University of Strathclyde

Department Of Naval Architecture, Ocean & Marine Engineering

Development of a Model for Integrating Resilience Engineering Principles to Ship Management System to Enhance Navigation Bridge Operation

By
Omar Hassn O Badokhon

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ABSTRACT

Analysis of the MAIB (Marine Accident Investigation Branch) accidents reports show that out of 127 recorded incidents between 2010 and 2015, 56 ship accidents were caused by operational failures on the navigation bridge. Setbacks on a ship's bridge led to three types of accidents: collision, grounding and contact. The analyses classified the reasons of the bridge deficiencies to task failures (causes of accidents), Sub-factors, mitigation deficiencies and accident impacts. This fact illustrates the need to improve safety standards with the bridge operation. This research work aims to address a new approach to barrier management concerning the operation of the navigation bridge system in a framework that incorporates the principles of resilience engineering to enhance shipping safety. The work process contains navigation bridge description, the definition of the safety performance, including fundamental resilience, developing application methods and a design scheme for control and maintenance. The approach introduces resilience-engineering elements: anticipation, monitoring, learning, and responding. The bow-tie model supports the approach by visualising the barrier system in a constructive perspective. The downside of this approach is the large amount of data received during the process, forcing the implementer to select the relevant information and to be specific when choosing the application area. Also, not all accidents have linear steps for the event, potentially forcing the implementer to be selective and bring the function elements and resilience resources effectively in line to be manageable and applicable. All these obstacles can be overcome by continuous application of the method. The benefits of this approach are minimising the errors of the bridge operator by improving the anticipation, enhancing the operation performance via the learning technique, improving the monitoring system and the efficiency of the safety planning, increasing the system reliability by maintaining a strong and flexible system able to response during changing conditions.

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Abbreviation

AB	**Able Seaman**
AHP	**Analytic Hierarchy Process**
AIS	**Automatic Identification System**
AMSA	**Australian Maritime Safety Authority**
ANP	**Analytical Network Process**
ARPA	**Automatic Radar Plotting Aid**
ATM	**Air Traffic Management**
BAC	**Blood Alcohol Content**
BBN	**Bayesian Belief Network**
BN	**Bayesian Network**
BNWAS	**Bridge Navigational Watch Alarm System**
BRM	**Bridge Resources Management**
CM	**Cognitive Map**
CMT	**Continuous Memory Tasks**
CoC	**Certificate of Competency**
COCOM	**Contextual Control Mode**
COLREGs	**The International Regulations for Preventing Collisions at Sea**
CPA	**Closest Point Of Approach**
CPC	**Common Performance Condition**
CREAM	**Cognitive Reliability Error Analysis Method**
CRM	**Crew Resource Management**
CSA	**Common Situation Awareness**

CTPA	**Collision Threat Parameters Area**
DEA	**Data Envelopment Analysis**
DEMATEL	**Decision Making Trial and Evaluation Laboratory**
DMUs	**Decision-Making Units**
DNC	**Digital Nautical Charts**
DSS	**Decision Support System**
ECDIS	**Electronic Chart Display and Information System**
EMSA	**European Maritime Safety Agency**
ENC	**Electronic Navigational Charts**
ENSI	**Enhanced Navigation Support Information**
EPIRB	**Emergency Position Indicating Radio Beacon**
ER	**Evidential Reasoning**
ETA	**Event Tree Analysis**
FAHP	**Fuzzy Analytical Hierarchy Process**
FRAM	**Functional Resonance Analysis Method**
FTA	**Fault Tree Analysis**
GOFREP	**Gulf of Finland obligatory ship reporting system**
GPS	**Global Positioning System**
HFACS	**Human Factors Analysis and Classification System**
HOF	**Human and Organisational Factors**
HRA	**Human Reliability Analysis**
HRV	**Heart Rate Variability**
HSC	**High-Speed Craft**
IACS	**The International Association of Classification Societies**

IAEA	**International Atomic Energy Agency**
IMO	**International Maritime Organisation**
IRE	**Integrated Resilience Engineering**
ISM	**International Safety Management Code**
KPI	**Key Performance Indicator**
LOP	**Line of Position**
MAIB	**Marine Accidents Investigation Branch**
MAPP	**Maritime Automated Path Planner**
MLNs	**Markov Logic Networks**
MRM	**Maritime Resources Management**
MTS	**Maritime Transport System**
NCS	**Norwegian Continental Shelf**
OFM	**Operator Function Model**
OOW	**Officer of the Watch**
OS	**Ordinary Seaman**
PCA	**Principal Component Analysis**
PSA	**Petroleum Safety Authority of Norway**
PsyCap	**Psychological Capital**
RAT	**Resilience Assessment Tool**
RE	**Resilience Engineering**
RICAS	**Risk-Informed Collision Alert System**
RPD	**Recognition Primed Decision**
SA	**Situational Awareness**
SARTS	**Search and Rescue Transponders**

SC	**Skin Conductance**
SEAHORSE	**Safety Enhancements in transport by Achieving Human Orientated Resilient Shipping Environment**
SMS	**Safety Management System**
SOLAS	**The International Convention for the Safety of Life at Sea**
SOP	**Standard Operating Procedures**
SOPEP	**Shipboard Marine Pollution Emergency Plan**
STAMP	**System Theoretic Accident Model and Process**
STCW	**International Convention on Standards of Training, Certification and Watchkeeping for Seafarers**
TRACEr	**Technique for the Retrospective and Predictive Analysis of Cognitive Errors**
UKC	**Under Keel Clearance**
VTS	**Vessel Traffic Service**

Chapter 1. Introduction

The overall thesis outline and information will be introduced in this chapter. It will also feature information on the dissertation chapters content to bring clarification to the thesis flow.

The global economy is majorly reliant on maritime transport, as over 90% of world trade occurs by sea and is extensively the best economical method for carrying large amounts of cargo and raw materials across the globe (IMO, 2017). Maritime enterprise has a major role in relieving poverty and hunger, as it is a major source jobs and wages for many developing countries, e.g. seafarer workforces and vessel recycling, ship owning and operation, shipbuilding and maintenance, and port facilities, among others (IMO, 2017). Maritime transportation is a multicultural and global business, leading to large alterations to the seafarers workforce, who are increasingly multinational (Lu et al., 2016). Approximately 70–80% of commercial ships globally have multicultural seafarers (Lu et al., 2016, Hanzu-Pazara and Arsenie, 2010).

A century after the Titanic sank, the shipping industry is trying to improve the performance of navigation safety so that 23 million tonnes of cargo and 55 thousand cruise passengers are carried safely (Fields, 2012). Figure (Figure 1-1) demonstrates bridge performance and safety development since the days of the Titanic. Establishing international cooperation develops maritime best practices. In 1914 the International Convention for the Safety of Life at Sea (SOLAS) was established, this is the first and most crucial international maritime resolution. Subsequently, there are three areas where bridge performance has improved, these are procedures, human factors and technology. Bridge procedures increased in efficiency after the international Safety Management code (ISM) was established. The Convention on the International Regulations for Preventing Collisions at Sea (COLREG) and the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), amongst other treaties which increase shipping safety. Designing the single-handed or one-man bridge was also an important breakthrough, this led to an improvement in performance while number of people on the bridge was reduced. Before this radar, and after that ECDIS and other technology breakthroughs, significantly reduced the amount of accidents (Fields, 2012).

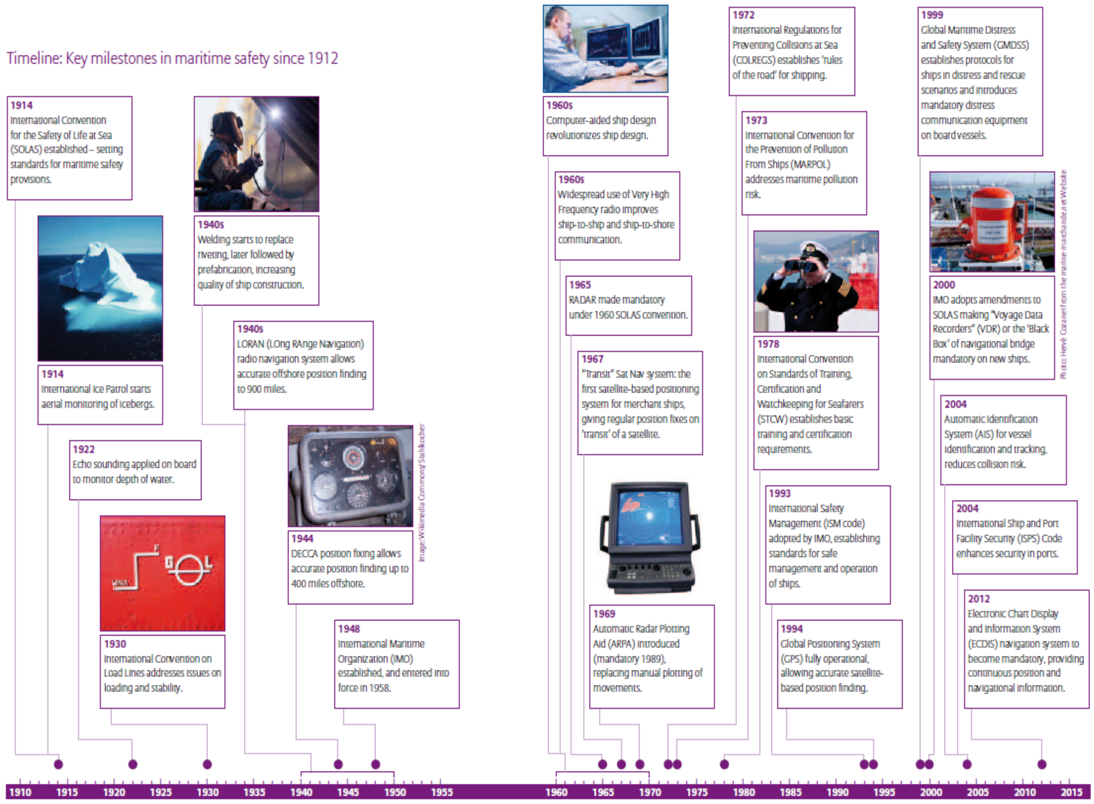


Figure 1-1 The development of bridge performance and safety (Fields, 2012).

The main navigation task performed by the ship's bridge crew is using the vessel safely and timely transfer of cargo in perfect condition. The working environment on the ship has a knowledgeable and skilful crew who use sophisticated equipment which is governed by a safety management system. The operating system on the bridge is separated into human, procedures and technology resources. Ship bridge procedures are policy which needs to be followed by crewmembers to ensure ship safety. Both human and technical factors are not the only reasons for problems to occur (violation of procedure may also lead to accidents) (Pomeroy and Jones, 2002).

In general, there are several regulatory sources. The International Maritime Organisation (IMO) is the central resource for onboard ship regulations. These have been developed in various forms, e.g. regulations or conventions, to be distributed amongst member states. Governments need maritime administrations for global regulation enforcement, such as ports, shipping organisation and onboard ships, which come under their enforcement area. Flag states require ships under their flag to follow specific guidelines. Shipping companies follow regulations from both maritime administration, port and flag states, who ensure that national and international regulations are applied on ships. Different authorities may inspect the ship, which includes flag states, port authorities, classification societies and the company.

Onboard crewmembers are governed by specific rankings; first is the master, then the officers and engineers, and lastly the rating. Each crewmember has specific duties which they must perform efficiently by following procedural guidelines for safety and operations. ICS (1998) stated that establishing bridge procedures and improving bridge teamwork are crucial for sustaining a safe navigational watch. In December 2000, an IMO resolution was amended to introduce the International Safety Management (ISM) code, which was enacted in July 2002. This code has since been amended several times. The code's beginning was in 1995 when the IMO used the code resolution and combined it with Chapter IX in SOLAS. In 1998, it became mandatory, enforcing IMO members' maritime administrations to establish safety management standards and documents which accord with the code guidelines.

The ISM code gives goals and recommendations for shipping companies to follow so that a safety management system (SMS) is formed. Such guidelines must be documented and organised in manuals for companies and onboard ships. The guideline documents define the responsibilities and the resources of the maritime operation, including the designated person who can access onshore management. The IMO (2006) state that successful ISM application is reliant upon constant commitment, capability, attitudes and enthusiasm of individuals in different organisational positions and onboard vessels for ISM code application. Additionally, code implementation requires the assistance of many professionals, this includes many financial resources, the organisation must ensure that personnel and resources are put in place to maintain the practice and to provide continuous development. Occasionally, government, company, flag states and port authorities will examine the safety management system.

Governments have responsibility for SMS validation, according to ISM code guidelines, and must provide a Certificate of Compliance to the ships under their flag. The bridge human element covers those who work on the ship's bridge. Safe manning minimum standards must be applied to create safe levels for each vessel. The SOLAS Convention (1974) states that each Contracting Government has responsibility for their national ships minimum safe manning standards and the issuing of appropriate documentation, crew safety performance and working language. For those who are trusted to control and operate the ships it is essential that they are qualified to perform their relevant tasks. Yet, teamwork and management quality have equal importance for performance reliability (ICS, 1998). Manning levels of the navigation watch must be assessed during the voyage depending on the operation conditions, sea state or workload (ICS, 1998). The Lloyd's Register shows the necessity for vessel designers to consider the human element to ensure a reasonable standard of maritime safety (Pomeroy and Jones, 2002).

The ship's bridge is where the command and control of the ship is performed. On the bridge, there is a location for steering the wheelhouse, or the ship's wheel, which is being phased out because of navigation technology development. Today, only smaller vessels have a wheelhouse. Previously, ship command was in the quarterdeck as ships were wind powered (sailing ships). Afterwards, during development of the steam engine, the paddle occupied the aft area, and the command location was moved above to provide clearer visibility to the master and engineering operation space. After the screw propeller was discovered and replaced the paddle wheel, the high command (bridge) stayed in the same place. Traditional bridge configurations were divided into two parts, one for navigational operations and the other for chart work. Navigation equipment is contained in the command area. Previously, the engine room was the centre of engine control and the captain had to give thrust orders via an engine order telegraph from the wheelhouse. The captain would give orders to the helmsman to alter the ship's direction. Nautical preparations are done via the chart room, such as passage planning or maritime chart and publication updates.

Bridge design and technology should achieve a minimum standard of the international maritime organisation for shipping safety and environment protection. Good ergonomics and design process require optimal performance on the bridge. The bridge configuration, console arrangement and equipment position must allow OOW to execute navigational missions and other tasks while sustaining a good lookout from the bridge (IACS, 1992). During ship navigation OOW must perform different functions simultaneously, such as lookout, chart and radar monitoring, and VHF communication while maintaining situational awareness (ICS, 1998). When the OOW has to leave the bridge to the wing, he must monitor the wheel and the engine indicators. All equipment must be tested and approved before being used on the ship. During operation, all bridge technology must be tested periodically.

There is the belief that ships' navigational systems are increasingly complex because of technological progress, which might alter the experience significantly, knowledge and plans required for large vessel navigation. Further, no systematic methods can identify the design flaws and training demands of technological innovation related to shipping. Such a lack of requirements can damage maritime safety instead of improving it. Technology's advantage is a reduction in physical activity repetition, but the size of the ship's crew is also reduced, thus increasing the mental demand placed of the operator. In stressful conditions the workload is especially increased. In some accidents, the operator misinterprets some technological information which leads to poor judgement. Other cases show an over-reliance on navigational technology (Lee and Sanquist, 2000).

Maritime transportation has continually improved its safety record through regulations and design improvements. Nevertheless, accidents still happen and with the passenger and cargo vessels increasing in size, the outcomes of not optimally handling the incidents may become critical (EuropeanCommission, 2016). The European Maritime Safety Agency, EMSA (2015) recorded 9180 incidents between 2011–2014, with reported damage of two thirds of the ships, 390 fatalities and 3250 injuries. EMSA is of the belief that human is responsible for 67% of these accidents. Mate (2012) (from Charles Taylor shipping insurance) states that the greatest hazard faced by ship owners is navigational accidents as claims of incompetent navigation are the biggest reason for shipping insurance claims. The Standard club's experience offers evidence for this, with 85 claims costing over $1 million, of which over half were linked to navigational cases (Mate, 2012).

Most maritime accidents are a result of human error, forming 80% of the total amount. For example, misjudgement, poor lookout and not following regulations are the human factors which can cause accidents. Bridge operation means carrying out many cognitive tasks simultaneously, requiring exceptional situational awareness and correct judgement, which on occasion can fail causing a collision. The usual method of human error analysis is not sufficient, as the relationship cannot be found between performance-shaping factors and human performance during operation, and does not benefit individual evaluation (Liu et al., 2016).

The maritime education domain frequently tries to achieve its training objectives in the subject of human factors related to the operator functioning in technological working environments alongside the ergonomic design of these settings (Hontvedt, 2015, Vicente, 2004). Marine simulators are usually used for learning professional skills, collaboration and teamwork in a safe operational environment. Research suggests that simulator training delivers content and scenarios alongside instructional features, which includes the chance to assess individual and team activities in various fields, such as medical, aeronautic and maritime (Hontvedt, 2015).

The barrier management domain continues to evolve, making it difficult to obtain an outstanding method, as the organisations develop their own approach (Øie et al., 2014). James Reason's 1997 "Swiss cheese" model, represents accident causation as breaking barriers. Reason states that accidents occur when failures and latent conditions accumulate. These active failures are unsafe acts which include latent conditions, shown as unsafe conditions, which are a timeline of cause and effect. Therefore, incidents can be prevented by strengthening those barriers (Reason, 1997). The navigation bridge accident, for example, happens as a result of unsafe actions (active failures) by the officer of the watch (OOW) and a lack of qualifications, shown as unsafe conditions (latent conditions) or non-ergonomic design of the bridge. These barriers must have beneficial design, control, monitoring and maintenance for intended performance.

Resilience is central to a system in modifying its activity before, during or after variations and disturbances, and it should be able to maintain the required performance even after misfortune or during continual stress (Nemeth et al., 2008). Unlike safety, resilience is not designed only through presenting further procedures, precautions and barriers — resilience engineering requires constant monitoring of system performance in respect of how things are done (Hollnagel and Woods, 2006). Resilience engineering designs systems which avoid accidents through anticipation, survive distractions through recovery, and develop through adaptation (Madni and Jackson, 2009).

Resilience Engineering (RE) is a novel safety management paradigm which accords with the complex nature of socio-technical systems (Righi et al., 2015). (Hollnagel, 2014) argues that if a system is resilient then it must be able to respond, monitor, learn and anticipate, and for these abilities to be able to interact. Resilience engineering innovates towards safety. Risk management methods rely on observation and error classification and failure probability calculations, resilience engineering research uses techniques which improve system capability to create a robust and flexible operation which can monitor and review risk methods, and effectively utilises resources during disruptions or during operational and economic stresses (Dekker et al., 2008). Resilience system failures have no concern with normal operation malfunctions; instead, they show that the system cannot adapt, which is essential in coping with real-world environment complexity (Dekker et al., 2008). Woods (2017) states that resilience is how well a system deals with disruptions and changes outside of base mechanisms and models, being as adaptive as determined in that system. To control a system, we must know what has occurred in the past, what is happening now, and what will occur in the future, as well as knowing the actions taken and having the necessary resources for the action (Hollnagel and Woods, 2006); this is necessary for a resilient organisation to anticipate, perceive and respond. Research has provided definitions, new models and extra enhancement to the resilience engineering approach.

This thesis addresses literature reviews on maritime research, focusing on the human factors of performance and safety on the bridge. The section covers the research written by researchers from several universities globally. Most of the reviewed research involves developing models for improving ships' operation and safety; a few of the cases assessed and analysed actual performance. The literature review covers many topics, including accessing analyses, risk assessment, collision avoidance, safety culture, and fatigue on board ships, situational awareness, bridge technology, maritime simulator experiments, barrier management, and resilience engineering. The research was chosen from various publications with the objective of finding research related to the PhD topic illustrating past progress in the same area. Each paper is summarised and details the writer(s), the model, their motivation (problem), the results, and any research gaps or areas for further research.

This approach addresses a new barrier management model which concerns the navigation bridge system operation in a context incorporating resilience engineering principles to improve shipping safety. The framework consists of the design integration of resilience abilities and safety elements, the development of application methods and a plan scheme for controlling and maintaining barriers. The model presents four resilience abilities: anticipation, monitoring, learning, and responding. At the end of the model process, the bow-tie model is used to visualise the barrier system from a productive viewpoint.

Marine navigation is an art and science involving strategic thinking, including collecting information, planning a voyage, finding the ship's position, anticipating risks, preparing for emergencies and managing resources (Bowditch, 2002). A vital part of bridge operation is good seamanship, requiring safe navigation. The research focuses on describing the bridge operation system. The navigation bridge environment is formed of three elements which are human, technology and procedure. Each of these elements will be discussed in this chapter.

Here, an in-depth analyses of ship accidents was carried out focusing on navigation. The navigation bridge where the ship's operation is carried out and its safety relies on the bridge team's correct actions. Therefore, the bridge must be carefully observed to investigate any deficiencies and how they reflect on accidents. The bridge consists of three aspects (human, technology and procedure) which work together to provide safe navigation. Humans control and operate the bridge, the performance of which depends on experience and knowledge. Technology increases the safety and efficiency of navigation, but it requires familiarisation and tests. Procedures on the bridge have been developed to give the operation process clarity, but the bridge team must commit in terms of following the procedures and the teamwork. The relationship between these aspects (human, technology and procedure) has not been investigated in the existing accident analyses.

The thesis will examine accidents which occur because of operational failures on the ship's bridge. The aim is to discover further detail about the causes and organise them so that solutions can be developed. Commercial ships rely on procedures to ensure safe navigation. Accident investigation records have documented several maritime events, experienced by different vessels, which applied high safety standard procedures. This study gives an overview of barrier management for improving ship safety by enhancing bridge operation resilience. This section illustrates how resilient safety management systems are developed. The model is applied on eight failed tasks, these are misjudgement, inadequate emergency response, inadequate situational awareness, poor lookout, poor alarm management, poor leadership, ineffective passage planning and poor learning.

Alarm management of the navigation bridge is chosen as an example to show the process application of the method. The remaining application cases are provided in Appendix A. From the accident reports investigation it was discovered that the Alarm Management task failed 12 times from 2010-2015 which caused grounding and collision to Britain's merchant fleet and the ships which sailed in UK waters. These events resulted in several ships being damaged, and marine pollution. The failed tasks (Alarm Management) are the navigation hazards which must be prevented by a planning barriers system which contains safety elements and resilience resources. These barriers must prevent the sub-factors from failing the Alarm Management task, and if the task fails the mitigation barriers should effectively function to avoid or minimise any impact.

Case studies are important for validating the implementation of the resilient solutions. The maritime simulator helps to define scenarios which assess the bridge team's performance quality. The experiment includes two groups with each bridge team consisting of one Officer of the Watch (OOW), one lookout and one helmsman. The first team performs scenarios by applying traditional procedures and checklists, which is used by the ships which are involved accidents. The second group implements the new developed procedure and checklists, including resilience solutions. Both teams performed the tasks without knowing details of the scenarios, which provides greater genuine and random actions attributed to their behaviours. The experiment includes five different scenarios, these are: normal navigation, passing agreement, restricted visibility, shallow water effect, and pilot onboard. The resilience abilities (anticipation, monitoring, learning and responding) of the two groups are assessed according to these indicators: 1- Ability for Judgment, 2- Emergency preparation, 3-Situation awareness, 4-Lookout quality, 5-Alarm Management, 6-Leadership, 7-Passage planning, 8- Learning environment on bridge.

