0.039	0.05	0.059	
C533	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	5	2	6	4	3				
		0.408	0.082	0.204	0.068	0.102	0.136				
C535	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37		
		2	3	5	1	4	8	7	6		
		0.184	0.123	0.074	0.368	0.092	0.046	0.053	0.061		
C538	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	9	4	2	7	5	6	8	
		0.353	0.118	0.039	0.088	0.177	0.05	0.071	0.059	0.044	
C543	1	EPC5	EPC6	EPC9	EPC12	EPC38					
		5	2	3	4	1					
		0.088	0.219	0.146	0.109	0.438					
C544	2	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	3	4	5	6	2				
		0.408	0.136	0.102	0.082	0.068	0.204				
C551	1	EPC10	EPC13	EPC16	EPC17	EPC21					
		2	1	4	5	3					
		0.219	0.438	0.109	0.088	0.146					
C552	1	EPC4	EPC24	EPC32							
		2	3	1							
		0.273	0.182	0.545							
C554	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	8	4	2	6	5	7	9	
		0.353	0.118	0.044	0.088	0.177	0.059	0.071	0.05	0.039	
C555	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		1	5	2	3	9	4	8	7	6	
		0.353	0.071	0.177	0.118	0.039	0.088	0.044	0.05	0.059	
C556	1	EPC2	EPC7	EPC32							
		1	3	2							
		0.545	0.182	0.273							
C557	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		1	5	2	3	8	4	9	7	6	
		0.353	0.071	0.177	0.118	0.044	0.088	0.039	0.05	0.059	
C558	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		1	6	3	4	2	5				
		0.408	0.068	0.136	0.102	0.204	0.082				
C561	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	3	4	6	5	2				
		0.408	0.136	0.102	0.068	0.082	0.204				
C562	2	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	5	2	3	4	6				
		0.408	0.082	0.204	0.136	0.102	0.068				
C565	1	EPC3	EPC13	EPC14	EPC32	EPC33					
		2	1	4	5	3					
		0.219	0.438	0.109	0.088	0.146					

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking and weighting									
C566	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		1	3	4	6	2	5				
		0.408	0.136	0.102	0.068	0.204	0.082				
C567	1	EPC4	EPC24	EPC32							
		2	3	1							
		0.273	0.182	0.545							
C569	2	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37		
		2	3	5	1	4	7	8	6		
		0.184	0.123	0.074	0.368	0.092	0.053	0.046	0.061		
C570	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	3	5	6	4	2				
		0.408	0.136	0.082	0.068	0.102	0.204				
C573	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		1	4	3	6	2	5				
		0.408	0.102	0.136	0.068	0.204	0.082				
C574	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	8	4	2	5	6	7	9	
		0.353	0.118	0.044	0.088	0.177	0.071	0.059	0.05	0.039	
C577	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	6	2	5	4	3				
		0.408	0.068	0.204	0.082	0.102	0.136				
C578	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	3	4	5	6	2				
		0.408	0.136	0.102	0.082	0.068	0.204				
C582	1	EPC10	EPC13	EPC16	EPC17	EPC21					
		2	1	3	5	4					
		0.219	0.438	0.146	0.088	0.109					
C584	2	EPC1	EPC12	EPC14							
		1	2	3							
		0.545	0.273	0.182							
C585	2	EPC8	EPC18	EPC37							
		1	3	2							
		0.545	0.182	0.273							
C586	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37		
		2	3	5	1	4	7	8	6		
		0.184	0.123	0.074	0.368	0.092	0.053	0.046	0.061		
C587	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		1	5	2	3	8	4	9	7	6	
		0.353	0.071	0.177	0.118	0.044	0.088	0.039	0.05	0.059	
C588	1	EPC4	EPC24	EPC32							
		2	3	1							
		0.273	0.182	0.545							
C589	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	5	2	6	4	3				
		0.408	0.082	0.204	0.068	0.102	0.136				
C590	1	EPC8	EPC9	EPC34	EPC35						
		1	3	4	2						
		0.480	0.160	0.120	0.240						
C593	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	9	4	2	7	5	6	8	
		0.353	0.118	0.039	0.088	0.177	0.05	0.071	0.059	0.044	
C594	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		1	6	3	4	2	5				
		0.408	0.068	0.136	0.102	0.204	0.082				
C596	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36	
		1	4	2	3	8	5	9	6	7	
		0.353	0.088	0.177	0.118	0.044	0.071	0.039	0.059	0.05	
C599	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	2	5	4	6	3				