Resilience is central to a system for modifying its activity before, during or after variations and disturbances, and the performance can be maintained even after great misfortune or the existence of continual stress (Nemeth et al., 2008). Unlike safety, resilience cannot be designed only via presenting further procedures, precautions and barriers, resilience engineering needs constant system performance monitoring in how things are done (Hollnagel and Woods, 2006). This study provides methods for assessing shipping organisations' resilience. This is vital as company resilience, whether in organisations or onboard ships should be promoted, assessed and improved using the same values and KPIs. A unified system helps to develop the same shared understanding, values and commitment regardless of the organisation's management positions, locations and operations. This is the only way that resilience onboard ship can be linked with resilience in the organisation.

In a nutshell, this chapter has provided a comprehensive introduction to the important elements of maritime transportation system. Shipping safety was improved in recent decades, yet maritime accidents still occur every year. This shows the importance of continual improvements in finding new solutions to reduce the number of accidents and improve ship operation efficiency. Integrating resilience engineering principles with the barrier management is a unique approach for bridge operations. The aim is to improve the safety and reliability of the navigation operation by effectively using the barriers. This chapter addresses the dissertation's flow and how the goal is achieved.

Chapter 2. Aims and Objectives

2.1. Introduction

This section includes the overall discerption of the research work which include Aim and Objectives, Major Contribution and Novelty and Thesis Instruction.

2.2. Aim and Objectives

The aim of this research is to address a new approach for safety management of maritime transportation, which is able to integrate the principles of resilience engineering with the safety elements in one system to enhance the safety of the navigation bridge.

The objectives of this study are:

- Describe the bridge operation system including resources, procedures, boundaries and limitations.
- Identify the bridge operation hazards that may lead to incidents, by analysing previous accident reports to find the gaps with the navigation watch and navigational safety.
- Build risk scenarios by performing cause – effect analysis using the fault tree (FTA) and mitigation analysis using the event tree (ETA) methods.
- Build a framework for integrated barrier management system with resilience abilities by selecting the critical functions and planning solutions for the risks through implementation of safety performance and resilience enhancement resources.
- Develop new barrier management system based on resilience principles and resources which include planning both sides of the bow-tie tool to present the prevention and mitigation barriers, and tying the relations among safety functions by applying the functional resonance analysis method (FRAM).
- Validate and test the new model in a full-mission simulator environment by performing comparative assessment of the traditional bridge procedure and the new resilience-based approach proposed by the author.

- Provide recommendations/resilience solutions such as improved standard operating procedures (sop) of the navigation bridge, trainings and leadership skills in order to enhance the navigational safety.
- Perform an assessment campaign to measure the resilience of shipping organisations. The resilience assessment tool (RAT) which was developed and validated by experts team of SEAHORSE project will be utilised for the first time to assess the resilience of a shipping organisation.

2.3. Major Contribution and Novelty

The purpose of this research work is to diminish and avoid tasks failures of navigation bridge that cause ships accidents which result in human injury and fatality, losses of assets, and marine pollution. The thesis presents three important contributions and Novelties to knowledge for the maritime transportation field.

1- An accident analysis was developed and conducted specifically to identify the navigation bridge deficiencies which affect the tasks and the duties of the bridge team. It classified 8 major navigation task failures in the ship's bridge. The analyses also found 20 sub-factors influence the navigation watch negatively. The consequences of all these deficiencies are identified as damage to ship or sink of the ships, injury or loss of crew member, and pollution of the marine environment. Application of the model proves that the accident reports can be used to identify the key safety problems, which can be used to develop new preventive and mitigative procedure.

2- Developed a model of safety management that have the capacity to integrate the resilience abilities with safety barriers management to improve the system anticipation, monitoring, learning, and response. The bow-tie method was utilised to demonstrate the safety barrier of preventing the deficient sub-factors from fail the bridge task. The Functional Resonance Analysis Method (FRAM) was used to illustrate the relationship among the function of the safety elements and to integrate the reliance enhancement to the barriers. The end results of the application provide a safety recommendation to improve the resilience of bridge operation.

3- Established an experimental process of testing and appraising the comparative performance of the navigation team and the effectiveness of the safety management procedure integrated with resilience abilities during the bridge operation. The navigation bridge simulator was introduced to perform different scenarios that help for the procedure assessment. It demonstrated that simulator can and should be used to develop resilience based procedures to enhance the safety by identify and deploying the most effective/suitable resilience resources for the task. First time, effectiveness of the resilience engineering principles on the performance of bridge team was quantified demonstrating that with the right assessment procedure effectiveness of resilience solutions can be quantified and their effectiveness in various scenarios/conditions can be measured to enhance the safety.

2.4. Thesis Instruction

Chapter 1 presents a broad introduction of the research topic and overview of the thesis arrangement.

Chapter 2 provides a comprehensive overview of the research work. The chapter presents the abstract of the research and also highlights on the research aim, objectives, and contribution to knowledge.

Chapter 3 provides the literature review of the recent research work that focused on the improvement of the bridge safety. The literature review cover varieties of topics include Acceding analyses, risk assessment, collision avoidance, safety culture, fatigue onboard ships, situational awareness, bridge technology, maritime simulator experiments, barrier management and resilience engineering.

Chapter 4 covers the introduction of the problem and how the new operation system have become complex because of the new technologies that require different training and regulation systems. The framework of the approach was clearly described, and each element was defined.

Chapter 5 covers the first step of the approach including the description of the bridge operation system. The three important elements in the navigation bridge (human, technology and procedure) were clearly analysed and defined.

Chapter 6 presents the second step of the model that examined the risks of the bridge operation. The MAIB accidents reports between 2010 and 2015 were analysed to find the causes of the operation failures of the navigation bridge.

Chapter 7 illustrates the process of developing the integrated barrier management with the resilience enhancement system. The alarm management task on Navigation Bridge is used as a case study to demonstrate the application.

Chapter 8 demonstrates the process of the case study to validate the implementation of the resilient solutions by utilizing the maritime simulator to perform the defined scenarios to assess the quality of the bridge team performance.

Chapter 9 provides methods to assess the resilience of shipping organisations. It applied the resilience assessment tool (RAT) that was developed and validate by experts team of SEAHORSE project. The RAT was applied to assess the resilience of one famous shipping company, as case study to validate the tool.

Chapter 10 provides a comprehensive overview of the research work. The chapter presents the conclusion of the research and also highlights on the research discussion and further Work.

Chapter 3. Literature Review

3.1. Introduction

This chapter presents a review of the literature on maritime research, focusing on the performance and safety of the human factor on the bridge. The section covers several research works written by researchers from several universities worldwide. The majority of the reviewed research involves developing models to enhance the operation and safety of ships, but a few cases assessed and analysed the actual performance. The literature review covers a variety of topics, including acceding analyses, risk assessment, collision avoidance, safety culture, and fatigue on board ships, situational awareness, bridge technology, maritime simulator experiments, barrier management, and resilience engineering. The research works were selected from numerous publications with the intention of finding research related to the PhD topic which illustrates previous progress in this area. A summary is provided for each paper, detailing the writer(s), the model, their motivation (problem), the results, and any research gaps or areas for further research.

3.2. Accident Analysis

Marine accidents could cause potential harm to people's lives, the marine environment, and assets. The aim of an accident investigation is to define why a particular combination of circumstances, events and actions has generated a certain consequence (Hollnagel et al., 2008). The goal of this section is to research previous literature and studies related to marine accidents caused by human error. The work covers several theoretical and practical research carried out in recent years.

Several Human Factors Analysis and Classification System (HFACS) frameworks have, to some extent, been modified and developed in recent years for accident analysis application. The HFACS is an assessment tool with which to analyse and classify operator errors, which was developed based on Reason's model (1990) of latent and active failures. The HFACS is a broadly used method for investigating human impact on accidents (Celik and Cebi, 2009). Chauvin (2011) adapted a psychology model which helps to understand the role of the human factor in the complex maritime system and in shipping accidents. The study applied the Reason method (Swiss cheese model) to analyse the role of the human factor. It distinguished between the active failures level, which concerns the first line of operation, such as the ship's crew, and the latent failures level, which involves the factors and people away from the event. The author examined the role of the human factor in marine incidents on three levels. The first level is that of the individual, which concerns the cognitive factors of the first-line operators; the second level concerns the social factors, which relate to interpersonal factors; the third level pertains to systemic or organisational factors, i.e. the latent failures. The shortage of this method is the lack of quantitative analysis, which motivates several researchers to develop model, which are able to fill this gap. Celik and Cebi (2009) developed a methodical approach of the HFACS, including the Fuzzy Analytical Hierarchy Process (FAHP), to detect the influence of human error on ship accidents. This adaptation advances the framework by presenting a quantitative assessment of events. The drawback of this approach is the use of a crisp point estimate technique of a nonlinear system of the FAHP, which, according to (Wang and Chin, 2011), produces analysis that has been discovered to be invalid, and its weights do not illustrate the relative status of the decision measures or the substitutes.

Chauvin et al. (2013) established a modified technique of the HFACS for ship accident analysis to examine human and organisational factors in events listed in reports of the UK Marine Accident and Investigation Branch (MAIB) and the Canadian Transportation Safety Board. Akyuz and Celik (2014) adapted a combined approach of the HFACS and a Cognitive Map (CM) to analyse the role of humans in shipping accidents. The model gives a distribution of human errors via recognising operational evidence. The main concern of the application of both models from Chauvin and Akyuz is the reliability of accident report data gathered by past maritime administrations and agents. It is difficult to confirm whether all of the accident factors were included in the utilised report. Chen et al. (2013) presented a method that integrated the HFACS-MA with a why–because diagram for accident analysis to set an additional measure for the HFACS method. The drawbacks of this adaptation include that the why–because diagram is merely appropriate for accidents that have already occurred, and that only discrete factors are measured (Sieker, 2006).

Akyuz (2017) presents a new hybrid approach to accident analysis, combining the Analytical Network Process (ANP) technique with the HFACS to examine potential operational risk in real ship accidents. According to (Akyuz) the approach offers a schematic conceptual framework with which to inspect and examine the role of human error in ship accidents. A typical drawback associated with the ANP technique is that it relies on people's perceptions (subjective biases), and in the creation of the network decision structure, it is not always obvious as to the interconnection to add or eliminate different factors (Coulter and Sarkis, 2006). Wang et al. (2013) developed a human error brittle model of a complex system which is designed to examine the internal brittle connection of the system. The gaps of this model include that the researcher could not present some results because of the complex interaction between several factors in the complex system, which renders the quantification of the initial entropy difficult. Graziano et al. (2016) developed a Human Error Identification tool named the Technique for the Retrospective and Predictive Analysis of Cognitive Errors (TRACEr taxonomy) in order to examine vessel accidents. The methodology shows advantages relating to error classification and demonstrates several deficiencies, such as bridge resource management and decision making. The limitations of this technique include the shortage of sequence identification of factors which have caused an accident and their interfaces, and also the distinction between task errors and technical failure events (Guedes Soares et al., 2000). Xi et al. (2017) state that the Cognitive Reliability Error Analysis Method (CREAM), which is the second generation of the HRA technique, is able to perform retrospective and prospective examination, thus being broadly applied in many fields and offering valuable understanding for quantitative examination of ship crew errors to lessen shipping risks due to human error. (Xi et al.) adapted a modified CREAM based on an Evidential Reasoning (ER) system and a Decision Making Trial and Evaluation Laboratory (DEMATEL) technique to generate quantification coherence with human error probability. The CREAM application has the advantage of retrospective and predictive analyses, though it is not effective when it comes to the prediction aspect (Kim, 2001).

Ung (2015) conducted research to define human performance deficiencies and developed a novel model of the fuzzy CREAM. The fuzzy CREAMs are well-recognised Human Reliability Analysis (HRA) methods. The author states that even with the developments in maritime transportation systems, ship accidents continue to occur. The primary factor that contributes to marine accidents is human error. Furthermore, the maritime system has become very complex, wherein technological, environmental and social factors combine in a way that increases the chance of human failure. The new model was able to solve the deficiencies of the old approach because its future is based on a rule-based approach. The model includes the weight of each Common Performance Condition (CPC), improvement of the certainty between the CPCs and the Contextual Control Mode (COCOM), and the flow of suitable data from each input. The researcher validated the model by applying it to a case study of an oil tanker in a state of discharging crude oil. The results concluded that the new CREAM is capable of generating reliable outcomes for human performance deficiencies and could be applied to different fields in the future.

In order to reduce ship accidents, worldwide maritime authorities ought to implement a number of conventions along with substantial determination to maintain an ideal level of safety standards aboard ships (O'Neil, 2003, Hetherington et al., 2006, Akyuz and Celik, 2014). Celik and Cebi (2009) argue that ensuring the consistency of maritime accident investigation reports is accepted as a significant method with which to evidently detect the root causes of events, which is a vital topic within constant research intended to enhance shipping safety. Mazaheri et al. (2015) suggested that accident reports have demonstrated being a credible source of evidence with which to define the major contributing factors of events, and they are useful for recognising the competent barriers as risk control procedures. Thus, evidence-based risk modelling, which presents actual accident scenarios as opposed to invented scenarios, is encouraged (Embankment, 2002, Kristiansen, 2010, Mazaheri et al., 2015). One of the major sources of proof which is obtainable and can be utilised for evidence-based risk modelling is that of accident reports that are set by professional accident investigators (Schröder-Hinrichs et al., 2011, Mazaheri et al., 2015). Nonetheless, accident reports sometimes cannot cover all of the sub-factors of an event; moreover, they could be subjective and rely on the investigator's experience.

Wang et al. (2013) believe that the key to avoiding ship accidents is to perceive the causing technique of human error and to research the impact degree of human error factors in relation to the entire system, which is relevant to accident control strategies. For example, the analysis demonstrated that the majority of ship collisions were due to decision errors (Chauvin et al., 2013). Akyuz and Celik (2014) claim that shipping safety aspects necessitate a set of actions on board vessels which are supported and observed by shore-based companies. This solution requires resources and procedures from organisations, including high commitment. The contributions of maritime safety researchers are discussed below.

3.3. Risk Assessment of Maritime Transportation

Sailing in sea traffic poses several risks which may cause ship accidents that could result in fatalities, environmental pollution, and a loss of assets. Human and organisational errors cause the majority of reported shipping accidents. However, the role of both humans and organisations may be larger than that found, as many incidents are not reported (Hänninen and Kujala, 2012). Solving such problems requires an inclusive ship accident risk model that is able to describe human error linked to the accident causation structure. For that reason, a number of studies have been carried out to enhance maritime safety. Trucco et al. (2008) developed a novel method of risk analysis for the Maritime Transport System (MTS) which incorporates Human and Organisational Factors (HOF). They used a Bayesian Belief Network (BBN) model and defined different factors in the model, such as the ship's owner, the shipyard, the port and the administrator, as well as their related influences. The standard probabilities for the BBN model were identified by expert judgement from several European states. The method was developed and applied to a shipping case study using risk analysis quantification of HOF on High-Speed Craft (HSC). The model provides probabilistic correlations between a collision and the BBN method of operational and organisational situations, which support finding and assessing the risk control options, including the organisational level. The approach could be applied as a support tool for decision makers to improve policies, designs or operations. Performing the full Bayesian Belief Network is great computational work, and networks tend to poorly execute high-dimensional data. Furthermore, the results of the application are difficult to interpret without having good experience with the model. Qu et al. (2011) conducted quantitative research to appraise the risks that could cause vessel collisions in the Singapore Strait. The approach proposes three different risk indicators of ship collisions, which are velocity dispersion, acceleration and deceleration rates, and different fuzzy vessel domain overlaps. The fuzzy ship domain model is used to assess the risks of collisions in the restricted waters of the Singapore Strait. According to the fuzzy approach, restricted waters will be defined as very safe, safe, less safe, dangerous or very dangerous based on the distance between ships. The authors describe the vessel domain as the water space that the ship's navigator decides to keep clear from other vessels, and the overlap of different vessel domains is used to determine the probability of a collision. The data for the three risk indicators are collected from Lloyd's MIU AIS, which provides real-time vessel locations and speeds from the Singapore Strait. The results of the analysis show that some lanes in the Strait are riskier, such as legs 4W, 5W, 11E and 12E. Therefore, the model solution for collision risk reduction would be implemented initially on the recognised four legs because of their critical condition. The study also found that around 25% of ships pass through the Strait above the speed limit, which increases the risk of collisions. The results also recommended that ships should obey the passage guidelines and not exceed the speed limit so as to improve traffic safety. The limitation of this study is that selecting only three factors to assess the risk in critical water, such as the Singapore Strait, is not sufficient. There are many external factors that could affect navigation in such a dense area, e.g. the weather.

Hänninen and Kujala (2012) examined the role of the human factor in ship collisions and analysed the validity of the maritime system in the Gulf of Finland. The authors used the Bayesian Belief Network model to determine the variables that influence the marine operating system. The probability of the cause of an accident is analysed by monitoring the condition of the network variables and by employing sensitivity and mutual information analyses. The variables include altering the ship's course, actions of the OOW, condition assessment, risk recognition, and personal conditions. The Bayesian Belief Network model helps to analyse the many variables that the maritime system includes and to produce accident probabilities. The results of this approach showed that the OOW's actions are the most influential variable, followed by steering failure and then situation assessment. Modelling the accident process is a challenging task, as not all accidents occur in the same manner or in a particular process. Mishaps usually take place for various reasons, which renders the process of identifying causes complex in many cases. The selection of variables is subjective and would differ from person to person.

Hänninen et al. (2013) conducted research to assess the impact of the application of the Enhanced Navigation Support Information (ENSI) navigation service on ship collisions and groundings in the Gulf of Finland. Their approach used expert judgement to assess the effect of the application. The Bayesian Belief Network was adopted to examine the impacts of various factors and the probability of collisions and groundings. The objective of the ENSI service is to prevent collisions and groundings of oil tankers by providing a system for exchanging information between vessels and the shore. It is a tool with which to improve the safety of shipping traffic by providing route plan exchange, meteorological information, oceanographic data, and marine safety knowledge. The results of the analysis indicate that the application of the ENSI system could reduce the number of incidents. According to experts' analysis of the model, the technology is useful, especially for preventing tanker groundings and collisions. The results also show that the ENSI system improves the VTS perception of hazardous situations by 12%. Furthermore, the number of open-water collisions could fall by 10%. Finally, implementing the Bayesian Belief Network provides the chance to update the model and reduce the uncertainties of the ENSI service. Hassel et al. (2014) examined the COLLIDE methodology system and identified areas for future improvement. The COLLIDE risk model has been used by offshore installations on the Norwegian Continental Shelf (NCS) for around 20 years to analyse the risk of shipping accidents. This research examines the COLLIDE model and compares its capability to the development of shipping technology, procedures, and operator education. It found that the two main components of the model (PFSIR and PFPIR) must be improved, since the results show that their capability is not as expected. The results also demonstrate that the COLLIDE framework, which includes three stages of hybrid models, could be improved by introducing a New methodology in order to provide decent quantification and integrate further risk-influencing factors. The shortcoming of the approach is that revising the COLLIDE system and the maritime operation system of the Norwegian offshore oil and gas industry requires a huge amount of work and the author could not revise the entire COLLIDE risk model because the progression needs extensive information collection.

Lema et al. (2014) conducted research to examine the sequence of several factors that co-occur with ship accidents. The researchers analysed 355 accidents from the European Maritime Safety Agency (EMSA). They used the K-means clustering method, which includes 15 selected clusters. The intention of this study was to establish a useful understanding of the factors involved in accidents in order to help developing crew training, personnel and maintenance standards so as to help reduce accident risk in the future. The shipping navigation schemes are quite complex and include several elements, such as humans, machines, technology and the environment, in a way that renders the risk impact high and complex. The results show that human factors are usually accompanied by parameters associated with the state of the ship's operation and other external elements, such as the weather and Traffic. Understanding these factors helps to prevent future events by introducing better procedures. The cluster numbers describe the vessel type, the accident category and the main accident-causing factors for each ship type. The analysis defined 15 different patterns of identical factors for vessel accidents. The results show accident patterns for vessel types, shortages, external conditions, and human factors, which act together in adverse events. Fishing vessels, for example, show the highest cluster numbers, as they are involved in collisions and flooding events alongside stability, rough weather, manning and training deficiencies. General cargo also has a large pattern in collisions, since a dense workload was noticed in the same state. The deficiencies of this model are that it does not provide clarification as to the patterns or suggest an explanation for accident causation.

Wang et al. (2016) conducted research to determine the management system deficiencies that cause the risk of inland accidents. They analysed three different subsystems: human, vessel and environment. They developed an entropy model for the risk of ship collisions. The study examines the causes of inland accidents and sailing routes in order to find the main factors that could influence the subsystems. The model is able to understand the interaction between the subsystems, which helps to provide a novel solution to ship collisions in inland water. The results of the application of the model show that when two ships encounter each other in inland water, there is a potential brittle relationship within the three defined subsystems of human, vessel and environment. In addition, the model proves that the effect of any subsystem failure could modify the other two subsystems. The brittle link entropy calculation result indicates that efficient manoeuvrability and safe sailing during an encounter between two vessels in inland water decrease the brittle link entropy between the three subsystems. The benefit of this model is that the quantitative results of brittle link entropy could afford entropy's value reference for the negative. The problem with this approach is that of which previous accident analysis results to use. It is insufficient to judge real sailing conditions, as ships are facing more dangerous conditions than those of other ships.

Aps et al. (2016) conducted research to implement the System Theoretic Accident Model and Process (STAMP) in order to design a safety management system for the maritime navigation of the Gulf of Finland (Baltic Sea). The researchers aimed to develop a dynamic safety management eco-socio-technical system of marine navigation that can link current, under-development and will-develop systems that facilitate the safety obligation. Furthermore, the system has the ability to improve communication, situational awareness, and perception. STAMP application requires developing a hierarchical order of levels, safety constraints and a control structure for marine navigation. Mishaps could take place because of inadequate or missed enforcement of the constraints between the various system levels, which could affect the control of system behaviour towards safe changes, and the adaptations that are enforced by the constraints. Moreover, it applied a hierarchy control framework and control loops, which are essential elements of the STAMP. The researchers used the International Regulations for Preventing Collisions at Sea and Safety of Life at Sea as navigational safety constraints. In addition, the ecosystem context of the GOFREP, the vessel navigation safety of manoeuvring, and ships' routeing restrictions were adopted as other constraints. The obligatory ship reporting system in the Gulf of Finland (GOFREP) is utilised to form maritime navigation safety control. The Common Situation Awareness (CSA) provided by NG-

SRW application is applied so as to frame the control loop. The authors did not show the advantages or shortcomings of such application, and the results did not clearly show that the application benefitted the maritime system.

3.4. Collision Avoidance

The deficiencies of collision avoidance of ship navigation have been investigated by a number of researchers by adapting alternative techniques. Vessel collision remains a problem for safe navigation and the marine environment, particularly in traffic waterways and complex maritime areas (Goerlandt et al., 2015, Wang et al., 2014, Lehikoinen et al., 2013), even though quite a lot of technological, training-related and procedural work have advanced and been implemented to avoid such events. Chauvin and Lardjane (2008) developed a study to analyse OOW decisions on board ferries that operate in the Dover Strait. They attempted to understand and characterise the courses of action that are available and recognise the strategy behind each choice. The Recognition Primed Decision (RPD) model utilised for this purpose was to understand how humans make quick and effective decisions under complex circumstances. The outcome of the approach indicates that different types of vessels act in different ways; for example, slow ships tend not to change their course and speed, and faster commercial vessels alter their course in compliance with the regulations. The drawback of this study is the lack of consideration in respect of the different sea states and weather conditions.

(Perera et al., 2010) developed a module of decision-making techniques for collision avoidance in ocean navigation, including a fuzzy logic-based parallel decision formulation; those decisions are framed into collision avoidance sequence actions by a Bayesian network. The approach demonstrates that the collision avoidance model has the ability of creating many sequence actions to prevent complex collision states of multiple ships; at the same time, it follows the COLREGs. The disadvantages of the model include the time and effort to develop the system, especially designing the Bayesian network programming.

Cummings et al. (2010) argue that human error is recognised as a major reason for ship accidents, yet there are other latent causes, e.g. deficiency of situational awareness, shortage of crew, and excessive workload in navigation work conditions. They proposed that an automated route-planning model for navigation has the ability to lessen workload and upgrade system efficiency, mainly under time pressure. The model is called the Maritime Automated Path Planner (MAPP), which integrates information requirements from a cognitive task analysis. The advantage of this tool is that of reducing the time necessary to create an enhanced, accurate and shorter route, which helps to reduce the workload and error. Goerlandt et al. (2015) proposed a framework for a maritime Risk-Informed Collision Alert System (RICAS) which slightly improved navigational performance, enhanced situational awareness of the OOW and supported decision making. What is not clear in this study is the real benefit of radar and the ARPA, since they provide the same alerting system.

Increasing ship traffic requires developing new methods and solutions to enhance the safety of shipping transportation. Szlapczynski and Szlapczynska (2017) state that the errors in collision avoidance actions are caused by unreliable data of target vessels or by OOWs working under high pressure. Thus, it is vital that the OOW receive reliable information and be in a position which is correctly assisting to make accurate decisions in proper time. (Szlapczynski and Szlapczynska) present a technique of displaying vessel collision avoidance data based on an unconventional Collision Threat Parameters Area (CTPA) method, which visualises potential route threats along with possible collision avoidance actions compliant with the International Regulations for Preventing Collisions at Sea (COLREGs). Despite the advantage of the CTPA technique the its algorithm of the model proposes a manoeuvre that drives the ship away from the state of collision at a specified time (Śmierzchalski, 2005); It does not, however, undertake the likelihood of the presence of new targets; moreover, it does not mention the time of returning the own vessel to its charted course. A Decision Support System (DSS) is a computer-based system which supports the operator in decision making, and is used in industrial operations to help manage complex systems. Lazarowska (2017) presents a DSS for collision avoidance that solves the route-planning difficulties when a ship is in a complex navigation condition based on the Trajectory Algorithm. It is a computer-based system dedicated to resolving complex states via collecting and analysing inputted data and making a decision based upon such data. The methodology has been tested on a simulation experiment and the results prove the successful ability of the method to resolve a path-planning difficulty for vessels. The limitation of this method is as much the user adding navigation conditions as it is the computational time increasing. Furthermore, encountered vessels' motion parameters are expected not to change during the problem solving of particular manoeuvre states.

The overall review of collision avoidance work demonstrated several gaps. The collision of ships remains a problem for safe navigation and marine environment, mainly in traffic waterways and complex maritime areas. It is difficult to understand and characterise the ways of action that are available for OOW and recognise the strategy behind each choice. Also how humans could make quick and effective decisions under complex circumstances. It was indicated that various types of ships behave in different ways; for example, slow steaming ships tend not to alter their course and speed, and faster commercial ships change their course in compliance with the regulations. Some studies show that lack of consideration in respect of the different sea states and weather conditions, which could affect the decision making. The decision making could affect by the creation of many sequence actions to prevent complex collision states of multiple ships. There are other latent causes, e.g. deficiency of situational awareness, shortage of crew, and excessive workload in navigation work conditions, include lessen upgrade system efficiency, mainly under time pressure. The errors in collision avoidance actions might cause by unreliable data of target vessels. The limitation increase of the computer-based system of decision-making support in the face of a complex situation and as much the user adding navigation conditions as it is the computational time increasing. Besides, encountered ships' motion parameters are expected not to change during the problem solving of particular manoeuvre states.

3.5. Safety Culture

Maritime transport is vital to the global economy, since more than 90% of the world's trade is transferred by sea and it is, by a long way, the best economical method to carry massive cargo and raw materials everywhere throughout the world (IMO, 2017). Maritime enterprise has a significant role to play in the relief of intense hunger and poverty, as it now offers a significant source of wages and occupation for countless developing states, e.g. seafarer workforces and vessel recycling, ship owning and operation, shipbuilding and maintenance, and port facilities, among others (IMO, 2017). Maritime transportation is an extremely global and multicultural business, which has led to major alterations to the workforce market of seafarers, who are becoming further multinational (Lu et al., 2016). Around 70–80% of the world's commercial ships have multicultural seafarers (Lu et al., 2016, Hanzu-Pazara and Arsenie, 2010). Multicultural ship crews with a shortage of a common language or culture might pose a great risk of work conditions on board (Lu et al., 2016, Theotokas and Progoulaki, 2007).

The safety culture concept was initially presented by the International Atomic Energy Agency (IAEA) following an investigation into the Chernobyl nuclear disaster in 1986, which concluded that nonconformity with operational procedures meaningfully contributed to the catastrophe, and indicated a poor safety culture in the power plant (Bhattacharya, 2015, Lee, 1998). In 1993 the ACSNI Study Group defined the term *safety culture* as the output of personal and team ethics, attitudes, abilities, and styles of behaviour that define commitment to an organisation's health and safety system (Bhattacharya, 2015).

Several researches have been conducted to examine safety culture in the shipping industry. Darbra et al. (2007) examined bridge safety culture and pilots' understanding of risk, as well as developing appropriate methods to improve navigation. They carried out a survey of 77 pilots from Australia and New Zealand, which included more than 20% of the pilots in each country. The questions covered four aspects associated with pilots' professional experience, safety culture and risk perception, navigational and pilotage danger, and their understanding of a pilot's responsibility. The research results show several deficiencies relating to piloting operation. They involve regulation recognition, economic pressure, accident-reporting systems, training, and bridge resource management. The current pilotage regulations have been developed in a way that confuses pilots' understanding of their responsibility and authority between the pilot, the ship's master, the administration and the port authority. Business pressures affect piloting operation negatively in terms of task quality, safety culture, accident reporting, fatigue control, and training. According to Darbra et al. the fear of liability causes pilots not to report incidents or deficiencies, which does not help the safety culture. The blame culture must transition to a safety culture that helps pilots to report any incidents or near misses. The study indicates the importance of unifying passage planning and communication channels between onshore and pilots. Commercial pressure causes pilots not to receive adequate training, which could affect navigational safety and environmental protection. The pilot is also not provided with effective bridge resource management training to avoid poor working environments on the ship's bridge.

Bhattacharya (2015) presents a study to realise the association that exists between the safety culture and safety climate on vessels as understood by the crew. The research defined safety climate factors by using factor analysis which selected seven factors: safety support, organisational support, resource allocation, work conditions, task demands, just culture, and safety compliance. The results found that the safety perception of the crew was low, which demonstrates misalignments between safety culture ethics and the existing safety climate, which results in, for example, the differentiations between senior and junior officers.

According to Lu et al. (2016), a small number of researches have been carried out to examine the national cultural influence on safety attitudes and behaviours, which are essential factors influencing the crew members on board ships. (Lu et al.) conducted research to examine the influence of national culture and leadership behaviour on safety performance in bulk ships. The study was based on a multiple regression analysis of 322 survey respondents in the form of crew members of dry bulk ships. It covered different indicators such as passive management and contingent rewards in relation to safety attitudes and performance. The outcomes demonstrate that nationalistic cultural dimensions, e.g. shared leadership, power distance, ambiguity avoidance, teamwork, and long-term relations, have a progressive impact on safety behaviour. Long-term orientation had a constructive impact on safety attitudes, with intensity having a harmful impact on the safety attitudes of crew members. In addition, shared leadership improves safety attitudes and behaviour on board ships. The limitation of this study is that seafarers' responses depend on the subjectivity of each person.

Different studies indicate that it is highly challenging to measure the relationship between safety culture and safety performance (Nævestad, 2017, Guldenmund, 2000, Cox and Flin, 1998). Nævestad (2017) adapted the approach to study the impact of safety culture and the working environment on injuries and risk awareness on cargo ships operating on the coast of Norway. The information was collected through surveys, group meetings and interviews. The study found that injuries and risk awareness on board ships are affected by organisational safety culture, manning numbers, job pressure, and demanding operational conditions. For future research to improve upon this study, it is required to conduct analyses of the correlations among safety culture, the working environment and job-related safety, which should emphasise the combined contribution of diverse separated frameworks of contributions. In addition, it is important to adapt novel research in dealing with the conflicts demining that have the ability to balance safety and the economy.

The review of the safety culture work shows different gaps. Shipping business is an extremely international and multicultural industry, which made seafarers to gain multinational character. Multicultural vessel crews with a lack of a common language or culture could pose a high risk of work conditions on board. Examining the piloting operation shows several deficiencies which include regulation understanding, economic pressure, accident-reporting systems, training, and lack of bridge resource management. The pilotage regulations are not clear regarding the responsibility and authority between the pilot, the ship's master, the administration and the port authority. High demand Work environment impacts piloting operation negatively in terms of performance quality, safety culture, accident reporting, fatigue management, and training. In some cases pilots do not report accident or deficiencies because of the fear of liability. It indicated that the importance of unifying passage planning and communication channels between onshore and pilots. Pilots do not receive adequate training such as bridge resource management because commercial pressure which affects the navigation safety and causes poor working environments on ship's bridge. The review discovered that the differentiation between senior and junior officers could make the safety understanding of ship's crew low, which demonstrates misalignments between safety culture ethics and the existing safety climate. Organisational safety culture, manning numbers, job pressure, and demanding operational conditions have tight relation with injuries and risk awareness on board ships.

3.6. Fatigue Onboard Commercial Ships

Fatigue might be defined in various ways. According to the (IMO, 2001a), it is a condition of feeling exhausted, tired or sleepy that results from long mental or physical effort, prolonged times of anxiety, disclosure to tough environments, or a lack of sleep, which weakens performance and alertness. Seafarers share a number of critical job features causing fatigue on board ships, such as working long periods of time, disturbed sleep as a result of, for example, motion noise, and working night shifts (Allen et al., 2008, Lutzhoft et al., 2007, Phillips, 2014). Poorly designed vessels or systems which cause seafarers to feel fatigued or unfamiliar with cultural awareness are contributing to the (doubtful) level of safety activity of vessels (Othman et al., 2015). Fatigue diminishes a person's cognitive ability by slowing response times, decreasing attention, and undesirably disturbing decision making — all abilities are essential for efficient navigation and system judgement (Strauch, 2015). The results of the Bridge Watchkeeping research conducted by the Marine Accident Investigation Branch indicated that third grounding accidents are associated with fatigued officers (Nævestad, 2017). There is a definite relation between fatigue conditions and work injury hazard, though more studies focus on the factors causing fatigue (Nævestad, 2017, Williamson et al., 2011). Fatigue might seem more predominant than the maritime industry is currently able or prepared to measure (Allen et al., 2008). Human fatigue is difficult to measure and even more difficult to mention as a reason for an event (Bal et al., 2015). Several studies have been accomplished by maritime researchers related to fatigue aboard ships.

Leung et al. (2006) conducted a study to investigate fatigue levels of officers stimulated by navigational duties on high-speed vessels, which was designed as a self-reported rating scale and questionnaire. It also analysed the work elements that contribute to fatigue, including day and night shifts. The results indicated that officers on the bridge are exposed to fatiguing conditions which affect their performance and could lead to an accident. Fatigue could occur because officers are working long hours and performing multiple tasks that generate a mental workload. The ship type also contributes to fatigue, such as the operation of high-speed vessels, which exposes the operator to a high information demand in a short period of time. Another problem that may cause fatigue is a watch schedule that contains day and night shifts. Long-term sleep disruption accounts for fatigue on board ships. The outcomes of this research provide a foundation for examining current work schemes and schedules for high-speed ship officers. It is also advised to revise the working health and safety procedures for the ship's crew. However, a shortcoming of this research is the difficulty of capturing all of the details for the experiment, such as the number of working hours, the number of voyages, the quality and quantity of irregular rest periods, overtime duties, the type of vessel, and the working season. The absence of these elements could affect the quality of the analyses.

Lützhöft et al. (2010) state that many commercial vessels nowadays navigate with only two bridge officers, with the timetable of their shift being that of 6 hours on and 6 hours off. (Lützhöft et al.) conducted a study to examine the effect of this shift pattern on fatigue. The techniques of electrooculography, actigraphy, diaries, and reaction time tests were utilised to measure the impact of this type of watch system on fatigue and sleep. The results of the research concluded that the shift system of 6 hours on and 6 hours off demonstrates more sleepiness than that of the shift of 4 hours on and 8 hours off. Akhtar and Utne (2014) present a method that applies the Bayesian Network (BN) for modelling bridge team fatigue and the risk of ship grounding. The BN application demonstrates that fatigue has a major impact on the probability of grounding, even increasing the possibility of an accident by 23%t. The study compared different watch timetables (6–6, 12–12, and 8–4–4–8) and the outcome shows that the shift system of 6 hours on and 6 hours off seems to produce less fatigue. The Bayesian Network approach has several limitations, the major one being the long time that the method takes to perform the computing preparation.

Bal et al. (2015) examined the factors that generate fatigue in a ship's crew and their quantitative significance by using the Analytic Hierarchy Process (AHP). The results show that sleep has a significant role in generating fatigue on board, which increases mainly for the duration of port calls. It is suggested that new multi-criterion decision-making techniques and different scales could be applied to define fatigue levels of a ship's crew by assessing a larger group of mariners on various types of vessels which have different operational routes. Hystad and Eid (2016) state that a seagoing profession is a naturally stressful job, including working periods and leisure periods being spent in the same limited setting for an extended time. (Hystad and Eid) studied the influence of periods at sea, seagoing experience, occupational stressors and psychological capital (PsyCap) on sleep quality and fatigue. PsyCap is a personal characteristic that has received considerable attention in positive psychological research, which is recognised by means of a higher-order personality construct encompassing four diverse features: self-efficacy, optimism, hope and resiliency. The results of the research demonstrated that PsyCap can be trained and shipping organisations may possibly have much to achieve by being aware of the criticality of adapting routines so as to enhance the PsyCap of their seafarers. Hystad et al. (2017) adapted the study to examine the effects of sleep quality, fatigue, and safety climate on the perceptions of risk among a ship's crew. The results show that the awareness of risk of individual injuries and ship accidents is boosted when the crew are fatigued, which is related to poor sleep. The limitation of these studies is that of relying on self-reporting, which depends on respondents' subjectivity in answering questions.

3.7. Situational Awareness

Situational Awareness (SA) is defined as being conscious about what is going on around oneself and understanding what that information means for the present and the future (Sandhåland et al., 2015, Endsley, 2012). Sætrevik and Hystad (2017) claim that SA is frequently contended in relation to being a sharp end indicator of work safety, and it may be argued that it could be the nearest cause of navigator error. The failure of SA could occur because of several factors. Research into coastal commercial ships sailing off the coast of Norway indicated that 33% of the respondents stated that they put themselves at risk to accomplish a task, whereas around 40% would violate procedures to complete a job, particularly for demand efficiency (Størkersen et al., 2011, Nævestad, 2017). Classic methods or experimental measures of SA are facing an issue surrounding associating large-scale data (influences on SA and safety results) to be analysed or organised (Sætrevik and Hystad, 2017).

Several efforts have been made to understand or measure the SA on board ships. Snidaro et al. (2015) adapted a software model to constantly detect anomalous events of the perceived environment so as to improve the situational picture for navigational officers in order to support decision making. It utilised the JDL fusion method and showed the power of Markov Logic Networks (MLNs) for programming uncertain knowledge concerning the observed evidence for situational assessment, which has the ability to deal with massive amounts of data and information. The model also provides a technique for early event recognition by assessing the level of finishing points of complex events, which is useful for early warnings before risky conditions occur. The limitation of the MLN model, according to (Lippi and Frasconi, 2009), is when it works with real valued attributes, e.g. multiple alignment profiles, which are well recognised as supporting prediction accuracy. Cordon et al. (2017) conducted a study to identify the human factor in seafaring. Exploratory Factor Analysis and Confirmatory Factor Analysis through Structural Equation Modelling techniques are used for data analysis. They identified two factors: situational awareness and adaptability. The results show that situational awareness is a crucial factor in ship navigation, which is supported by psychometric evidence of construct validity. Sandhåland et al. (2015) examined accident reports for collisions between ships and offshore platforms in Norwegian water because of SA, which is valuable in understanding the progressions that lead to an event. The results of the analysis prove that ship collisions with offshore facilities took place as a result of diminishing in three types of SA: failure to recognise circumstances correctly, failure to understand conditions, and failure to conceive of conditions in the future. The results also identify the factors that affect OOWs' situational awareness: inadequate operational planning, a poorly designed bridge, a lack of training, communication breakdowns, and distracting elements. The drawback of this study is that of relying on accident reports that do not always include all of the accident factors, which is according to the understanding of the investigator.

(Sandhåland et al., 2017) examined the influences of active and passive leadership character (authentic leadership, laissez-faire leadership) and psychological work requirements on safety-related SA and the readiness to control the risk of everyday operations. The study developed a model of path analysis including maximum likelihood estimation. The results show that authentic leadership improved SA, unlike the laissez-faire leadership style. Sætrevik and Hystad (2017) adapted research to measure the SA of seafarers working on offshore vessels by implementing a self-reported scale. They argue that ship captains could play a vital role in imposing the organisation's anticipated safety level on board, and the captain's leadership character might be more or less appropriate to attain this. The theory of authentic leadership defines leadership as (1) transparency, openness and trustworthiness, (2) being direct towards worthy goals, and (3) an insistence on follower advancement (Sætrevik and Hystad, 2017, Gardner et al., 2005). The method selected the authentic leadership aspect as a predictor, whereas a self-report of an unsafe act during work and subjective risk assessment were displayed as outcome measures. The results of the study demonstrated that the leadership style of a ship captain is responsible for the variation of SA. Furthermore, SA is responsible for variation in unsafe acts and in subjective risk assessment. The study agreed with the notion that SA has a key role in shipping safety. The disadvantage of the authentic leadership approach is the absence of an appropriate theory or model.

In general, all of the studies relied on distributing surveys and a self-reporting system, which has some inherent weaknesses related to self-serving bias or receiving answers that are subjective in respect of the respondent's understanding and experience.

3.8. Bridge Technology

Lee and Sanquist (2000) examined the mental requirements needed for OOWs to cope with the development of shipping and navigational technology. They believe that ships' navigational systems are becoming more complex because of the progress of technology, which might significantly change the experience, knowledge and plans required for the navigation of large vessels. Furthermore, there are no systematic methods to identify the design flaws and training demands of technological innovation in relation to shipping. The lack of these requirements may harm maritime safety rather than improve it. The advantage of the technology is that of reducing the repetition of physical activity, but the size of the ship's crew is also reduced, which increases the mental demand placed on the operator. The workload is especially increased in stressful conditions. It has been observed that in some accidents, technological information is misinterpreted by the operator in a way that leads to poor judgement. Other cases show over-reliance on navigational technology (Lee and Sanquist, 2000).

Lee and Sanquist (2000) presented the Operator Function Model (OFM) as a solution that provides a foundation for analysing the development of ship technology. The OFM is able to classify the distinction between classical navigation systems and modern systems. It has the capacity to examine the cognitive requirements that support the operator in coping with advanced technological equipment. The nodes symbolise operator activities and the arcs that link the nodes symbolise the transition or could be the trigger conditions that initiate, terminate or sequence the activities. The results of the application of this approach show that several modern advanced radars could reduce the probability of collisions and the present training procedures do not address the cognitive requirements of such innovative technology. The study also points out that the ECDIS can lessen redundancy, which has helped traditional systems. The OFM has shortcomings, e.g. not providing a clear description of specific cognitive demands. It is not able to address personnel allocation; OFM only provides multi-person states. If the OFM analysis includes the task allocation it could increase the complexity of the team, which necessitates a cautious analysis. Besides, the behaviour of several systems cannot be anticipated by examining individual systems, which requires a holistic perspective. The model is designed at a level that does not define the detailed activities required for the technology, which shows several vital conflict management concerns that are associated with some technological aids. Augmenting the OFM with a description of cognitive operations has several advantages. It produces an organised cognitive task analysis method of the OFM that is able to recognise the scheme and training elements needed to protect the system's performance. This approach identifies the process of improving designs, creating a training programme and modifying qualifications to reduce the human errors that could arise from technological innovations. The OFM has a structure that specifies the information that the operator requires so as to perform the task and the way of combining this information includes the technique of displaying.

Harati-Mokhtari et al. (2007) examined the introduction of the Automatic Identification System (AIS) on board ships and its possible impact on navigational safety. They analysed the AIS regulations, correct application monitoring, training, and user conduct. Previous AIS analyses were examined along with potential operating problems. The Swiss cheese model of system failure was harnessed and modified in order to explore a potential accident process. The authors state that the main problems derive from innovative technological equipment, which is introduced to the bridge system following a minimal assessment of the possible effects on human–machine performance. The results of the analysis demonstrate the inadequate impact of the AIS on the ship's bridge. The AIS shows poor performance and transmission of information, which is vital and can affect the efficiency of the ship. The operator enters the ship and voyage data manually, which increases the possibility of entering incorrect information, as recorded in several cases. If the officer does not check the transmission information frequently it could result in incorrect information being sent to nearby ships. Another AIS shortcoming that appears in high traffic or anchorage areas is that of mixing ships' information when they are transmitting close to each other. Besides, the AIS database is limited, since not all ship types are included; the navigation status is not applicable to all types of ships and the screen only shows a maximum of 20 ships. Finally, in the AIS database, information can be recorded incorrectly — some of the ships show the wrong length, beam and draught measurements.

Gould et al. (2009) assessed the impact of switching from traditional paper charts for ship navigation to the Electronic Chart Display and Information System (ECDIS). They evaluated mental workload as well as navigational and safety performance. A simulation of a high-speed vessel was conducted to compare navigation using the ECDIS with navigation using paper charts. The researchers planned a 50-nautical-mile course to be executed by 20 cadets. To record cognitive workload data, Heart Rate Variability (HRV) and Skin Conductance (SC) methods were utilised. The authors state that ship automation development had changed the role of the bridge operator in a way that increased their cognitive workload. Their duties changed to monitoring tasks. They mention that the overload state is a result of the absence of feedback, interface mode confusion, excess information, and high care requirements. The design has developed by increasing the ship's size and speed. The critical change is ship automation, since it affects operational and safety performance, especially by replacing paper charts with the ECDIS. Automation could cause mental underload through reducing the operator's focus by having fewer tasks to apply themselves to, which prevents the navigator from taking immediate action in the event of a sudden risk. The results show that the ECDIS enhances navigational course keeping. However, the results also indicate that communication is reduced on the bridge. Regarding mental workload, no difference was observed between using paper charts and the ECDIS. The HRV and SC measurements showed that conventional navigation (paper charts) has a higher workload, but not significantly. The experiment was performed in normal sailing conditions and the results showed that the ECDIS improves operation. The researchers should assess performance in different sailing conditions to gain accurate measurements of the cognitive workload.