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking and weigting								
C609	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28			
		1	6	4	3	2	5			
		0.408	0.068	0.102	0.136	0.204	0.082			
C610	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	2	4	6	5	3			
		0.408	0.204	0.102	0.068	0.082	0.136			
C611	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		1	3	8	5	2	7	4	6	9
		0.353	0.118	0.044	0.071	0.177	0.05	0.088	0.059	0.039
C613	1	EPC2	EPC7	EPC32						
		1	3	2						
		0.545	0.182	0.273						
C619	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	6	3	4	5	2			
		0.408	0.068	0.136	0.102	0.082	0.204			
C620	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		1	3	9	5	2	7	4	6	8
		0.353	0.118	0.039	0.071	0.177	0.05	0.088	0.059	0.044
C623	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	6	2	3	4	5			
		0.408	0.068	0.204	0.136	0.102	0.082			
C625	1	EPC5	EPC15	EPC27	EPC34					
		2	1	3	4					
		0.240	0.480	0.160	0.120					
C626	1	EPC4	EPC24	EPC32						
		2	3	1						
		0.273	0.182	0.545						
C627	1	EPC10	EPC13	EPC16	EPC17	EPC21				
		1	2	3	4	5				
		0.438	0.219	0.146	0.109	0.088				
C631	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37	
		2	3	6	1	4	7	8	5	
		0.184	0.123	0.061	0.368	0.092	0.053	0.046	0.074	
C634	1	EPC8	EPC18	EPC37						
		1	3	2						
		0.545	0.182	0.273						
C635	1	EPC1	EPC3	EPC10	EPC11	EPC14	EPC16	EPC17	EPC21	EPC36
		1	5	2	3	8	4	9	7	6
		0.353	0.071	0.177	0.118	0.044	0.088	0.039	0.05	0.059
C636	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38			
		1	6	2	5	4	3			
		0.408	0.068	0.204	0.082	0.102	0.136			
C637	2	EPC10	EPC13	EPC16	EPC17	EPC21				
		2	1	3	5	4				
		0.219	0.438	0.146	0.088	0.109				
C640	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	3	4	5	6	2			
		0.408	0.136	0.102	0.082	0.068	0.204			
C641	1	EPC2	EPC8	EPC14	EPC16	EPC18				
		2	1	4	3	5				
		0.219	0.438	0.109	0.146	0.088				
C642	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23			
		1	2	3	5	6	4			
		0.408	0.204	0.136	0.082	0.068	0.102			
C644	1	EPC5	EPC19	EPC33	EPC36					
		3	4	1	2					
		0.160	0.120	0.480	0.240					
C645	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28
		1	3	9	5	2	7	4	6	8
		0.353	0.118	0.039	0.071	0.177	0.05	0.088	0.059	0.044

Table B.3 (continued) : Ranking and weighting result of each EPC in accident cause.

Cause	Times	EPC, ranking and weighting									
C647	1	EPC13	EPC17	EPC20	EPC22	EPC26	EPC28				
		1	6	3	4	2	5				
		0.408	0.068	0.136	0.102	0.204	0.082				
C649	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	2	3	6	5	4				
		0.408	0.204	0.136	0.068	0.082	0.102				
C650	2	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	6	2	5	4	3				
		0.408	0.068	0.204	0.082	0.102	0.136				
C655	1	EPC10	EPC13	EPC16	EPC17	EPC21					
		2	1	4	5	3					
		0.219	0.438	0.109	0.088	0.146					
C659	1	EPC4	EPC24	EPC32							
		2	3	1							
		0.273	0.182	0.545							
C660	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	6	2	5	4	3				
		0.408	0.068	0.204	0.082	0.102	0.136				
C663	1	EPC8	EPC9	EPC34	EPC35						
		1	3	4	2						
		0.480	0.160	0.120	0.240						
C670	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	9	4	2	7	5	6	8	
		0.353	0.118	0.039	0.088	0.177	0.05	0.071	0.059	0.044	
C671	1	EPC1	EPC9	EPC10	EPC14	EPC23	EPC38				
		1	6	2	5	4	3				
		0.408	0.068	0.204	0.082	0.102	0.136				
C674	1	EPC5	EPC6	EPC9	EPC12	EPC38					
		2	2	3	1	4					
		0.219	0.219	0.146	0.438	0.109					
C675	1	EPC2	EPC4	EPC7	EPC11	EPC12	EPC17	EPC21	EPC26	EPC28	
		1	3	9	4	2	7	5	6	8	
		0.353	0.118	0.039	0.088	0.177	0.05	0.071	0.059	0.044	
C683	1	EPC10	EPC13	EPC14	EPC15	EPC16	EPC20	EPC25	EPC37		
		2	3	5	1	4	7	8	6		
		0.184	0.123	0.074	0.368	0.092	0.053	0.046	0.061		
C689	1	EPC8	EPC9	EPC34	EPC35						
		1	4	3	2						
		0.480	0.120	0.160	0.240						
C690	1	EPC2	EPC8	EPC14	EPC16	EPC18					
		2	1	4	3	5					
		0.219	0.438	0.109	0.146	0.088					
C691	1	EPC11	EPC16	EPC19	EPC20	EPC22	EPC23				
		1	2	4	6	5	3				
		0.408	0.204	0.102	0.068	0.082	0.136				
C692	1	EPC4	EPC24	EPC32							
		2	3	1							
		0.273	0.182	0.545							