The overall of the bridge technology review demonstrated several gaps. The bridge technology intended to reduce the repetition of the human activity. Likewise, the size of the ship's crew is also decreased, which generate stressful work environment by boosting the mental demand and the workload placed on the operator. It has been observed that in some accidents, technological information is misinterpreted by the operator in a way that leads to poor judgement. They believe that ships' navigational systems are becoming more complex because of the progress of technology, which might significantly change the experience, knowledge and plans required for the navigation of large vessels. Furthermore, there are no systematic methods to identify the design flaws and training demands of technological innovation in relation to shipping. The lack of these requirements may harm maritime safety rather than improve it. The AIS shows poor performance and transmission of information, because of several factors that include entering manually incorrect information of ship and voyage data, the officer does not check the transmitted information, incorrect information being sent to nearby ships, mixing ships' information when they are transmitting close to each other, and limited database. Ship automation development had transformed the duty of the OOW in a way that increased the mental workload and becomes monitoring tasks. The technology also could face several deficiencies such as the absence of feedback, interface mode confusion, excess information, and high care requirements. Replacing paper charts with the ECDIS could affect operational and safety performance by causing mental underload through reducing the operator's focus by having fewer tasks to apply themselves to, which prevents the navigator from taking immediate action in the event of a sudden risk. Though ECDIS enhances navigational course keeping, the review indicates that bridge team communication is reduced on the bridge.

3.9. Maritime Simulator Experiment

The most common reasons for maritime accidents are attributed to human error, comprising more than 80% of the total amount. For example, misjudgement, poor lookout and not following regulations are examples of mishap causes related to the human factor. Bridge operation requires performing various cognitive tasks at the same time, necessitating excellent situational awareness and correct judgement, which can sometimes fail, whereby causing a collision. The traditional method of analysing human error is not enough, as it cannot find the relationship between performance-shaping factors and human performance during operation, and is not beneficial for individual evaluation (Liu et al., 2016). The maritime education domain often tries to meet training aims within the subject of human factors related to operator performance in technological working environments along with the ergonomic design of such settings (Hontvedt, 2015, Vicente, 2004). Simulators (marine) are usually utilised for learning professional skills, collaboration and teamwork in a safe operational environment. The current research displays that simulator training can deliver content and scenarios along with instructional features, including opportunities of assessing individual and team activities in different professional fields, such as medical, aeronautic and maritime (Hontvedt, 2015).

Schuffel et al. (1989) conducted a study on the feasibility of an extremely automated ship's bridge for single-handed navigation. The research defined a function allocation process, which forms the foundation for an automated bridge concept that can be applied to future merchant vessels. The approach provides an effective ergonomic design to optimise the safety of the navigational system and the working conditions. It provides balance to the relationship between the four core elements of the man–ship system: software (procedures, rules, regulations), hardware (displays, controls, process dynamics), environment (climate, vibrations, noise) and lifeware (motivation, stress, skill). The authors believe that the most important task in the integration process is function allocation, which concerns the differentiation between human and automated functions. This step is necessary in order to define the efficiency of the bridge layout, especially the workstation. To validate the model and the innovative bridge design, they used a sequence of simulation experiments. They investigated the navigational performance efficiency and the safety conduct of such application. The simulator helped to verify the performance ability of this assumption by implementing the model in operating conditions similar to those in reality. The study focused on measuring the workload of the primary tasks. The experiments were carried out by conducting navigational tasks and Continuous Memory Tasks (CMT). The authors selected 32 OOWs for participation in the ship simulation. The results showed that correct function allocation can increase the safety of navigation by improving task performance. The study places large emphasis on the feasibility of human performance on the ship's bridge. The new approach had no effects on the navigator's mental load. However, the consequences of repetitive duty conditions for operators' situational awareness were not discussed. Besides, not all of the functions can be automated. Furthermore, operators' skills and motivation required after changing the task structure from active manual control to passive monitoring control need further investigation.

Kim et al. (2007), using a ship-handling simulator, examined the influence of alcohol on the performance of navigation officers and harbour pilots in respect of three Blood Alcohol Content (BAC) levels (0.0%, 0.05% and 0.08%). In order to investigate the effects of alcohol on seafarers' capacity during watchkeeping, different measurement methods were utilised: bio-signals using an Electrocardiogram (ECG), a maritime simulator, and NASA-TLX to measure mental workload. The outcomes of the experiment show that alcohol consumption considerably weakens the physical and mental capability of OOWs. In particular, alcohol intake was found to have a direct correlation with changes in bio-signals and simulator performance. Moreover, alcohol intake changed the heart rate and boosted mental workload. The shortage of results means a lack of quantitative measurement of the effects of alcohol.

Nilsson et al. (2009) conducted a comparison study between an integrated navigation system bridge and a bridge which did not contain modern conventional navigational equipment. Both of them are maritime navigation simulators. Actual event scenarios were designed to contain several challenging conditions during sailing in a fairway. Different elements were assessed in the scenario, such as performance, workload, and effective responses. Experiment outcomes demonstrated not much of a statistical difference between both bridges' performance. Yet, with regard to technical performance, it was found that experienced navigators executed much more effectively on the conventional bridge and less experienced officers performed more effectively on the technically advanced bridge.

(Gould et al., 2009) presented a study to examine mental workload and performance, and used a high-speed ship simulator. It compared two navigational systems for defining the vessel location: Electronic Chart Display and Information System (ECDIS) and conventional paper charts. The experiment scenario included a navigational track of 50 nautical miles containing various sailing conditions, which was performed by 20 cadets. The results illustrated that using the ECDIS for bridge navigation significantly enhanced course-keeping quality; nonetheless, it decreased the communication among the bridge team. No differences were observed in the mental workload aspect between groups. After measuring the heart rate variability and skin conductance of different groups, it indicated higher workload in the conventional method for navigation, but the variances were not great.

(Chauvin et al., 2009) adapted the study to examine the impact of training programme on the capacity of the Officer of the Watch (OOW) to make decisions in collision avoidance conditions in a bridge simulator. Drills were planned so as to assess the impact of the training course. It developed a set of indicators which must be recognised by the OOW: cue recognition, formation of anticipation, appropriate objective identification, and realisation of distinctive actions. The observation results of the simulator experiment indicated that students were incapable of managing such conditions or even remembering their key features as learned in class. As a result, the decision-making training did not develop students' capacity to the level that helped them to examine the complex situation. It is consequently essential to develop new educational methods that give cadets the capacity to analyse a situation rapidly and precisely in order to take suitable actions. It is recommended that to improve OOWs' capacity to perform navigational tasks, shipping organisations should replace the long onboard training with an intensive training program on maritime simulators so as to repeat the same critical situations in a safe environment.

The shipping industry is facing problems owing to the shortage of seafarers, as well the rapid development of onboard technology, which requires the crew's skills to develop in line with the technology (Håvold et al., 2015). The training of Crew Resource Management (CRM) has become vital to tackling such deficiencies. The validity of this training requires assessment, especially as the majority of accidents occur because of human errors, such as those from operators, organisation, maintenance, design, installation and assembly. Håvold et al. (2015) evaluated and examined the training of CRM in the anchor-handling simulator training at the Offshore Simulator Centre in Norway. The authors mention that ships' owners refer their crew to the CRM training to improve their skills in respect of teamwork, leadership and communication. The researchers selected 369 mariners, the majority of whom had more than 1 year of experience. A questionnaire was distributed among the participants that covered the course quality and content, knowledge and skills acquired, and future application. General satisfaction with the training was examined by ANOVA, including other variables such as age, employment, and anchor-handling practice. The research results showed that CRM training methods demonstrate great promise for the maritime profession. The outcomes specify that 64% improvement of the variation, such as change-intended behaviour, improved skills, knowledge and understanding and the content of the course. The problem with the research model is that the assessment could be affected by the objectivity of participants. The authors state that the debriefing stage is critical in the course. They also suggest that more research is required in the CRM area.

Liu et al. (2016) conducted research aimed at improving operator assessment and understanding the relationship between brain workload and stress and the performance of cadets. They used electroencephalography in a human factor analysis system designed for full-mission simulator assessment and measurement of cadets' cognitive abilities. The researchers sought to obtain a broad understanding of mariner performance by observing different brain conditions, such as workload, stress, and situational awareness, during bridge operation. Electroencephalography is able to monitor cadets' cognitive capacity and senses emotion. Cadets were exposed to different scenarios of night and day navigation, and sailing in varying weather and traffic conditions. Their performances were recorded for analysis and assessment. The outcomes of the research indicated that the model was useful for detecting cadets' emotions, situational awareness, brain workload and stress levels during operation. In addition, the model shows whether the operator is ready to perform the task or requires more training in a full-mission simulator. The model can help a shipping company to evaluate crew performance before hiring them, since it has the capacity to detect their readiness. Another possible application of the model is in assessing the condition of officers before performing a navigation watch.

The overall review of the maritime simulator experiment demonstrated several gaps. Bridge operation involves performing several cognitive tasks at the same time that require great situational awareness state and right judgement, which could occasionally fail and causing a collision. Analysing human error require more than the traditional technique which can be performed by utilising the maritime simulator. Some results were short of quantitative measurement. With regard to technical performance, it was indicated that experienced OOWs performed more effective on a conventional bridge and less experienced navigators performed much efficient on the technically advanced bridge. The review shows that using the ECDIS for bridge navigation significantly enhanced course-keeping quality; nonetheless, it decreased the communication among the bridge team. Provide the maritime cadets with decision-making training in class did not develop students' capacity to the level that helped them to examine the complex situation. The outcomes of the simulator experiment indicated that students were unable of managing such circumstances or even remembering their key elements as learned in class. The maritime education and training institute must design innovative educational tools that provide cadets the capability to examine a situation quickly and accurately in order to take appropriate actions. It is recommended replacing the long onboard training with an intensive training program on maritime simulators which help to repeat similar critical situations in a safe environment. The maritime transportation is facing challenges owing to the shortage of seagoing people, besides the fast development of onboard technology, which require the crew's to develop skills in line with the technology. It is suggested that more research is required in the bridge resources management area.

3.10. Barrier Management

Barrier management's purpose is to guarantee that a working system is constantly running in a safe routine and that the designed barriers are effective and robust. The barrier management technique must involve and become part of the everyday work. Accident investigations point out that insufficient barrier management has been a key cause of many accidents in the operational industry (Johansen and Rausand, 2015). A maritime organisation is accountable for building a barrier management system that finds and maintains safety barriers so that any risks encountered can be managed via preventing an accident from occurring or by reducing the event's impact.

According to the Petroleum Safety Authority of Norway (PSA, 2013), a barrier could be designed in many forms, e.g. technical, operational and organisational elements in a single or collective style, in diminishing the likelihood of a certain error, risk or accident occurring, or in containing its damage. Øie et al. (2014) argue that a barrier refers to standards initiated with a precise goal to prevent a threat from being reached, or to mitigate the consequences of a hazardous condition. The barrier function is the task or job of a barrier in the system, such as preventing leakage or fire, shrinking flame size, and securing sufficient evacuation, whereas the barrier element concerns the solutions that present the role of a barrier function performance, such as technical, operational or organisational standards (PSA, 2013).

The barrier management domain is continually evolving at a rapid pace, which makes it difficult to obtain an outstanding method, since each organisation develops its own approach (Øie et al., 2014). The "Swiss cheese" model, developed by James Reason in 1997, represents accident causation as breaking barriers. Reason believes that accidents are an accumulation of active failures and latent conditions. The active failures are unsafe acts that include latent conditions, shown as unsafe conditions, which are complex linear of cause and effect. From this point of view, the incident can be prevented by strengthening those barriers (Reason, 1997). The navigation bridge accident, for example, could occur because of unsafe action (active failures) by the officer of the watch (OOW) and a lack of qualifications, shown as unsafe conditions (latent conditions) or non-ergonomic design of the bridge.

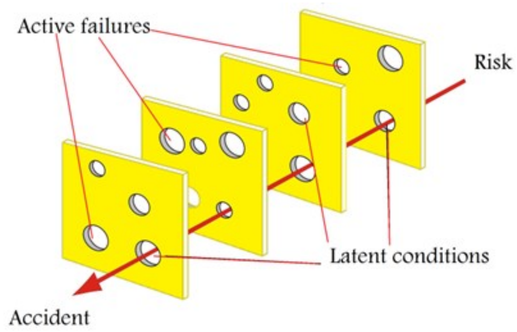


Figure 6-3-1 Swiss cheese model developed by Reason, 1997

The barriers require beneficial design, control, monitoring and maintenance so as to perform as intended. According to Øie et al. (2014) the Swiss cheese model illustrates the management barrier strategy:

- Every barrier in the system should block risks from release
- In the case of the failure of one barrier, the following should become active
- Each barrier should be as independent as possible from others
- The barriers should have the ability to diminish as much danger as possible
- Single failure should not cause a major accident by breaking all barriers
- Barrier enforcement should contain as few and as small holes as possible.

Johansen and Rausand (2015) adapted the study to explain the notions and principles of barrier management and offer an outline of requirements and challenges in the offshore oil and gas domain, with particular emphasis on the Norwegian offshore industry. In 2013, the Norwegian Petroleum Safety Authority (PSA) issued a collection of principles and a system for barrier management in the petroleum domain to be integrated into the safety management system. Organisations that have implemented the concept realise both advantages and challenges of the system, which has evoked a great deal of discussions. Barriers are vital aspects for preventing and mitigating large accidents, though they are systematically managed during the lifetime of an organisation. The results of the study defined several challenges of this system, such as terminology, integration through analyses and control, and application in operation. The gaps present critical subjects which need additional research that might intend to close the gap between theoretical models and practical demand. King et al. (2016) adapted research and examined the main accident risk of large passenger vessels' stability, which is focused on analysing the impact risk of stability. The approach presents the barrier management concept as a solution to controlling the hazard of stability. The results of the study indicated that the application of barrier management is beneficial to the system by introducing preventative and mitigating notions in order to control risk through addressing human, operational and technological systems. Whereas the vessel is designed and built with an inherent standard of safety, it addresses the vital elements of stability in holistic vision and over time. For example, watertight doors illustrate a worthy model of barrier management covering all elements of stability management: design, tactical, operational and emergency. The authors believe that applying a barrier management system for stability management could reduce the risk of accidents that might involve a significant loss of life.

Pitblado et al. (2016) argue that during working time, barriers start to degrade at various rates, and devolution begins to escalate facility threats. Some barrier deficiencies could boost hazards dramatically. Traditional barrier management implements static assessment and maintenance intervals. (Pitblado et al.) present a dynamic barrier management system that integrates several datasets. The advantage of the method is that during operation, actual information becomes obtainable through developing a system that is able to (1) inspect, audit and assess, (2) display monitoring sensors, (3) analyse near-miss and accident records, (4) develop records for maintenance and examination, and (5) implement records for staff training and competence. Li et al. (2017) developed a quantitative technique of safety management to define in what way the delivered management factors influence risks that affect the function of a barrier. For example, people's competency could be modelled as a competency delivery system, which is in the form of a competent person being delivered to perform a task of a barrier, and this task assures the barrier's effectiveness. In this method, barriers are collected in five groups: behavioural, socio-technical (a), socio-technical (b), active hardware, and continuous/passive hardware. For each barrier type quantifying competence indicators and the performance should be established, including the links between a delivery system (competence). The advantage of the application is that of improving the efficiency of barrier management by providing performance monitoring and quality quantification assessment; furthermore, quantification could be utilised as input for audits. The drawback of this research is that of indicating an accurate relationship among various groups of barriers and several delivery systems.

The outcomes of the review indicated a number of challenges of this system, such as terminology, integration through analyses and control, and application in operation, which need additional research that might intend to close the gap between theoretical models and practical demand. During working time, barriers could start to degrade at various rates, and devolution begins to escalate facility threats and some barrier deficiencies could increase danger significantly. Traditional barrier management tools have shortage of quantification measurements. The general limitation of the barrier management approach is that the concept of the application relies on a cause-and-effect process; besides, the theory assumes that an accident may occur as a result of inline causes that take place one after another.

3.11. Resilience Engineering

Resilience is the core capability of a system to modify its activity before, during or after variations and disturbances, and it can maintain the required performance even following a great misfortune or the existence of continual stress (Nemeth et al., 2008). Unlike safety, resilience could not be designed merely through presenting further procedures, precautions and barriers — resilience engineering demands constant performance monitoring of a system in respect of how things are done (Hollnagel and Woods, 2006). Resilience engineering is about designing systems that are able to avoid mishaps via anticipation, survive distractions through recovery, and develop through adaptation (Madni and Jackson, 2009). Resilience Engineering (RE) has been promoted as a novel safety management paradigm, harmonious with the complex character of socio-technical systems (Righi et al., 2015). (Hollnagel, 2014) argues that to consider a system to be resilient, it must have the ability to respond, monitor, learn and anticipate, and it demands perception of the way that makes the four abilities coupled and thus relying on one another.

Resilience engineering symbolises an innovative approach towards safety. Whereas risk management methods rely on observation and error classification and calculation of failure probabilities, resilience engineering research focuses on techniques with which to improve the capability of a system to create robust and flexible operation that is able to monitor and review risk methods, and to utilise resources effectively during disruptions or ongoing operational and economic stresses (Dekker et al., 2008). Failures of a resilience system are not concerned with its breakdown or malfunctioning of normal operation; rather, they illustrate that the system does not have the capacity for adaptation, which is essential in coping with the complexity of the real-world environment (Dekker et al., 2008). Woods (2017) mentions that resilience is the larger ability of how well a system can deal with disruptions and changes which exist outside of the base mechanisms/models, being as adaptive as determined in that system. In order to control a system, it is essential to know what has occurred in the past, what is occurring now and what will occur in the future, in addition to knowing what action should be taken and possessing the required resources for the action (Hollnagel and Woods, 2006); for that it is necessary for a resilient organisation to attain the capability to anticipate, perceive and respond. Several studies have presented definitions, new models and extra enhancement in respect of the resilience engineering approach.

Resilient organisations, groups and individuals are able to identify, adjust and engage in variations, alterations, conflicts, disorders and surprises that could result in a disruptive situation, in the sense that the system is constructed to remain stable; they understand the criticality of adapting and absorbing during the changing event (Rasmussen, 1990, Weick et al., 1999, Sutcliffe and J., 2003). Efficient teamwork should enable rapid reaction to a sudden and unexpected demand during an operation, with the least loss. The crew must then return to the standard operation conditions (Cook and Nemeth, 2006). The resilience method facilitates teamwork, employing with valuable skills necessary for addressing extensive and variable demands to recover from the loss, obstacles, struggles or any other issue that may disturb crew's integrity (Morel et al., 2008).

The resilience concept is different from the traditional safety approach. Hollnagel et al. (2006) states that "*safety is something a system or an organisation does, rather than something a system or an organisation has*", safety does not exist in the absence of threat. In the last decade, major accidents and ensuing analytical conclusions indicate that organisations are required to highlight human and organisational errors by assessing their technical procedures and their abilities (Jackson, 2002, Jackson and Hann, 2004). The promotion of proactive resilience engineering applications, according to Madni and Jackson (2009), can play an essential part (in the operation of systems) because it entails finding the weaknesses in complex systems, thereby highlighting organisational and human operational risks. The resilience engineering approach considers a system failure when it is unable to adapt sufficiently in the face of disturbance or fluctuations in global resources and time. Indeed, the setback or breakdown of an ordinary organisation framework indicates a lack of resilience involvement (A. M. Madni, 2002, Hollnagel et al., 2006, Westrum, 2006, Madni, 2007). The success of a resilience system counts on its ability to monitor the risk of change and to select a suitable action to avoid the possibility of mishap (Madni and Jackson, 2009). The significance of this claim is that individuals and organisations should adopt such a procedure to control changing conditions, allowing them to remain within safety boundaries and continue with their schedule (A. M. Madni, 2002).

The Functional Resonance Analysis Method (FRAM) offers a framework and a technique for systematically describing and assessing functions and performance variability (Woltjer and Hollnagel, 2008). The origins of systemic models date back to control theory (Sheridan, 1992), focusing on the need to base accident analysis on a conception of the functional character of a system, instead of assumptions or hypotheses regarding internal techniques or cause–effect series that are impossible to demonstrate graphically (Hollnagel and Goteman, 2004). The models are based on a resilience engineering method whose purpose is to present a new paradigm to manage complex system safety, which concentrates on understanding system functionality and performance instead of analysing accident causation (De Carvalho, 2011). The FRAM (Hollnagel, 2004) describes socio-technical systems by means of functions that perform instead of how they are designed; it describes the dynamics by displaying nonlinear needs and performance diversity of system functions (Woltjer and Hollnagel, 2008). Each function must now be described using the six relations: input, preconditions, resources, time, control and output.

There have been several attempts to utilise the FRAM to enhance the safety management system. Hollnagel et al. (2008) state that accident analyses of complex critical operation, such as aviation, are often interpreted as the outcome of system setbacks; nonetheless, few approaches can sufficiently be applied to examine the variability combination results of organisational, technical and individual performances that might cause an adverse consequence. The FRAM offers a technique with which to describe these elements and define their interrelationship. Hollnagel et al. (2008) demonstrate the technique of FRAM by examining an extremely publicised flight event: the accident of Comair Airlines in 2006. FRAM analyses provided specifications that were not discovered by NTSB (National Transportation Safety Board) analysis. The results of the NTSB explained that the procedures were not followed by crewmembers, which generated recommendations to reinforce the procedure compliance constraints. FRAM analyses focus on the deficiencies of managing performance as well as controlling sources of performance variability, which include considering the conditions/circumstances during the entire event time, e.g. the lack of information. De Carvalho (2011) developed an accident analysis approach by using the Functional Resonance Analysis Model (FRAM) to analyse mid-air collisions. FRAM application helps to examine the main resilience features of the Air Traffic Management (ATM) system. The analysis of flight monitoring functions demonstrates system constraints include supervision, time, training and equipment that generate variation in system behaviour, producing a need resource imbalance that affects the perceive and control functions during evolving conditions. These deficiencies lead to control and coordination failures and automation shocks. The drawback of the approach is the shortage of quantification outcomes, which would strengthen the analysis results of the model.

Lately, resilience engineering has been given substantial consideration among safety scholars and experts, since it introduces a new approach towards safety. Traditional risk management methods depend on past information, accident reporting and risk assessment quantification, and probabilities based on historic data; resilience engineering searches for techniques with which to improve the ability of a system to be resilient in the way it perceives, adapts to and absorbs differences, variations, turbulences, disruptions and shocks (Steen and Aven, 2011). Madni and Jackson (2009) believe that operational systems have become complex, imposing further challenges on risk management. Errors are not always on the part of humans — organisations also play a greater role in creating mishaps. Organisations face several challenges when implementing the resilience engineering principles, e.g. making a decision between production pressures and essential safety, measuring system resilience and defining methods to design such resilience. (Madni and Jackson) adapted a conceptual structure for comprehending and analysing disruptions, and provided principles and heuristics of lessons learned which could be used to design a resilient system. For an organisation to face challenges of complexity, the resilience system must have the abilities of avoiding, absorbing, adapting to and recovering from disruptions. The model for resilience engineering relies on four critical columns: indexed disruptions, system attributes, methods of probabilistic risk, and resilience metrics. The limitation of this adaptation is the lack of applications or case studies which help to validate the developer's claims.

Shirali et al. (2012) contend that safety matters in a chemical plant are definitely crucial, as failure in control could produce a catastrophic result; thus, a risk assessment method is required to prevent mishaps, survive disorder through recovery, and deal with disruptive occasions through adaptation. (Shirali et al.) adapted the study to analyse hindrances in the procedure of designing resilience engineering in a chemical plant. The main data were gathered via conducting site observations and setting personal interviews. The research outcomes pointed out the key challenges of implementing RE: absence of RE experience, ambiguousness of the RE level, selecting production demand on safety, absence of reporting schemes, religious issues, outdated procedures and manuals, lack of feedback, and economic difficulties. Dinh et al. (2012) state that the resilience notion is not completely adopted in the industrial operation domain, in spite of its possible strong advantages related to safety management, which is as a result of obstacles in the application. (Dinh et al.)developed an approach to present resilience principles and factors to be applied in plant operation. Six principles are introduced into the system: flexibility, early detection, controllability, failure minimisation, effects limitation of, and organisational controls. Moreover, it presents five key contributing factors: designing, detection potential, response plan to emergency, human factor, and safety management. The principles and contributing factors are used to evaluate the resilience of process operation or a design.

Shirali et al. (2013) believe that even though the theory of resilience engineering has been discussed scientifically in several studies, there are merely limited researches addressing RE measurements through quantitative techniques. (Shirali et al.) adapted a new model of RE quantitative assessment. It selected six resilience indicators: commitment of highest management, learning environment, just culture, awareness and opacity, readiness, and flexibility. The relevant information was gathered by using 11 units of a process industry in a questionnaire. The information was analysed using the Principal Component Analysis (PCA) technique. The examination results determined the score of resilience indicators and process units. The outcome indicated poor indicators and the process units, which assist management in realising the existing weaknesses and deficiencies of system resilience. The drawback of this study is that the number of process units of the research is small — a large number could verify and validate the resilience model in an efficient way. Azadeh et al. (2014) developed a new model of Integrated Resilience Engineering (IRE) which helps to assess the performance of safety and human resources by focusing on several indicators, including self-organisation, teamwork, redundancy, and fault tolerance. This approach examined IRE performance via analysing the gathered information from questionnaires and a Data Envelopment Analysis (DEA) technique. The outcomes indicated that even though there is a solid, straight correlation among the DEA outcomes in two frameworks, the mean scores of IRE effectiveness are slightly higher than those of the RE model.

Azadeh et al. (2017) adapted the study to examine the reciprocal influences of management and organisational factors and resilience engineering applied in a gas refinery. The assessment indicators of the factors are commitment, learning, awareness, flexibility, self-organisation, redundancy, organisation and management. Different questionnaires were distributed based on the factors and indicators, which were analysed using a Data Envelopment Analysis (DEA) approach. The impact of managerial and organisational factors on RE was mainly calculated using Decision-Making Units (DMUs) to indicate the number and average of the efficiency scores. The results indicated that the organisational factor has a greater impact on resilience engineering than the management factor has. The outcomes also demonstrated that learning and flexibility indicators have the highest impact on management and organisational factors (Azadeh et al., 2017). The drawback of these studies is that they are based on questionnaires and interviews, which could be affected by people’s experience and subjectivity.

Reading about the resilience engineering concept provides a great, optimistic feeling about the benefits of the approach which can help to improve the socio-technical system, resulting in enhancement and efficiency of safety performance. Nevertheless, it is clear that the mission of designing resilience in safety management systems is a challenging task, and needs a significant paradigm shift, including measuring the application as well as considering the huge difference in safety management among the originations (Lofquist, 2017).

3.12. Key findings of the Critical Review

Maritime accident

Maritime transportation has witnessed continuous improvement in its safety record during the past decades; nonetheless, mishaps continue to occur. The European Maritime Safety Agency (EMSA) (2017) recorded 16,539 ship accidents between 2011 and 2016. Regardless of advanced developments in ship technology and the execution of safety procedures, maritime accidents remain the primary concern of international shipping. Several efforts are made by maritime safety researchers to understand the gaps causing the continuing occurrence of such events, yet ship accidents have not decreased to the anticipated level.

Risk assessment

Several major works have accomplished improving maritime safety; however, concerns remain high regarding enhancing operational reliability, which requires more research on the safety of the operation in order to attain key performance indicators in respect of international shipping transportation. The majority of existing risk approaches to shipping risk analysis concentrate on providing risk figures instead of showing existing background information of a system. The absence of background information on the fundamental reasons of a system or the inadequate demonstration of existing background information causes less confidence in the application of risk models.

Human Factor

The human factor has become the main cause of ship accidents in recent years. Human factor studies require further effort regarding the subject of maritime safety management, since researchers neglect the recessive factors, e.g. the preconditions of unsafe behaviour, unsafe observation and organisational deficiencies, rendering the reliability of management measures weak.

The shipping business is a very international and multicultural industry, meaning seafarers inherit multinational character traits. Crews which are multicultural and lack a common language or culture can increase risk onboard.

Seagoing job is a highly demanding career that exists in one of the riskiest work conditions, which are unpredictable and demanding, promoting a high potential for accidents. Other causes such as excessive workloads in navigational working conditions, crew shortages, and a lack of situational awareness can lessen upgrade system efficiency when under time pressure.

The differentiation between senior and junior officers (Power distance) can lower the crew's understanding of safety, demonstrating that safety culture ethics and the existing safety climate are misaligned.

There is difficulty in the understanding and comprehension of any means available for OOW and for recognising the strategies that leads to each of the choices especially in complex and busy waterways. How can humans be quick and effective decision makers for creating multiple sequence actions to prevent multiple ship collisions?

Piloting operations exhibit deficiencies including the understanding of regulations, economic pressures, accident reporting systems, training, and a lack of resource management on the bridge.

Bridge Technology

Bridge technology is designed to reduce the repetition of human activity has decreased the number of ship's crew, generates a stressful working environment via boosting of the mental demands and workload of the operator. In some accidents, technological information can be misinterpreted by the operator through a lack of judgement. They believe that the navigation systems on a ship are becoming increasingly complex as technology progresses, which may alter the experience, knowledge, and planning which are needed when navigating large vessels. Further, no systematic methods exist which can identify design flaws and training demands of innovation in technologies related to shipping.

The AIS demonstrates poor performance and information transmission, as several factors can lead to entering the wrong system information manually regarding ship and voyage data, officers do not check transmitted information cause incorrect information sent to nearby ships, the interference of transmissions when ships are close to each other, and a limited database.

Developments in ship automation have transformed the duties of the OOW so that it has increased mental workload and is more about monitoring tasks. Maritime transportation has a challenge to face because of the shortage of seagoing people, aside from the rapid development of onboard technology, which requires the crew to develop skills associated with the technology. Thus, more research is needed in the bridge resources management area.

This technology also lacks feedback, interface mode confusion, excess information, and high care requirements. Using the ECDIS instead of paper charts may affect safety and operational performance through mental underload by reducing the operator's focus as they have fewer tasks in hand, thus preventing the navigator from an immediate response should there be a sudden risk. The review indicates bridge navigation using the ECDIS significantly enhanced course-keeping quality; nevertheless, communication amongst the bridge team decreased.

Simulator Training

Bridge operations requires several simultaneous cognitive tasks which require a high level of situational awareness states and correct judgement, which may fail and lead to a collision. Human error analysis requires more than traditional techniques which can be improved by using the maritime simulator. Maritime cadets who were given decision-making training did not develop a capacity which helped them examine the complex situation. Simulator experiment outcomes showed students could not manage such circumstances or even remember the key elements learned in class. The maritime education and training institute needs to produce educational tools to give cadets the capability to quickly and accurately examine situations, so that they can take the appropriate action. Recommendations include replacing the long onboard training with an intensive training programme in maritime simulators to replicate similar critical situations in a safe environment.

Barrier Management

The outcomes of the review indicated a number of challenges of this system, such as terminology, integration through analyses and control, and application in operation, which need additional research that might intend to close the gap between theoretical models and practical demand. During working time, barriers could start to degrade at various rates, and devolution begins to escalate facility threats and some barrier deficiencies could increase danger significantly. Traditional barrier management tools have shortage of quantification measurements. The general limitation of the barrier management approach is that the concept of the application relies on a cause-and-effect process; besides, the theory assumes that an accident may occur as a result of inline causes that take place one after another.

3.13. Conclusion

In this section, a literature review of earlier research was provided. It covers a range of papers from past years focusing on important developments in respect of the ship's bridge, operation and safety which are related to the main research area of the PhD thesis. The literature review takes the readers from the initiation of extreme automation of the bridge to the optimisation of training and procedures. Human factors and their related errors are the key elements which have motivated many researchers to develop their own approaches in this area, including several maritime simulation experiments. Development of the technology was explained and the related difficulties were defined. The increasing amount of technology and automation, combined with human and procedural factors, has created a complex maritime system that causes several accidents every year, requiring consideration of safety culture and socio-technical systems. This chapter discusses the assessment of several researchers and how they developed measurements. The developed models were explained as clearly as possible, and the results of all of the papers and authors' recommendations were summarised. Furthermore, the advantages and disadvantages of each approach were explained.

Chapter 4. Approach Adopted

4.1. Introduction

The introduction of computer software to transport organisations, power plants and hospitals has led to complex systems that have, unfortunately, contributed to accidents and unnecessary tragedies (Hollnagel et al., 2006). Human error is not often recognised as the source of such accidents (Leveson, 2002). Madni and Jackson (2009) suggested that there is a strong belief that such mishaps and failures can be linked to organisational factors generating the circumstances that lead to undesirable consequences. In 2003, organisational factors played a significant role in the Columbia space shuttle disaster (Hollnagel et al., 2007). The continuous quest for better, quicker outcomes and desire for low-cost drives organisations to make choices that affect safety margins, unnoticed by management, dramatically escalate risks (Woods, 2003). It is important to remark that the safety is one of the system assets, originating from the behaviours of complex systems, based on collaborations within subsystems such as automation, organisations and people (Rechtin, 1990). According to Madni and Jackson (2009), investigations into major accidents over the past thirty years and following case studies prove that organisations are frequently required to re-examine and revise their assumptions about their capabilities by addressing technical, human and organisational risk factors on an ongoing basis. Developing different approaches to continually support system operations is essential for managing potential hazards by discovering methods to maintain a balance between safety and accomplishing the work (Madni and Jackson, 2009).

In the maritime industry domain, the analysis of the MAIB accidents reports between 2010 and 2015 illustrated that out of 127 recorded incidents, 56 ship accidents were caused by failures in the navigation bridge. This outcome demonstrates the need to enhance safety standards of the bridge operation. This approach address a new model to barrier management concerning the operation of the navigation bridge system in a context that incorporates the principles of resilience engineering to improve the shipping safety. The framework contains the designing integration of safety elements and resilience abilities, developing application methods and a plan scheme to control and maintain the barriers (Figure 4-1). The model presents four resilience abilities: anticipation, monitoring, learning, and responding. In the end of the model process, the bow-tie model utilised to visualise the barrier system in a productive viewpoint.

The obstacles of this approach are the great quantity of data received during the process especially during the accident analysis which force the implementer to select the relevant information and to be specific when choosing the critical function. Also, not all accidents have same linear route for an event, potentially constraining the implementer to be selective and bring the barrier functions effectively in line to be manageable and applicable. All these difficulties can be overcome by continuous implementation of the model. The advantages of this method are minimising the errors of the bridge team by providing anticipation ability, improve the operation performance via proposed learning environment, improving the monitoring system and the efficiency of the safety planning, increasing the system reliability and maintaining a strong and flexible system to be able to respond during changing conditions.

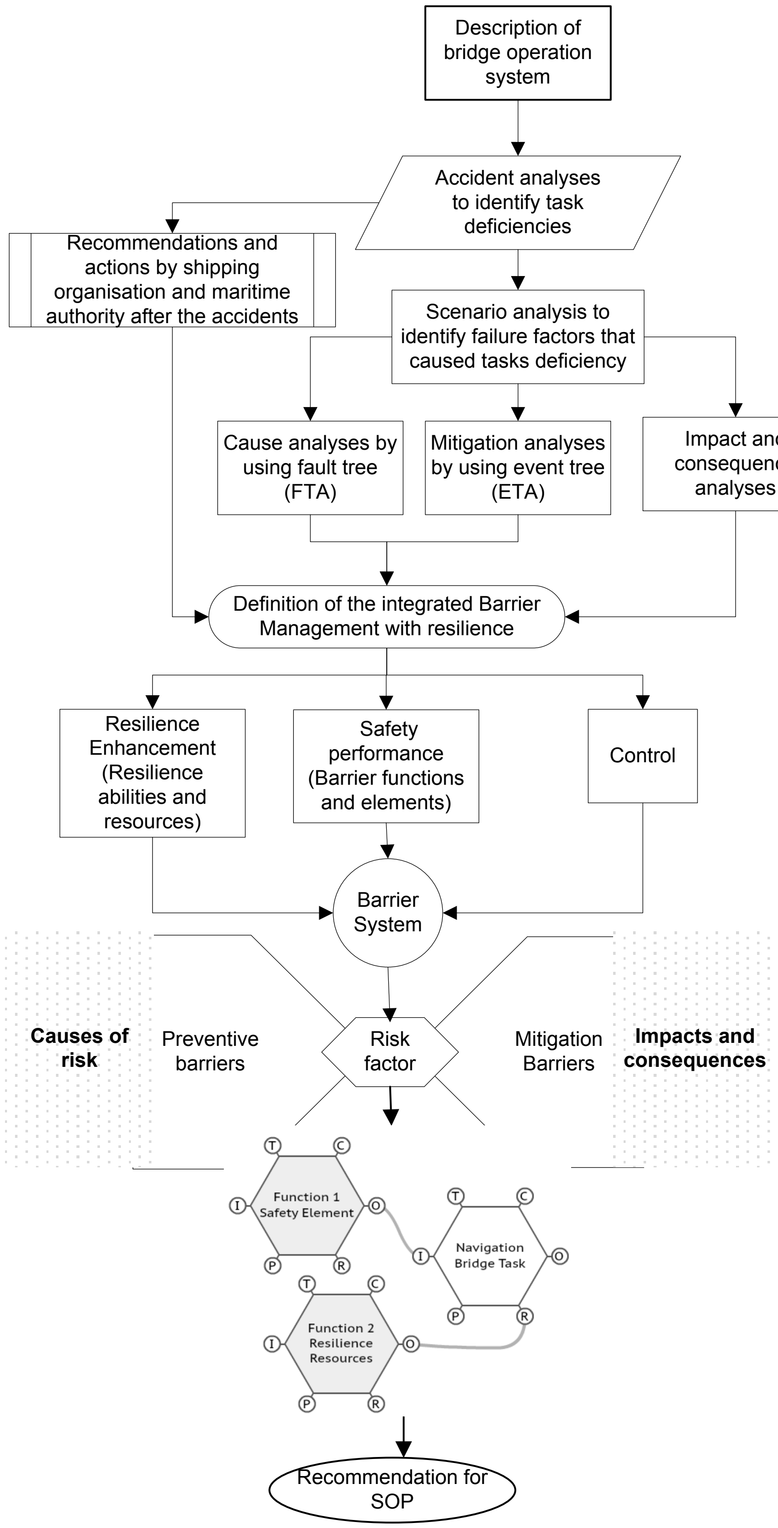


Figure 4-1 the framework of developing a resilient safety system

4.2. Outline of Methodology

Developing resilience abilities in the barrier management system is required a dedicated process that presented in Table 4-1. The model initiates by describing the bridge operation system, which contains the human, technology, procedures, boundaries and limitation. The threats must be identified by analysing the accidents and the risk. The general framework of the barrier management requires definition of barrier need by explaining and setting a barrier function, barrier elements and other correlated terms. The barrier function has two important tasks, which are the prevention of undesirable event and the mitigation after an event takes place. The barrier elements are the resources that support the function, such as technology or procedure. The resilience enhancement attempts to determine four resilience abilities which are anticipation, monitoring, learning and responding. Both the safety performance function and the resilience abilities are established in a parallel perspective and the relation between them are explained. The system ability and limitation will be assessed via a case study in the maritime simulator to measure the quality and the performance of the barriers. The last step is applying the resilience assessment tool to evaluate the system.

Table 4-1 Structure of the approach methods process

Methods process	Discretion
1.Description of bridge operation system	Description of resources, procedure, boundaries and limitations
2. Risks analyses of navigation bridge operation	Identify bridge operation hazards that may lead to incidents by analysing previous accidents and applying risk analysis of normal operation
3.Build risk scenarios	Perform Causing analysis by using the fault tree (FTA) and mitigation analysis by using the event tree (ETA)
4. Define the system of integrated barrier management with resilience	Planning solution for the risks, and select critical function (Safety performance and resilience enhancement)
5. Define Safety Performance	A- barrier functions: 1-Preventive function (capacity error, performance error, lack of communication and unsafe act) 2-Mitigation functions (unsafe act, unnoticed risky cause, an event acceleration and confusion after an event took place B- barrier elements: resources and requirements for each function: technology, procedure and human
6. Define resilience enhancement	A- abilities: 1- Preventive: Anticipation, Monitoring, Learning, and responding 2- Mitigation: Plan /prepare, Absorb , Recover and Adapt B- Resources/ Control: Method, Training & Procedure
7. Develop barrier system by using Bow-tie and FRAM model	Constructing both sides of the bow tie and tying the relations among the functions by applying the functional resonance analysis method (FRAM) model
8-Recommendation	Helps to develop or improve the standard operating procedures (sop) , and suggest training
9- Case study	Evaluate the application of the model by using a full mission maritime simulator. The performance of two groups (A classic procedure and B new procedure) will be assessed.
10. Resilience assessment tool	providing methods to assess the resilience of shipping organisations that helps to monitor, maintain and update the barrier system.

4.2.1 Bridge Operation Description

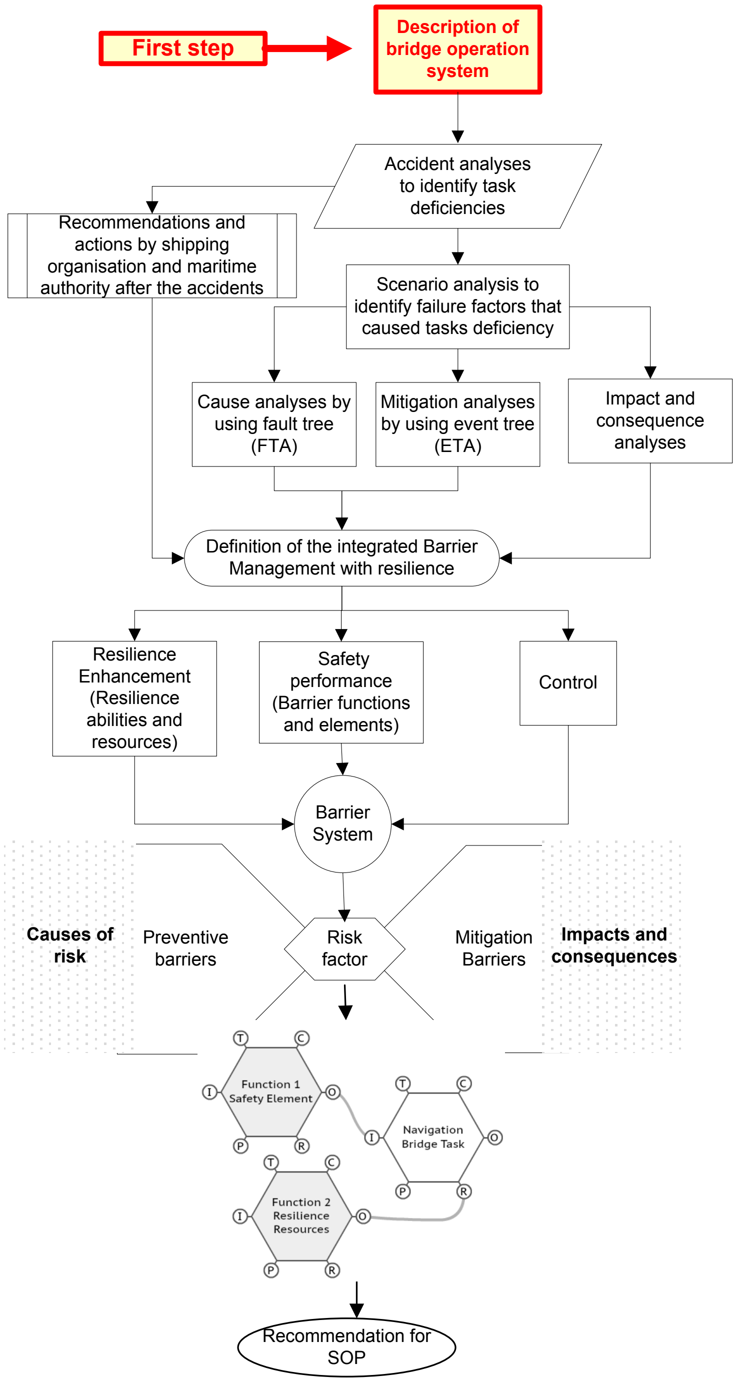


Figure 4-2 indicate the first step of the resilient safety system framework

Figure 4-2 indicates the first step in the method, which requires a description of the navigation bridge resources, procedures, boundaries and limitations. The major mission of a navigation bridge, which should be accomplished by the ship's crew, is to operate the ship safely and transport cargo on time and in a perfect state. The navigation bridge operating environment includes a knowledgeable and skilful navigation team who depend on sophisticated technology that is regulated by a safety management system. To understand how resilience can perform in a system, or how it can improve, the elements of the system must be analysed. Generally, the bridge operating system is divided into human, procedural and technological resources (Figure 4-3).

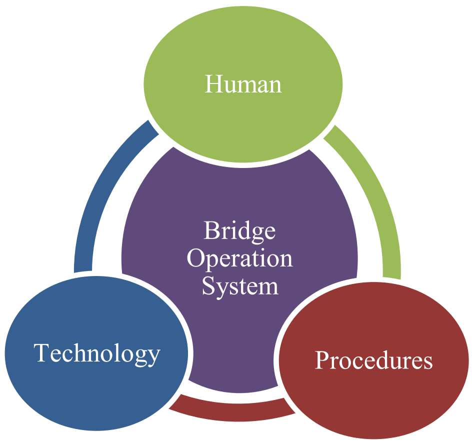


Figure 4-3 Elements of bridge operation system

The human element comprises all humans who are working on the bridge. The procedural element concerns the bridge administration that controls the operations, governed by the ISM code that provides goals and recommendations to be followed by shipping companies so as to develop a safety management system (SMS) on their ships. The technological element is the third element upon which the operational system of the bridge counts in order to provide navigation efficiency and safety, which accomplishes several tasks, such as navigation, weather forecasting, communication, etc., creating an effective operational environment.