Table B.4 : Comprehensive results for discharging process of propylene oxide cargo.

Step	Sub-step	Gep value	EPC	EPC max. affect	EPC APOA	HEP value
1.	1.1	4.00E-04	EPC2	14.01	0.648	7.24E-03
			EPC38	3.61	0.352	
	1.2	2.00E-05	EPC8	14.15	0.142	3.18E-04
			EPC14	6.72	0.525	
			EPC18	2.15	0.334	
	1.3	4.00E-04	EPC2	14.01	0.320	2.32E-02
			EPC11	8.60	0.557	
			EPC35	10.30	0.123	
	1.4	4.00E-04	EPC5	5.76	0.311	7.12E-03
			EPC13	12.55	0.100	
			EPC15	10.03	0.182	
			EPC22	1.64	0.406	
	1.5	3.00E-03	EPC2	14.01	0.286	7.77E-02
			EPC11	8.60	0.271	
			EPC17	2.79	0.443	
	1.6	2.00E-05	EPC12	12.51	0.211	1.72E-03
			EPC13	12.55	0.387	
			EPC33	9.90	0.402	
	1.7	2.00E-05	EPC2	14.01	0.309	2.88E-04
			EPC17	2.79	0.189	
			EPC26	3.28	0.502	
	1.8	4.00E-04	EPC1	17.00	0.320	1.96E-02
			EPC10	11.00	0.557	
			EPC17	2.79	0.123	
	1.9	4.00E-04	EPC2	14.01	0.258	1.15E-02
			EPC11	8.60	0.419	
			EPC17	2.79	0.323	
	1.10	2.00E-05	EPC17	2.79	0.602	1.89E-04
			EPC33	9.90	0.398	
	1.11	3.00E-03	EPC2	14.01	0.198	1.64E-01
			EPC14	6.72	0.348	
			EPC15	10.03	0.454	
	1.12	2.00E-05	EPC17	2.79	0.750	1.51E-04
			EPC33	9.90	0.250	
	1.13	4.00E-04	EPC2	14.01	0.503	1.04E-02
			EPC14	6.72	0.233	
			EPC17	2.79	0.264	
	1.14	2.00E-05	EPC2	14.01	0.289	1.24E-03
			EPC12	12.51	0.303	
			EPC23	5.69	0.405	
	1.15	2.00E-02	EPC17	2.79	1.000	5.58E-02

Table B.4 (continued) : Comprehensive results for discharging process of propylene oxide cargo.