4.2.2 Risk Analyses of Navigation Bridge Operation

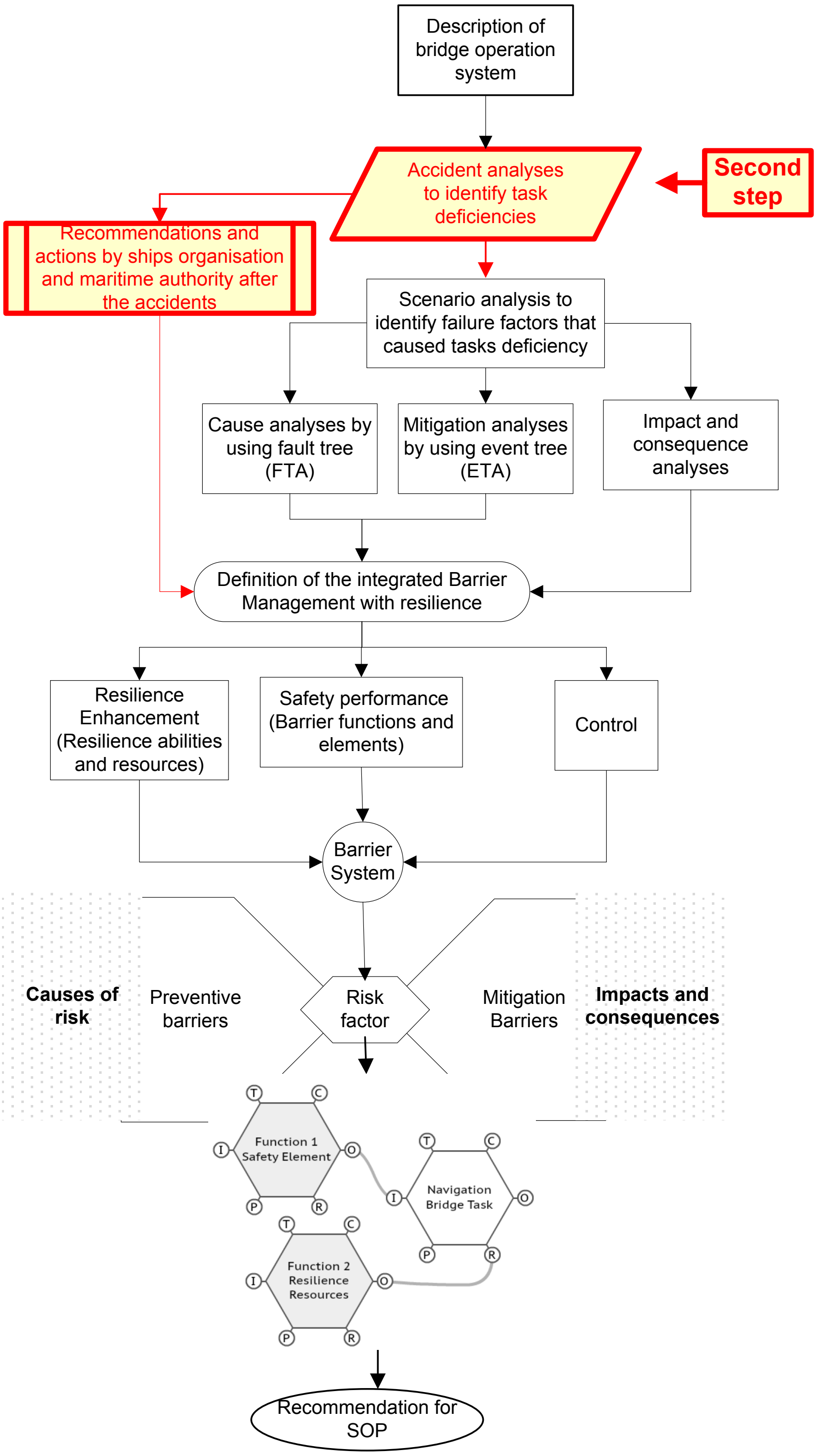


Figure 4-4 indicate the second step of the resilient safety system framework

Figure 4-4 indicates the second step of the methodology, which requires analyses of previous accidents in order to identify the risks that lead the task failures. Shipping companies should continue working to understand bridge operation risks, since it helps to control such hazards. Bridge threats can be identified using two methods: accident analysis and risk analysis. In our model, risk can occur when a bridge team member fails to perform a bridge operation task (Figure 4-5). The task might go wrong because of sub-factors, which are actions or behaviours from one of the bridge team that influence the performance of the operational tasks in a way that places the ship at risk of accident.

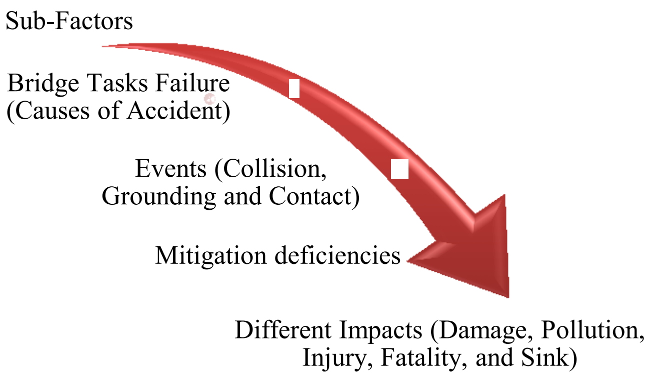


Figure 4-5 Failure escalation of bridge operation

The MAIB (Marine Accident Investigation Branch) records are significant tools for the evaluation of the maritime industry safety, which is harnessed to examine the mishap scenarios to find the bridge task failure (cause of accident). The structure of examining the MAIB accident reports was as the following:

1- It focused on the accidents that occurred because of a failure during bridge (navigation) operation. The source of the accident analyses is the result of examining the MAIB reports, which cover the UK ships accident including the accidents in the British water.

2- Identify the failed tasks (function) that lead to the operation (navigation) deficiencies. This step is important for the resilience performance analyses, which are focus in the functions performance and their integration together.

3- Identify the sub-factors that affect the bridge (navigation) tasks which are could take different form of human error, technology negligent and organisation violation. It is important to understand the internal influences which help to provide solution and suggest resources to the safety management to prevent the risk.
4- Organising and terming the sub-factors according to the Taxonomy that developed by the Seahorse project.
5- Recognise the impact of the deficiencies which help the research to define the severity and the form of the events.
6- Identify the mitigation elements that helps to reduce or diminish the critical condition after the operation (navigation) task are failed.
7- Find the solutions and recommendations that suggested after the accident by the experts, maritime organisation, and maritime authority. It helps for constructing the solutions and selecting the required resources to improve the safety and resilience of the bridge operation.

4.2.3 Build Risk Scenarios

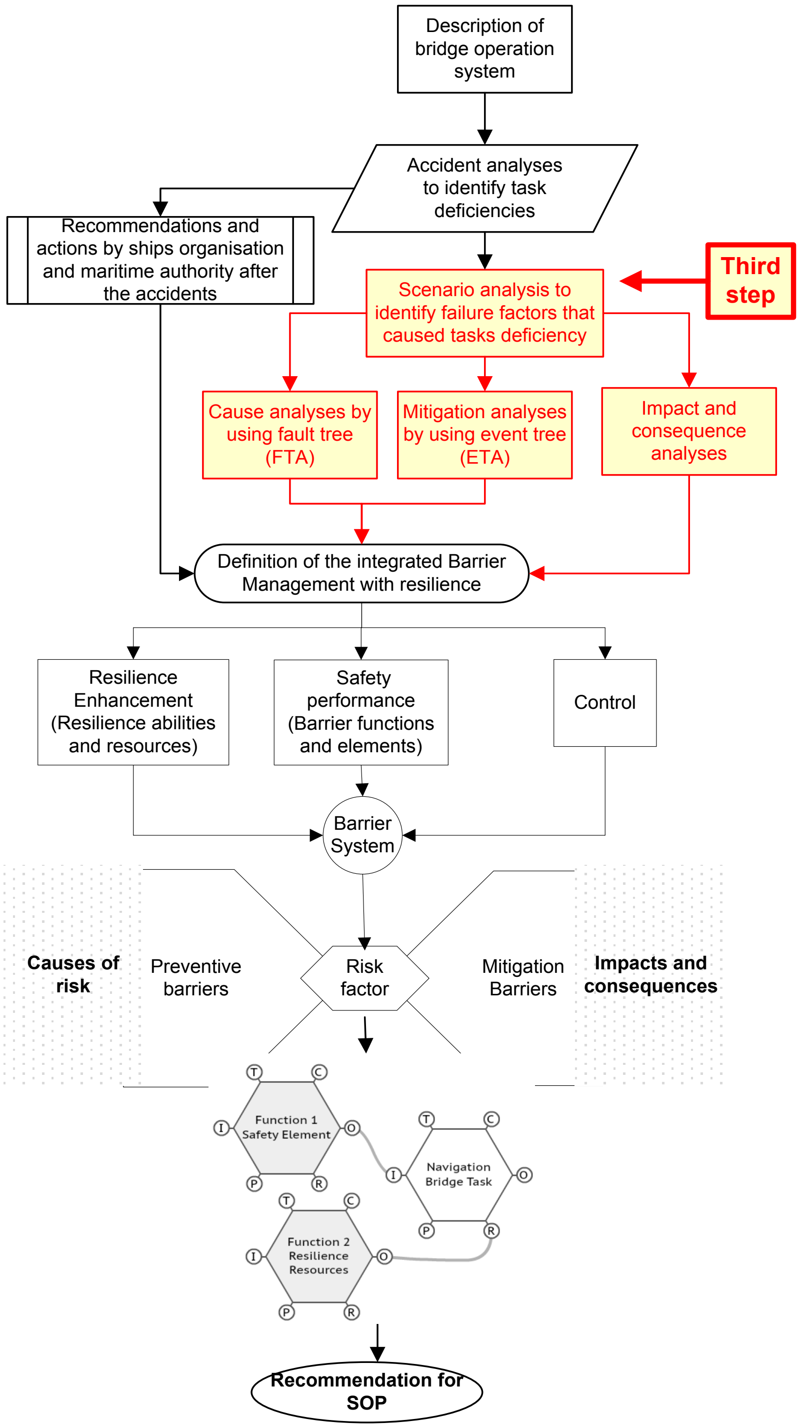


Figure 4-6 indicate the third step of the resilient safety system framework

The intention of this step (Figure 4-6) is to connect the fault tree analysis with the event tree analysis on a common platform in order to represent both sides of the bow tie so as to show the scenario of the top event between accident causes and mitigation (Figure 4-7). On the left-hand side of the bow tie is the fault tree analysis, which plays a major role in examining the potential causes that lead to the top event. On the right-hand side, the event tree analysis shows the consequences after the top event has occurred, and ends up with the impact. Ferdous et al. (2012) mention that FTA and ETA are firmly developed methods that exclusively analyse risk and safety via conducting a qualitative examination of threat and a calculation of quantitative estimation of probability analyses for undesired events. This approach helps to identify and validate the preventative and mitigating barriers.

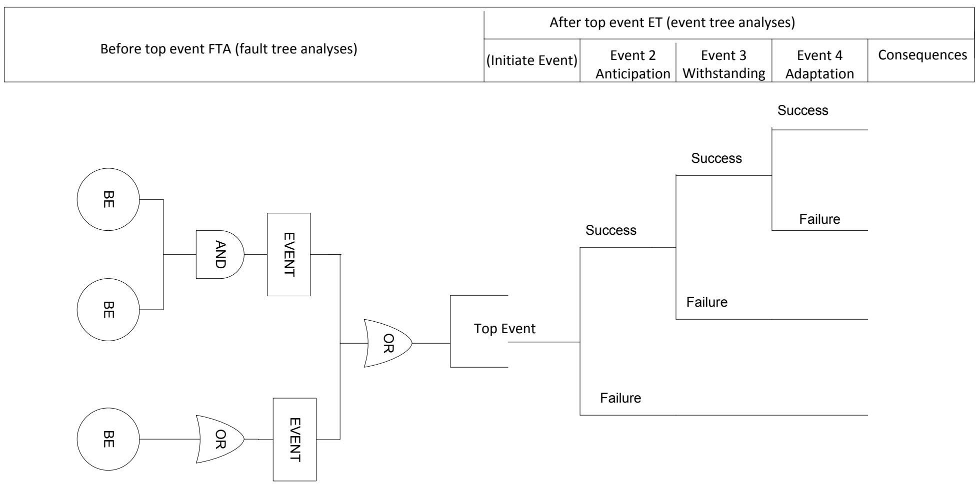


Figure 4-7 Bow-tie Illustration include FTA and ETA

4.1. Fault Tree

Ericson (2015) states that fault tree analysis (FTA) is a system analysis method which helps to obtain the root causes and determine the likelihood of an undesired event. He adds that FTA is used to assess large, complex, dynamic systems with the intention to perceive and avoid possible harm. The method contains a logical and graphical framework showing the potential development from the basic event to the undesired event. The graphical symbol of the fault tree analysis starts with the basic events and develops different logic gates representing the accident conditions, and ends up with the top event (undesired event) as presents in Figure 4-8. All graphical samples are able to be translated into a mathematical number that calculates the probabilities of failure occurrence.

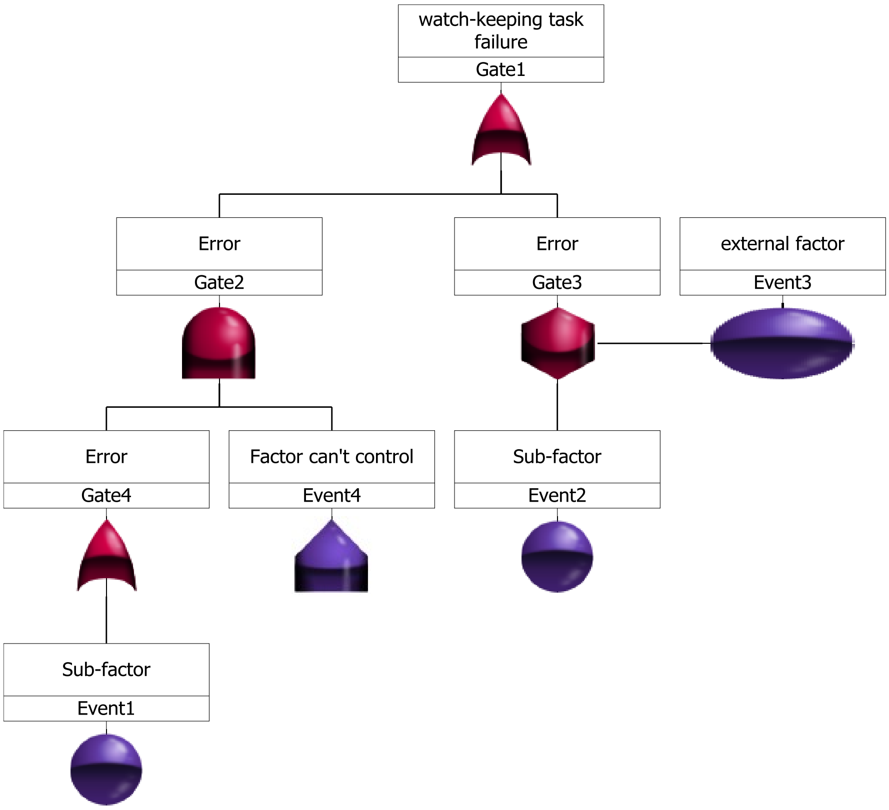


Figure 4-8 FTA generic outline

4.2. Event Tree

Event Tree Analysis (ETA) is an analysis method for recognising and assessing the sequence of events in a possible accident scenario after the occurrence of an initiating event (Ericson, 2015). It helps to identify if the initiating event could be controlled by the safety system or if it would progress into a critical accident. ETA is able to produce various potential results. It could demonstrate qualitative and quantitative results. Mokhtari et al. (2011) state that event tree qualitative analysis is able to define the possible consequent events following an initiating event taking place, while quantitative analysis could calculate the probability of the event outcome. Figure 4-9 presents the Event Tree generic framework.

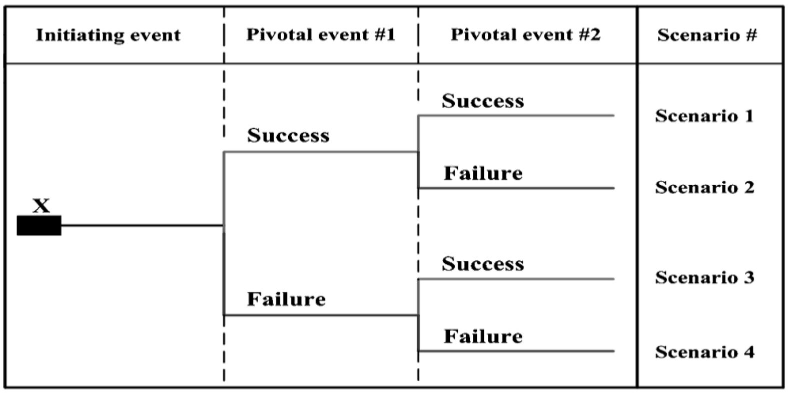


Figure 4-9 Event tree generic gramework (Abdollahzadeh and Rastgoo, 2015)

Ericson (2015) believes that event tree analysis methodology has the ability to shape a whole system, with analysis covering subsystems, installation, components, IT systems, regulations, environments, and human error. Several different industries successfully apply the ETA technique to their systems, e.g. nuclear plants, aviation, space shuttles, and chemical plants. Using this method in the early stages of designing the system helps to avoid the huge cost of mishap occurrence after completing the construction. The Event Tree Analysis (ETA) method recognises and assesses the possible mitigation sequence of the different impacts of the event scenario. It identified various potential results and solutions after the failure of the bridge tasks took place.

4.2.1 Definition of the Integrated Barrier Management with Resilience

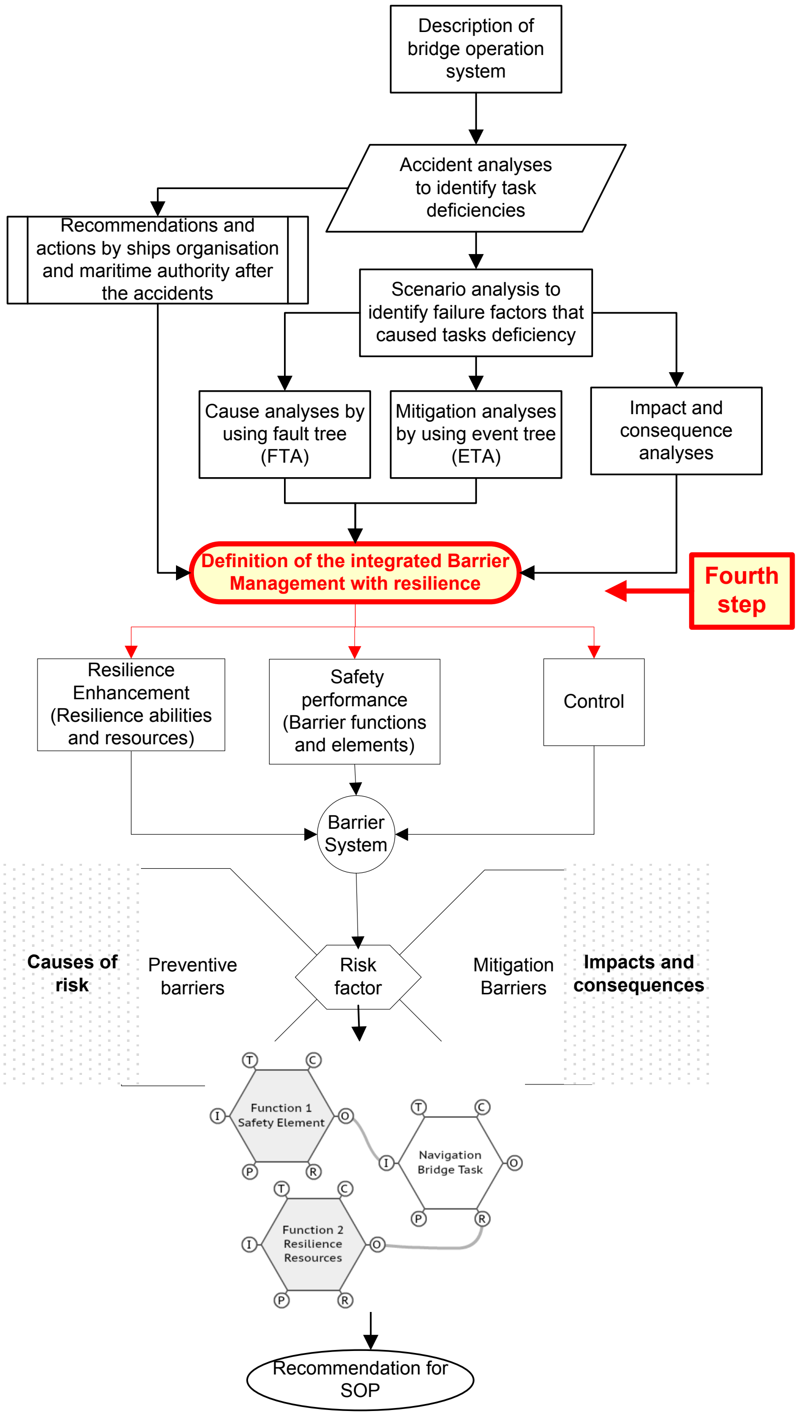


Figure 4-10 indicate the fourth step of the resilient safety system framework

The barrier management domain is continually evolving at a rapid pace, which makes it difficult to obtain an outstanding method, since each organisation develops its own approach (Øie et al., 2014). Figure 4-10 indicate the fourth step of the resilient safety system framework which aims to define the integrated barrier management with resilience principle in relation to the operation of the navigation bridge system. The work process includes defining safety performance and resilience enhancement. Safety performance includes barrier purposes, types, functions and elements. Resilience enhancement contains resilience ability, resources and control. All of these terms are discussed below. The elements and the resources will integrated together in one Bowtie framework to demonstrate the barrier management system.

The purpose of this step is defining the broad outline of the integrated barrier management with resilience system. The presented approach is a novel model which required extra work than the normal barrier management because of the resilience integrating. This method develops new application to enhance the resilience of the navigation bridge operation. The failure tasks were identified via accident analyses of events that occurred because of failures took place in ships navigation bridge. From the results of previous step the risk scenarios is assembled by using the FTA and ETA to collect the errors that lead to the task failure and initiated by the sub-factor. The defined failure tasks are considered as critical functions that must be controlled by the integrated barrier management with resilience system. The model includes two sides, first one deal with the safety performance and the second deal with reliance enhancement. The safety performance focuses on the cause and effect aspect of the system which relies on inline process of prevention and mitigation functions and elements. The other side of the tool provide a technique to enhance the resilience of the bridge operation by introducing the resilience abilities and resources to the navigation tasks. The result of the process presents safety elements and resilience resources for building a bow-tie framework and the FRAM model.

Barrier management's role is to ensure that an operational system is continuously operating in a safe manner and that the designed barriers are effective and robust. The barrier management method must involve and become part of the safety system. A shipping organisation has the responsibility of building a barrier management system that includes creating and sustaining barriers so that any hazards encountered can be managed through preventing an accident from taking place or by reducing the accident impact. The barrier takes many forms, such as technical, operational and organisational barriers in a single or combination mode, in diminishing the possibility of a particular error, risk or mishap occurring, or in restricting its damage (PSA, 2013).

A barrier refers to standards established by a specific goal to prevent a risk from being reached, or to mitigate the consequences of a dangerous situation (Øie et al., 2014). The barrier element can comprise technical, operational or organisational standards or solutions that play a role in performing a barrier function (PSA, 2013). There are two barrier elements - technical and operational (or organisational) - which solely or collectively perform single or several barrier tasks (Øie et al., 2014). The barriers require beneficial design, control, monitoring and maintenance so as to perform as intended. According to Øie et al. (2014) the Swiss cheese model illustrates the management barrier strategy:

- Every barrier in the system should block risks from release
- In the case of the failure of one barrier, the following should become active
- Each barrier should be as independent as possible from others
- The barriers should have the ability to diminish as much danger as possible
- Single failure should not cause a major accident by breaking all barriers
- Barrier enforcement should contain as few and as small holes as possible.

4.2.2 Definition of Barrier Safety performance (Functions and Elements)

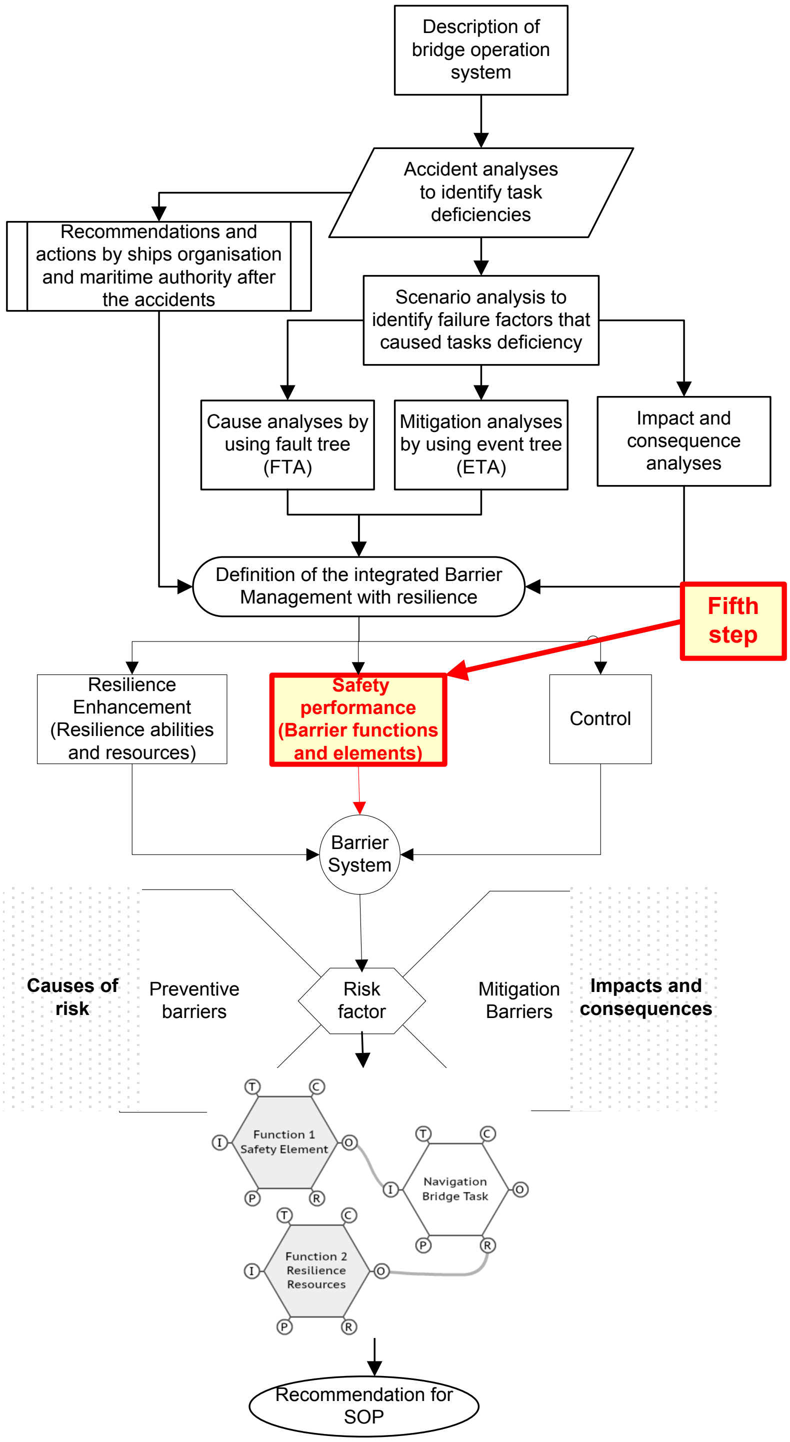


Figure 4-11 indicate the fifth step of the resilient safety system framework

Figure 4-11 indicate the fifth step of the resilient safety system framework which focus on defining the Safety performance includes barrier types, functions and elements, which are controlled by barrier management. The main task of barrier management is to guarantee that an operational system is continuously functioning as planned and that the designed barriers are efficient and robust. The concept of barriers requires clarification from the organisation by establishing definitions of barrier functions, elements, and other associated terms (Øie et al., 2014). A shipping company should be responsible for building a barrier management framework, that includes establishing and maintaining barriers so that any risk which appears can be managed and prevented from becoming an accident; if it does occur, its impact could be reduced. The barrier takes various forms, such as technical, operational and organisational elements that are in a single or integration mode, in reducing the probability of a particular error, hazard or accident happening, or in limiting its damage (PSA, 2013).

Table 4-2 The Safety Performance Features

Safety Performance		
Type	**Barriers function**	**Barrier elements**
Preventative	• Prevent capacity error • Prevent performance error • Prevent lack of communication • Prevent unsafe act	Human or Technical or Procedure
Mitigative	• Mitigate unsafe act • Mitigate from unnoticed risky cause • Mitigate from an event acceleration • Mitigate from confusion after an event took place	Human or Technical or Procedure

The barrier function is the responsibility or duty of a barrier in the system, e.g. preventing leakage or fire, decreasing the flame extent, and ensuring sufficient evacuation (PSA, 2013). Barriers have two major functions: prevention of an undesirable event and mitigation after an event. Table 4-2 demonstrates the Safety Performance features. The approach concerns designing preventative barriers that encompass the principles of resilience engineering. From the accident analyses an accident deficiency pattern is recognised, i.e. risk might develop from four threats. The aspects which may occur before an accident are capacity error, performance error, a lack of communication, and an unsafe act, and the other threats that could take place after an accident are an unsafe act, missing a risky cause, event acceleration, and confusion after an event has taken place. The mitigation function exists within the normal barrier management functions, but will be supported by the resilience abilities so as to increase the efficiency of the system. Barrier elements are the resources that facilitate the function of a barrier. The resources can take several forms, such as human, technological and procedural. The barrier elements could perform as an individual resource or be combined with other elements. The elements are developed from: recommendation of maritime authority after the accidents, action done by shipping organisation after events, and best practise of navigation that recommended by maritime agencies. The details of the functions and the elements must consider the limit of the documentation.

4.2.3 Definition of Resilience Enhancement (Abilities, Resources, and Control)

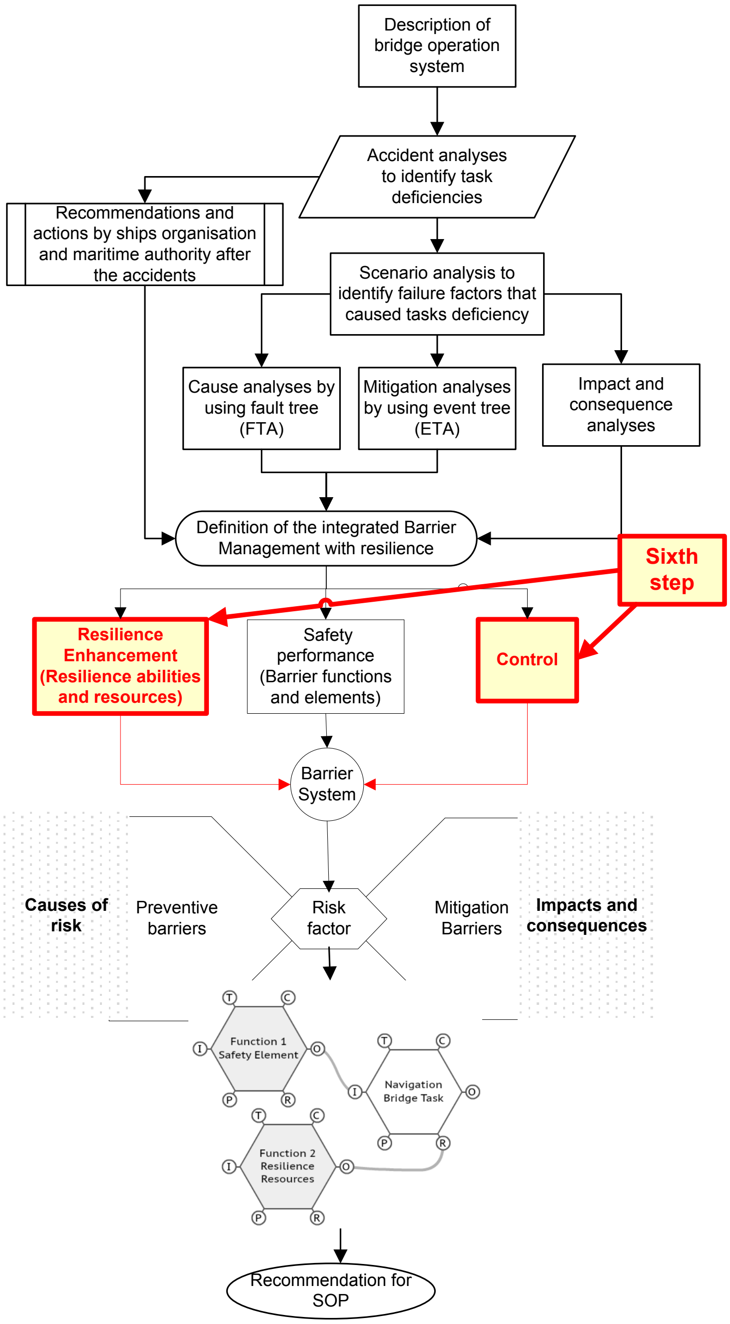


Figure 4-12 indicate the sixth step of the resilient safety system framework

4.3. The Resilience Principles

Figure 4-12 indicate the sixth step of the resilient safety system framework that focuses on identifying the resilience enhancement process that includes resilience abilities, resources and control. Resilience engineering is a proactive method of searching for techniques to improve a system's monitoring capability, identifying threats and establishing suitable exchanges between the demands of safety, operation and finance before any challenge occurs (Leveson, 2002, Hollnagel, 2004, Woods, 2006, Madni and Jackson, 2009). Resilience engineering confers larger perception and depth towards safety than normal safety standards. Failure is not just a malfunction or breakdown of a regular system; it illustrates the inability of a system to adapt sufficiently in the face of disturbance and changes due to the limitation of resources and time in the real market (A. M. Madni, 2002, Hollnagel et al., 2006, Westrum, 2006, Madni, 2007). Westrum (2006) believes that a resilient system features have the capacity to avoid hazards from taking place, prevent them from becoming worse and recovering from them. The promotion of proactive resilience engineering applications, according to Madni and Jackson (2009), can play an essential part (in the operation of systems) because it entails finding the weaknesses in complex systems, thereby highlighting organisational and human operational risks.

This approach aims to initiate barrier management that includes the resilience engineering principles. This method looks for more innovative barriers than the common management barriers. The traditional management barriers contain inline safety barrier to prevent or mitigate an event that focus on the cause and effect aspect. These barriers are passive that can be barely seen unless there is an emergency condition. The resilience barrier is a proactive and dynamic process of monitoring and adapting relating to the identify threats and define solutions to cope with changing conditions. The resilient barriers encompass resilient abilities which are anticipation, monitoring, learning and responding. Each resilience ability requires allocated resources and methods to control them. Resilience resources and control are the assets that support resilience ability. They could take different forms, such as method, procedure and training. Control concerns the way in which the resources could be applied and managed in the system.

4.4. Resilience Enhancement

The resilience barrier is a proactive and dynamic method of anticipation, monitoring, learning, responding to system threats, and finding solutions to changing situations. Resilience enhancement includes resilience abilities, resources, and control. The main goal is to construct a barrier management system that includes the resilience engineering principles, which are more an innovative barrier than that of common safety. The resilience engineering approach regards a system as failing when it is incapable to adapt adequately in the face of changes or fluctuations in external resources and time. The resilience enhancement features is demonstrated in the Table 4-3.

Table 4-3 The Resilience Enhancement Features

Resilience Enhancement		
Resilience ability	**Resources**	**Control**
Anticipation	Resource to improve the expectation	Method, procedure and training
Monitoring	Define area, element and function required supervision	Method, procedure and training
Learning	Improve the feedback	Method, procedure and training
Responding	Prepare for the required action	Method, procedure and training

Resilience barriers contain resilience abilities: anticipation, monitoring, learning and responding. The anticipation capability concerns identifying the expectation which could affect the operation, such as the lack of education and training. The monitoring skill is that of recognising the area or subject that requires observation. The deficiency of this capacity might occur because of the negligence in utilising alarm technology or observing external traffic. The learning capacity concerns perceiving the conditions which require receiving or understanding information. The responding capability is that of identifying what action should be taken, requiring procedures and knowledge that help the bridge team to perform a safe act. Each resilience ability needs assigned resources and methods so as to control them.

Resources and Control concern the assets that support resilience ability. They could take different forms to enhance or develop the resilience of bridge operation tasks. The control concerns the way in which resources could be applied and managed in the system. It could take different arrangements such method, procedure and training.

4.4.1 Bow Tie Framework and FRAM Model

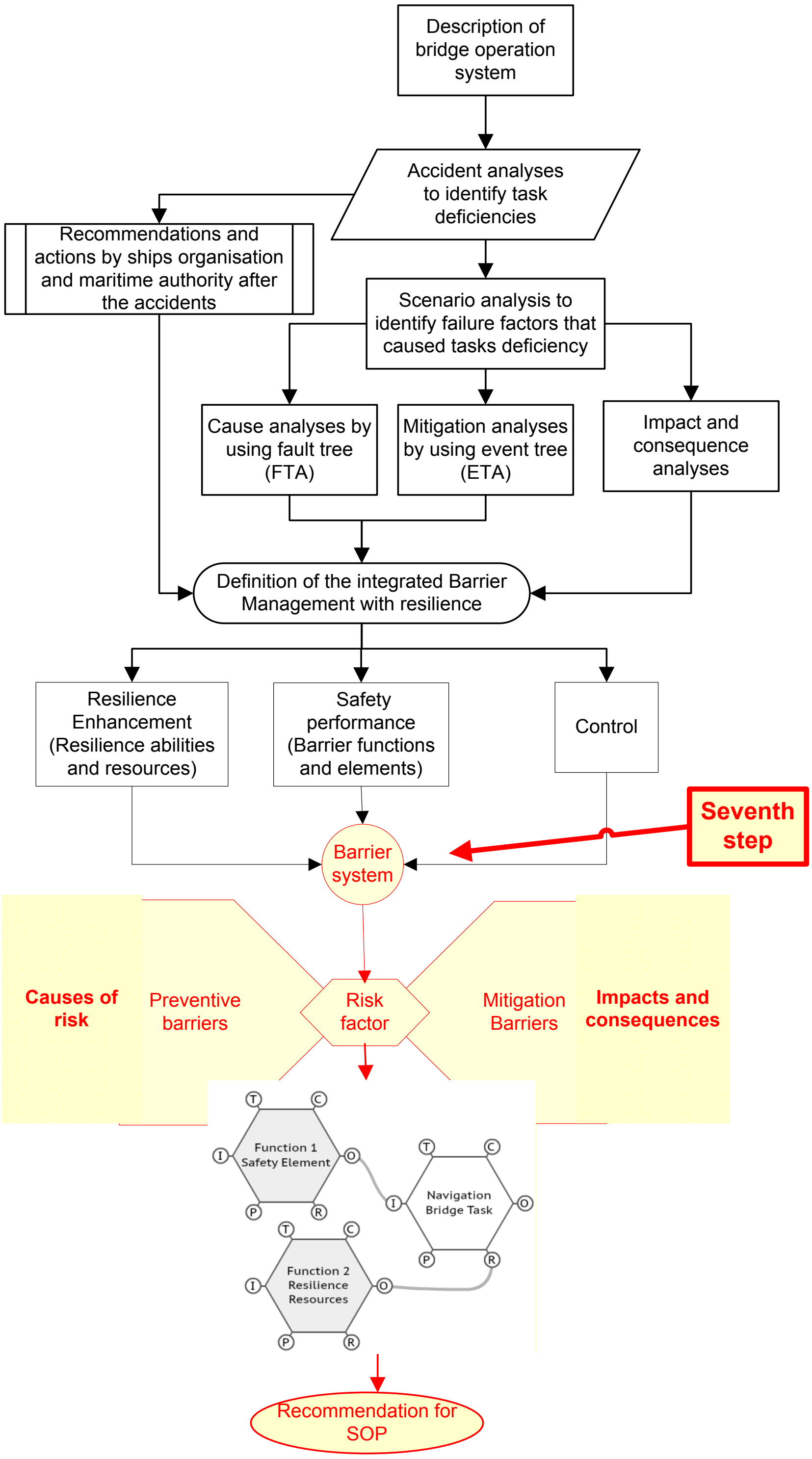


Figure 4-13 indicate the seventh step of the resilient safety system framework

Figure 4-13 indicate the seventh step of the resilient safety system framework which focuses on constructing both sides of the bow tie and tying the relations among the functions by applying the functional resonance analysis method (FRAM) model. The bow tie is a useful tool, which helps to demonstrate the scenario of an event in a simple way that initiates by the causes and end with the impacts and consequences (Figure 4-14). It also illustrates the safety control system that includes the safety elements that required to prevent the risk or to mitigate after the event took place. The bow-tie technique presents a model that is able to link the sub-factors of the task failures with the impacts of the events. The bow tie method was applied because it has the ability to demonstrate all of these factors in one system. Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) represent both sides of the bow tie, illustrating the accident scenario in a single image. On the left-hand side of the bow tie is the fault tree analysis, which plays a significant part in investigating the potential causes that led to the top event. The Event Tree Analysis, on the other side, presented the outcomes after the top event happened, completing with the impacts. The ETA model has identified and assessed possible mitigation progression for the four various impacts of the event scenario. It identified different potential consequences and solutions after the failure of the bridge took place. The advantage of this tool is its ability to communicate with the people who are not safety expert by providing a straightforward a visual clarification of multiple possible of risk scenarios in one image.

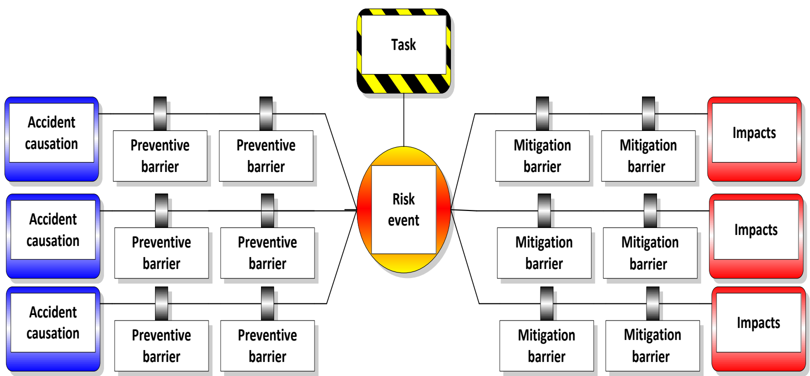


Figure 4-14 Bow-Tie generic diagram

The Functional Resonance Analysis Method (FRAM) (Figure 4-15) delivers a structure and a technique for systematically describing and assessing functions and performance variability (Woltjer and Hollnagel, 2008), which is make this method suitable for this type of analysis. The tool are based on a resilience engineering method whose purpose is to present a new paradigm to manage the safety of complex system, which concentrates on understanding system functionality and performance instead of analysing accident causation (De Carvalho, 2011). The FRAM (Hollnagel, 2004) describes socio-technical systems by means of functions that perform instead of how they are designed; it describes the dynamics by displaying nonlinear needs and performance diversity of system functions (Woltjer and Hollnagel, 2008). Each function must now be described using the six relations: input, preconditions, resources, time, control and output. A free of charge FRAM Model Visualiser software is utilised to perform the functions framework which is from http://www.functionalresonance.com/.

Figure 4-15 Generic outline of Functional Resonance Analysis Method (FRAM) Model

4.5. Case Study and Validation

The application of the method produced solutions to improve the resilience of the navigation performance, which are incorporated into the bridge procedure. The case study aims to validate the implementation of the resilient solutions. The maritime simulator helps to perform the defined scenarios to assess the quality of the bridge team performance. The experiment includes two groups and each bridge team contains 1 Officer of the watch (OOW), 1 Lookout and 1 helmsman. The first team will perform the scenarios by applying the traditional procedures and checklists, which is used by the ships that involved in the accidents that discussed above. The second group implements the developed procedure and checklists. Both teams perform the tasks without knowing the scenarios details, which gives more originality and random action to their behaviours. The experiment includes five different scenarios which are normal navigation, passing agreement, restricted visibility, shallow water effect, and pilot onboard. The resilience abilities (anticipation, monitoring, learning and responding) of the two groups will be assessed according to these indicators: 1- Ability for Judgment, 2- Emergency preparation, 3-Situation awareness, 4-Lookout quality, 5-Alarm Management, 6-Leadership, 7-Passage planning, 8-Familiarisation.

4.6. Resilience Assessment Tool

After implementing the barrier management procedure, the quality of the system should be assessed and maintenance factors can be designed. Examining the barrier performance by investigating its ability, limitation, affordability, time, role and capacity to stand helps to understand the quality. Planning for the sub-system to support the developed barrier demands extra resources or procedures. The organisation must monitor the system and actively look for areas that require improvement or updating. Lastly, the continues surveying and testing by the ship's company help to understand what could degrade the barrier

The aim of this stage of the model is providing methods that help to provide validation of the system. The resilience assessment tool (RAT) was utilised to serve this purpose. The RAT was developed and validate by experts team of SEAHORSE project. The application of the tool show promising results and beneficial capability of assessing the resilience. The application covered the four resilience abilities (anticipation, monitoring, learning and responding) for the multi levels of the function: multi-party, organisation, team and individual.

4.7. Summary

This chapter presents the methodology of the proposed model, which integrates the principles of resilience engineering with the model of barrier management to enhance the operation of the ship's bridge. The main aim of the model is to enhance the safety and reliability of navigation performance of ships by improving the efficiency of the barriers designed for ship bridge operations. It is expected that the application of the approach will demonstrate optimistic improvement. The common barrier management method comprises passive functions and elements with which to prevent or mitigate accidents. The resilience abilities and resources have proactive characters that can advance operational quality. Anticipation, monitoring, learning and responding become part of the system, which perform different roles from the classic barriers.

Chapter 5. First Step of the Model: Description of Bridge Operation System

5.1. Introduction

Marine navigation is an art and science that involves strategic thinking, which includes collecting information, planning a voyage, finding the ship's position, anticipating risks, preparing for emergencies and managing resources (Bowditch, 2002). One of the important functions of bridge operation is good seamanship, which requires safe navigation. This chapter aimed to accomplish the first step of the model, which focuses on describing the bridge operation system. The navigation bridge environment contains three elements which are human, technology and procedure. Each element will be discussed in this chapter.

100 years after the sinking of the Titanic, the shipping industry is working hard to improve navigation safety performance to ensure that the 23 million tonnes of cargo and 55 thousand cruise passengers carried by ships every day are safe (Fields, 2012). Figure 5-1 shows the development of bridge performance and safety since the sinking of the Titanic. The progress involved establishing international cooperation to develop maritime best practices. The maritime industry witnessed the birth of the International Convention for the Safety of Life at Sea (SOLAS) in 1914, which is the first and most important international maritime resolution. Since then, bridge performance has improved in three vital areas, which are procedures, human factors and technology. Bridge procedures became more efficient after establishing the international Safety Management code (ISM). The Convention on the International Regulations for Preventing Collisions at Sea (COLREG) and the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) and other treaties enhance the safety of shipping. Another major technological breakthrough was designing the single-handed or one-man bridge, which provides improved performance whilst reducing the number of people on the bridge. Before that the radar and after that the ECDIS and other technological advancements reduced the number of accidents significantly (Fields, 2012).