Step	Sub-step	Gep value	EPC	EPC max. affect	EPC APOA	HEP value
2	2.1	2.00E-05	EPC1	17.00	0.334	1.84E-03
			EPC13	12.55	0.525	
			EPC16	8.42	0.142	
	2.2	3.00E-03	EPC15	10.03	0.557	2.21E-02
			EPC17	2.79	0.123	
	2.3	2.00E-05	EPC2	14.01	0.458	5.71E-04
			EPC14	6.72	0.542	
	2.4	4.00E-04	EPC12	12.51	0.310	1.32E-02
			EPC15	10.03	0.690	
	2.5	4.00E-04	EPC11	8.60	0.489	8.89E-03
			EPC15	10.03	0.411	
3	3.1	2.00E-05	EPC2	14.01	0.236	4.90E-04
			EPC18	2.15	0.389	
			EPC32	9.43	0.375	
	3.2	3.00E-03	EPC2	14.01	0.355	3.63E-02
			EPC17	2.79	0.645	
	3.3	2.00E-02	EPC17	2.79	1.000	5.58E-02
	3.4	4.00E-04	EPC17	2.79	0.406	4.56E-03
			EPC27	4.35	0.100	
			EPC33	9.90	0.182	
			EPC36	3.85	0.311	
	3.5	2.00E-05	EPC17	2.79	0.315	6.62E-05
			EPC34	2.63	0.685	
4	4.1	3.00E-03	EPC13	12.55	0.290	4.41E-02
			EPC27	4.35	0.710	
			EPC17	2.79	1.000	
	4.2	2.00E-02	EPC17	2.79	1.000	5.58E-02
			EPC1	17.00	0.125	
			EPC15	10.03	0.369	
	4.3	4.00E-04	EPC22	1.64	0.506	6.88E-03
			EPC17	2.79	0.348	
			EPC22	1.64	0.652	
	4.4	3.00E-03	EPC17	2.79	0.348	6.90E-03
			EPC22	1.64	0.652	
			EPC27	4.35	0.383	
5	4.5	4.00E-04	EPC38	3.61	0.617	2.38E-03
			EPC2	14.01	1.000	
			EPC8	14.45	0.320	
	4.6	3.00E-03	EPC14	6.72	0.123	9.35E-03
			EPC36	3.85	0.557	
			EPC15	10.03	0.250	
	4.7	4.00E-04	EPC17	2.79	0.750	2.29E-02
			EPC2	14.01	1.000	
			EPC8	14.45	0.320	
	4.8	3.00E-03	EPC14	6.72	0.123	9.35E-03
			EPC36	3.85	0.557	
			EPC15	10.03	0.250	
	4.9	4.00E-04	EPC17	2.79	0.750	2.29E-02
			EPC2	14.01	1.000	
			EPC8	14.45	0.320	
5	5.1	4.00E-04	EPC2	14.01	0.817	8.64E-03
			EPC23	5.69	0.183	
			EPC17	2.79	0.334	
	5.2	2.00E-02	EPC22	1.64	0.525	7.11E-02
			EPC23	5.69	0.142	
			EPC8	14.45	0.311	
5	5.3	2.00E-05	EPC8	14.45	0.311	1.88E-03
			EPC8	14.45	0.311	
			EPC8	14.45	0.311	
	5.4	2.00E-05	EPC8	14.45	0.311	1.88E-03
			EPC8	14.45	0.311	
			EPC8	14.45	0.311	

Table B.4 (continued) : Comprehensive results for discharging process of propylene oxide cargo.

Step	Sub-step	Gep value	EPC	EPC max. affect	EPC APOA	HEP value
6	5.4	2.00E-02	EPC11	8.60	0.100	
			EPC13	12.55	0.182	
			EPC14	6.72	0.406	
			EPC22	1.64	1.000	3.28E-02
			EPC2	14.01	0.320	8.64E-03
	5.5	4.00E-04	EPC17	2.79	0.557	
			EPC33	9.90	0.123	
			EPC2	14.01	0.750	1.40E-02
	6.1	9.00E-02	EPC15	10.03	0.250	
			EPC22	1.64	0.366	1.53E-01
			EPC29	1.59	0.634	
			EPC12	12.51	0.204	7.67E-03
			EPC22	1.64	0.363	
	6.2	4.00E-04	EPC32	9.43	0.433	
			EPC17	2.79	0.310	8.71E-05
			EPC38	3.61	0.690	
7	7.1	4.00E-04	EPC2	14.01	0.311	1.37E-02
			EPC32	9.43	0.689	
			EPC14	6.72	0.406	2.33E-04
	7.2	2.00E-05	EPC27	4.35	0.182	
			EPC36	3.85	0.412	
			EPC2	14.01	0.625	8.67E-04
	7.3	2.00E-05	EPC10	11.00	0.375	
			EPC23	5.69	0.701	6.28E-03
			EPC33	9.90	0.299	
	7.4	4.00E-04	EPC15	10.03	0.199	1.39E-04
			EPC25	1.22	0.287	
			EPC38	3.61	0.514	
	8.1	4.00E-04	EPC10	11.00	0.308	1.45E-02
			EPC13	12.55	0.453	
			EPC17	2.79	0.239	
8	8.2	2.00E-05	EPC8	14.15	0.389	5.50E-04
			EPC14	6.72	0.611	
			EPC2	14.01	0.504	3.59E-03
	8.3	4.00E-04	EPC15	1.03	0.216	
			EPC22	1.64	0.280	
			EPC17	2.79	1.000	1.12E-03
	8.4	4.00E-04	EPC11	8.60	0.478	6.64E-04
			EPC14	6.72	0.366	
			EPC32	9.43	0.156	
	8.5	2.00E-05	EPC17	2.79	1.000	5.58E-02
			EPC1	17.00	0.203	1.69E-03
			EPC2	14.01	0.412	
	8.6	2.00E-05	EPC27	4.35	0.398	
			EPC38	3.61	0.130	

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