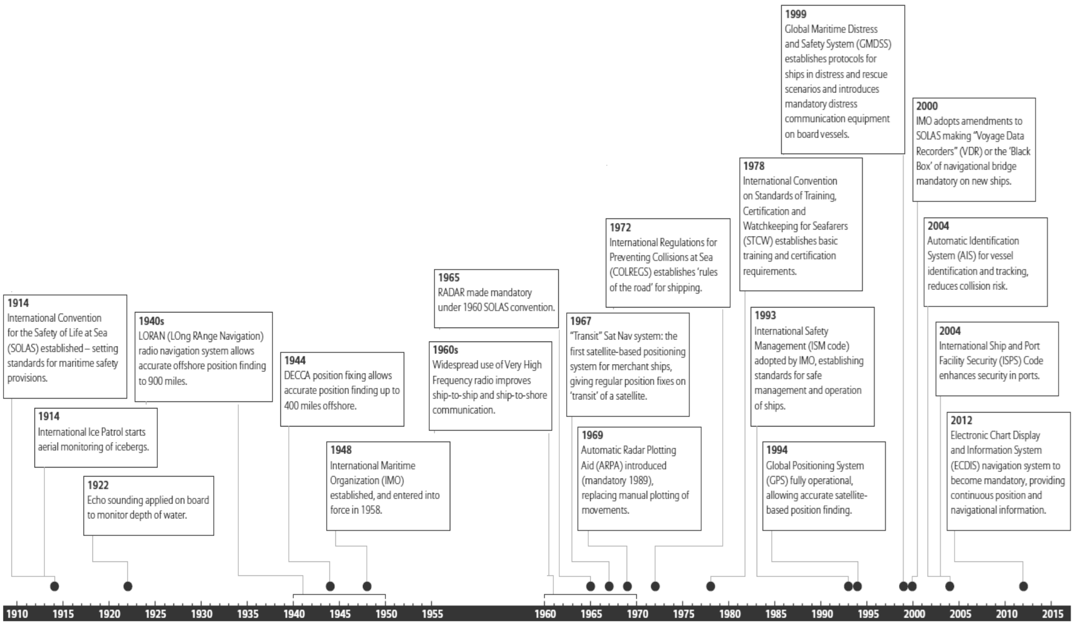


Figure 5-1 The development of bridge performance and safety (Fields, 2012).

The main navigation bridge task performed by the ship's crew is operating the vessel safely and transferring cargo on time and in perfect condition. The ship's working environment contains knowledgeable and skilful crew who rely on sophisticated equipment that is governed by a safety management system. To understand how the resilience is performing in a system, or how can be improved, the functions of the system must be analysed and distributed in relation to their natural purpose. The system will be seen as elements, which can be monitored, improved, increased and mitigated. The bridge operating system is divided into human, procedures and technology resources (Figure 5-2).

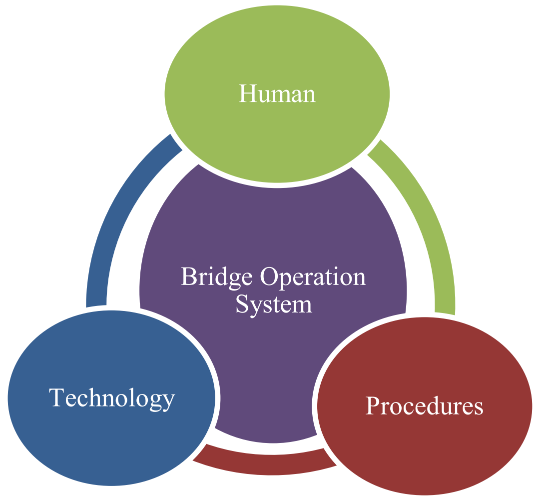


Figure 5-2 Elements of Bridge operation system

5.2. Bridge Procedures

The procedures on the ship's bridge are policy that must be followed by crewmembers to ensure the safe ship operation. It is essential to recognise that both human and technical factors are not the only reasons for the problems (violation of procedure could also cause an accident) (Pomeroy and Jones, 2002). Figure 5-3 demonstrates bridge navigation procedures. Generally, regulations may come from several sources. The International Maritime Organisation (IMO) is the main source of the regulations onboard ships. These were developed in different forms, such as conventions or regulations, to be distributed to the member states. Governments rely on their maritime administrations to enforce the regulations in several locations, such as ports, shipping organisation and onboard ships, which they locate under their area of enforcement. Flag states also require each ship under their flag to follow specific guidelines. Shipping companies are subject to regulations from both maritime administration, port and flag states, which make sure that national and international regulations are applied on their ships. The ship could be inspected from time to time by different authorities, which include flag states, port authorities, classification societies and the company. The crewmembers onboard are governed by specific rankings; at the top is the master after which come the officers and the engineers, and the rating is the last. Each member of crew has specific duties to perform efficiently by following the safety and operation procedures.

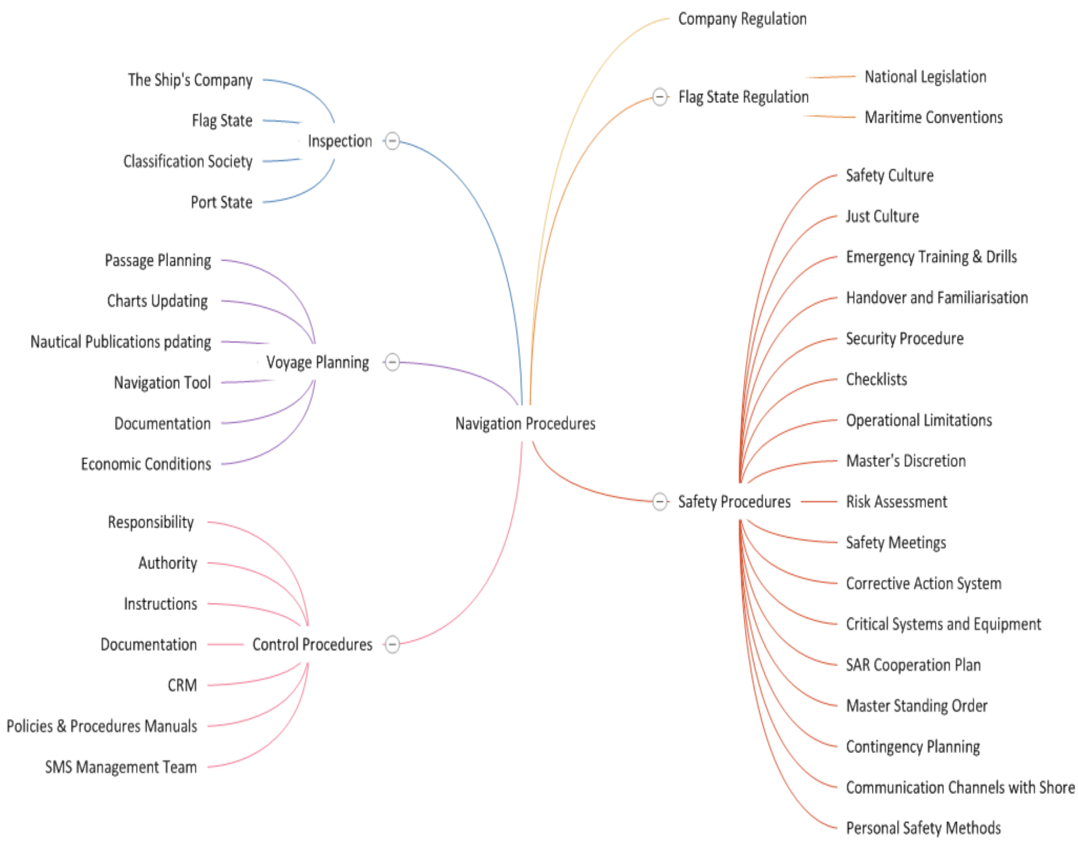


Figure 5-3 ship bridge procedures.

5.2.1 The International Safety Management Code

ICS (1998) state that appropriately establish bridge procedures and the improvement of bridge teamwork are vital for sustaining a safe navigational watch. In December 2000, one of the main IMO resolutions was amended to introduce the International Safety Management (ISM) code, which came into force in July 2002. Since then the code has been amended many times to fulfil its purpose. The beginning of the code was in 1995 when the IMO adopted the code resolution and combined it with Chapter IX in SOLAS. In 1998, it became mandatory, which enforced the maritime administrations of the IMO members to establish safety management standards and documents according to the code guidelines.

The ISM provides a regulated safety culture that significantly improves shipping safety and performance, if properly implemented. Psaraftis (2002) stated that the ISM code is recognised as an instrument of a sequence, which will improve the safety of vessels that are certified to meet its terms. He added that the International Association of Classification Societies (IACS) and its members are likely to play a key part in the application of the ISM code, which supports shipping companies that rely on the code for the quality of the management. The code is intended to offer a global standard for the safe management and operation of ships and to protect the environment from pollution.

The ISM code provides goals and recommendations to be followed by shipping companies to form a safety management system (SMS). All these guidelines must be documented and organised in manuals to be distributed within the company and onboard ships. The documents define the responsibilities and the resources of the maritime operation, including the designated person who has direct access to the onshore management. According to the IMO (2006), successful ISM application relies on the constant commitment, capability, attitudes and enthusiasm of individuals in different positions in the organisation and onboard vessels to which the ISM code applies. It added that the implementation of the code requires the assistance of several devoted professionals, including many financial resources, and the organisation needs to put personnel and resources in place to maintain the practice and to provide continuous development. From time to time, government, company, flag states and port authorities shall examine the safety management system. Governments are responsible for the validation of the SMS, according to the ISM code guidelines, and are required to provide a Certificate of Compliance to the ships under their flag.

5.2.2 Voyage Planning

According to the IMO (1999), passage planning is the framing of a plan for a voyage, along with the constant monitoring of the ship's performance and location during the execution of the plan, which is critical for human safety, ship safety, marine environment protection and effectiveness of navigation. According to the IMO Guidelines for Voyage Planning, passage planning has four stages:

1. The appraisal, which involves gathering as much information as possible relating to the voyage;
2. Planning the details of the entire voyage from berth to berth;
3. Carrying out the voyage plan according to the guidelines; and
4. Monitoring the vessel's progress and position during the voyage

The voyage route must be safe and economically viable, and should contain information regarding the coastal, port arrival and pilotage areas that form the basis for maritime navigation (ICS, 1998). If necessary, the plan should have a margin of flexibility in case a change is required, for instance the pilot could require changes to the plan after he arrives on board the ship. If a change happens, the bridge team must be briefed about any update to the plan. According to the ICS (1998) before the passage planner decides on the route, he must consider the marine environment, the proper charted hydrographic data and navigation aids, including landmarks, the draft and type of cargo, traffic areas, weather forecasts and tide, pilotage area, ships' routeing schemes and ship reporting systems. The navigator must make sure that all the charts and publication are up to date and correct. Finally, the master must check and confirm the plan and verify with the chief engineer that there is sufficient fuel for the voyage. All these measures are important to reduce the chance of accidents or damage to the environment.

5.2.3 Navigation Methods

The marine navigation methods are changing with the times. They have developed in a way that improves the safety and the capabilities of the navigator's task. According to Bowditch (2002), there are different types of navigation:

1- Dead reckoning, which is a method of determining the ship's position using the speed, course and time from the previous position. The external effect such as the wind and current could affect the quality of such navigation.

2- The piloting method, which is useful when the ship is sailing in restricted water or near the coast. It involves continually determining the ship's position by using the geographical location, which can be recognised from the ship. The officer of the watch (OOW) determines the direction of two landmarks and then plots them on the chart; the cross position of the two lines is the ship's position. By repeating this process, the bridge team can see the ship's course on the chart.

3- Celestial navigation (astronavigation) is finding the ship's position by using astronomical objects. The OOW must use a sextant to determine the angle between the celestial bodies and the horizon. This angle can then be used to calculate the line of position (LOP). Nowadays there are several software programs that can help to determine the LOP. Using two or more celestial bodies and performing the calculation to obtain the LOPs, the intersection of these LOPs gives the ship position. This type of navigation relies heavily on the weather and the clearness of the horizon Visibility.
4- Radio navigation, which involves using the radio waves that received by an antenna to determine the ship's position. The method relies on the receiver to determine the broadcast station location, which helps to determine the ship's position through conventional navigation techniques or a variety of electronic devices.
5- Satellite navigation, which uses a satellite radio signal to determine the ship's position. The system includes a GPS receiver for the signal to calculate the time difference and provides the ship's latitude and longitude.

5.2.4 Collision Avoidance

The main bridge navigation task that must be performed by the ship's crew is operating the vessel safely and transferring the cargo on time and in perfect condition. The ship's working environment involves knowledgeable and skilful crew who rely on sophisticated equipment governed by a safety management system. During navigation, the OOW is responsible for following safe procedures and performing the correct actions to ensure the ship avoids any collisions. The OOW must not use the VHF radio for collision avoidance since it could waste valuable time contacting the other ship, especially if he does not recognise the other ship's identity or the communication between the two ships is misunderstood (ICS, 1998).

The risk of ship collision may increase as a result of different elements. Rough weather makes it hard for the OOW to make the correct decision to avoid collision since detecting the action of other ships becomes harder. The restricted visibility also increases the risk of collision, so extra precautions must be taken by following the Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGS) procedures. Each ship requires different manoeuvring procedures because of differences in ship size, speed or operating conditions, such as undertow or technical deficiencies. Generally, the OOW should take early action, determine the ship's position, find the other ship's bearing, maintain a safe speed, keep a good lookout and monitoring, and follow good seamanship procedures and COLREGS.

The COLREGS includes 38 rules. The first three rules provide the application conditions, responsibilities and definitions. Rules 4 to 9 cover visibility, lookout, information verification, safe speed, action to avoid collisions and sailing in narrow channels. One of the most important regulations is number 10, which is recognition of traffic separation schemes for shipping navigation. The remaining rules are ships' conduct in sight of one another and restricted visibility, lights and shapes, sound and light signals, and exemptions.

5.2.5 Vessel Traffic Services

Vessel traffic services (VTS) is a navigation facilitator that operates within the port approach water to manage and monitor shipping traffic as well as to enforce safe navigation and environment protection. The VTS might have a range of functions, as required by IMO regulations, starting with sending messages that contain regular information about the navigation in a certain area, for example, traffic locations or metrological warnings, and the function could involve traffic management in ports or waterways (Imo, 1998). VTS might be mandatory inside the territorial water of a country's coastal waters to ensure that passing ships are in compliance with the local regulations (ICS, 1998). The ICS also adds that the VTS requirements must be included in the passage plan, which are the radio frequencies that should be observed by the bridge navigation team when the ship passes through the VTS territorial water, which could contain warnings or guidance about traffic flow to make sure that the ships are proceeding according to the safety regulations.

According to the SOLAS Convention, the contracting governments should establish VTS services where required, such as areas that contain high shipping traffic or a high degree of risk, by following the IMO guidelines. Some information about the VTS reporting requirements could be stated in the navigation charts, yet the specific information is covered in the sailing directions and the list of radio signals. Usually, ships use VHF radio to communicate with the VTS stations; as such, they must monitor a specific radio channel for navigation warning and they could communicate with the station for advice or to report hazards.

5.2.6 Emergency Procedures

Each shipping organisation provides their ships with a safety management system, which includes emergency procedures. The OOW must follow emergency checklists in the case of an emergency, which could take different forms, such as the initial action to take after an incident such as a collision, grounding or man overboard. It helps OOW to provide immediate actions, which must be performed before the master arrives at the bridge or after taking command. The SOLAS convention demands that all ships perform emergency drills on certain events. The emergency training prepares the crew to counter events and familiarises them with the ship's emergency plans and procedures, where the crew should go during an event, alarm signals and the use of firefighting and lifesaving equipment. The bridge team play an important role during such events since they become the head of the operation that provides commanding orders to the rest of the crew.

5.2.7 Fatigue and Alcohol Consumption

Fatigue onboard a ship involves a person or crew feeling exhausted or tired because of working long hours or changing shifts from day to night, which includes not having sufficient rest period to allow the body or the mind to face the next task. The STCW requires each ship to control fatigue conditions by providing a strict work-rest hours system. The mandatory rest period is at least 10 hours in any 24 hour period. In the case of the watch divided into two periods, then the minimum duration of the rest period between the watches must not be less than 6 hours, which gives a total rest time of not less than 72 hours a week. When it comes to alcohol consumption, the STCW stipulates a blood alcohol level (BAC) of not more than 0.05% or 0.25

mg/l alcohol in the breath. The STCW also gives each state the right to apply limits that stricter than the recommendations. ICAS (1998) believes that humans can make mistakes so it is important to provide monitoring and checking procedures to avoid chains of error evolving.

5.3. Bridge Human Element

The bridge human element covers all people who are working on the ship’s bridge. Minimum standard regulations of safe manning have to be applied to create the appropriate level of safety for each vessel. According to the SOLAS Convention (1974), each Contracting Government is responsible for ensuring that their national ships maintain appropriate minimum safe manning and issuing appropriate documentation, crew safety performance and working language. Individuals are trusted to control and operate the ships, and therefore, it is essential that they are qualified to accomplish their obligations. However, the management and teamwork quality are equally important for the reliability of their performance (ICS, 1998). It is vital to reassess the manning level of the navigation watch during the voyage depending on the operation conditions, sea state or workload (ICS, 1998). The Lloyd's Register highlights the necessity for vessel designers to consider the human element in order to guarantee a reasonable standard of maritime safety (Pomeroy and Jones, 2002). The navigation crew is governed by a specific ranking structure, as shown in Figure 5-4.

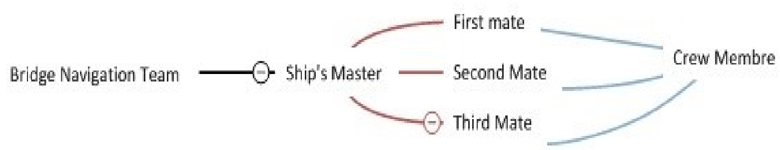


Figure 5-4 the manpower ranking on ship's bridge

The Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) was adopted in 1978, which provides an international standard for the minimum requirements for manning of ships. The Convention sets out standards for the deck section, engine section and radio section, in which it prescribes the minimum age, periods of sea-going service, knowledge demanded for each position and certification requirements. The bridge must be commanded by an officer of the watch (OOW), which is the minimum manning level required by the Imo (1998). The OOW should be supported by a rating person, such as an ordinary seaman (OS) or an able seaman (AB), for lookout or controlling the wheel. When the conditions become critical, the OOW must call the ship's master to support the bridge team. Table 5-1 describes the bridge team duties onboard ship.

Table 5-1 Bridge team duties

Rank	Responsibilities
Master	• The overall command of the ship. • Ensuring the vessel complies with all existing regulations. • Issuing orders related based on his own judgements and International regulations. • Ensuring the seaworthiness of the ship and preparation for the intended voyage. • Responsible for safe navigation. • Supervising all operations on board including cargo. • Ensuring ship and crew safety and environmental protection. • Reporting directly to the home office. • Keeping ship log books. • Ensuring that all the equipment are maintained. • Ensuring the proper manning of the ship.
1st Officer	• Second in command of the vessel. • Head of the deck department on board. • Making sure that mooring and anchoring operations are always performed safely. • Ensuring that all ship's stability calculations are made for the intended voyage. • Watch stander, at sea and in port. • Planning and performing cargo operation. • Participating in safety drills and assists the Safety Officer in crew training.
2nd Officer	• Watch Stander, at sea and in port. • Ensuring the safety and efficiency of navigation instruments and their maintenance. • Correcting all charts, sailing directions and all navigational publications, • Preparing the voyage plan. • Assisting master for preparation port authority and agent documents.
3rd Officer	• Watch Stander, at sea and in port. • Carrying out mooring and anchoring duty. • Maintain lifesaving and firefighting equipment.

Bosun	• Keeping 1st Officer well informed on a daily basis. • Supervising all non-officer deck personal in decks. • Sanitation/maintenance of deck spaces including tools, equipment, associated gear. • Performing mooring and anchoring operations. • Participating in all major safety drills.
Able Seaman/ Ordinary Seaman	• Carrying out the works given by the officers and the Bosun. • Carrying out the jobs (chipping, painting, scraping etc.) to keep vessel in good condition • Watch stander at sea and Security Watch in port. • Participating in lines handling and warping during anchoring/ berthing and departure.

5.3.1 Master

The ship's master is the highest grade certified person on the bridge team as well as its commander. He is fully responsible for the bridge operation efficiency, safety, security and technology, and the ship's compliance with the regulations. The master should be familiar with the bridge equipment, layout and procedures. He must supervise the bridge team and manage all resources, and make sure that the bridge operations, including navigation, are performed in a competent manner. The communication channel between the master and bridge team must be clarified, and the master must attend the bridge during critical conditions and take command if necessary. It is essential to write his requirements in the form of Master's Standing Orders since he is the most senior and most experienced member of the bridge team and the one who knows the abilities and limitations of the ship best. He must make sure that the OOWs are familiar with the ship. It helps to avoid crew misunderstandings and provides rules that are not covered in the safety management system. The night standing orders are in addition to the master's standing orders but come in handwritten form so that his requirements can be applied during his night rest.

5.3.2 Officer of the Watch (OOW)

The OOW or the deck officer is the person who is responsible for the bridge watch keeping and the navigation safety when the master is not in command. He needs to have a certificate of competency (CoC) before performing the bridge duty, which involves maritime education, training and sea experience in line with the minimum requirements of the STCW standards. The OOW must ensure that the navigation is performed in a safe way and that the bridge procedures, including the master's orders, are followed. He must not leave the bridge unattended, and he needs to utilise all methods to ensure good lookout. In addition, he confirms the closed loop communications, checks the weather forecast, checks that all equipment are running as should be and calls the master in case of any doubt or risk conditions. The COLREG regulations must be followed during the watches for the ship's safety and protection of the environment. All bridge team members are required to know the information that would be routinely reported to the master and the situations when the master should be called (ICS, 1998). The bridge officer is also responsible for preparing the voyage plan, executing the plan, and monitoring the progress and position.

5.3.3 Rating

The deck rating is a crewmember who does not have a certificate of competence and they are required to carry out some safety courses. They support the OOW and the master when require but, generally, they are responsible for the duty of lookout or helmsman. The rating member starts as an Ordinary Seaman (OS) and after a few years of experience will be promoted to an Able Seaman (AB). According to (The.Swedish.Club, 2011) the lookout must be familiar with what to expect, be located in a position with clear vision, not be occupied by other activities and have basic knowledge of radar. The rating person during his standing watch must ensure that he works and communicates with the OOW as a team, including reporting any hazards.

5.3.4 Pilot

The maritime pilot or harbour pilot is a seafarer who manoeuvres the vessel through special waters that are considered hazardous for navigation and that the ship's master is not familiar with, such as ports or congested waters. He has local knowledge and experience of the manoeuvre area, including effective communication with shore and tugs in the local language. The port authority or the maritime administration employs pilots to provide pilotage services to ships for fees.

The operations are governed by many regulations and recommendations that provided by the IMO. The transfer arrangement shall be prepared and arranged according to the SOLAS standard to allow the pilot to board and disembark securely on both sides of the vessel. He joins a ship temporarily so the bridge team must familiarise him with the ship's layout and operation. The master and the pilot must exchange information regarding the passage planning, check if updating is required and make sure the communication is in English. If the master has to leave the bridge, the duty OOW should continually verify the pilot's intentions in case of any doubt and if necessary the OOW must call the master and take any required action before his arrival to the bridge (ICS, 1998). During pilotage operations, the master remains legally responsible for the ship's safety. As such, if the master feels any doubt, he can relieve the pilot and take command or change the pilot if piloting services are mandatory.

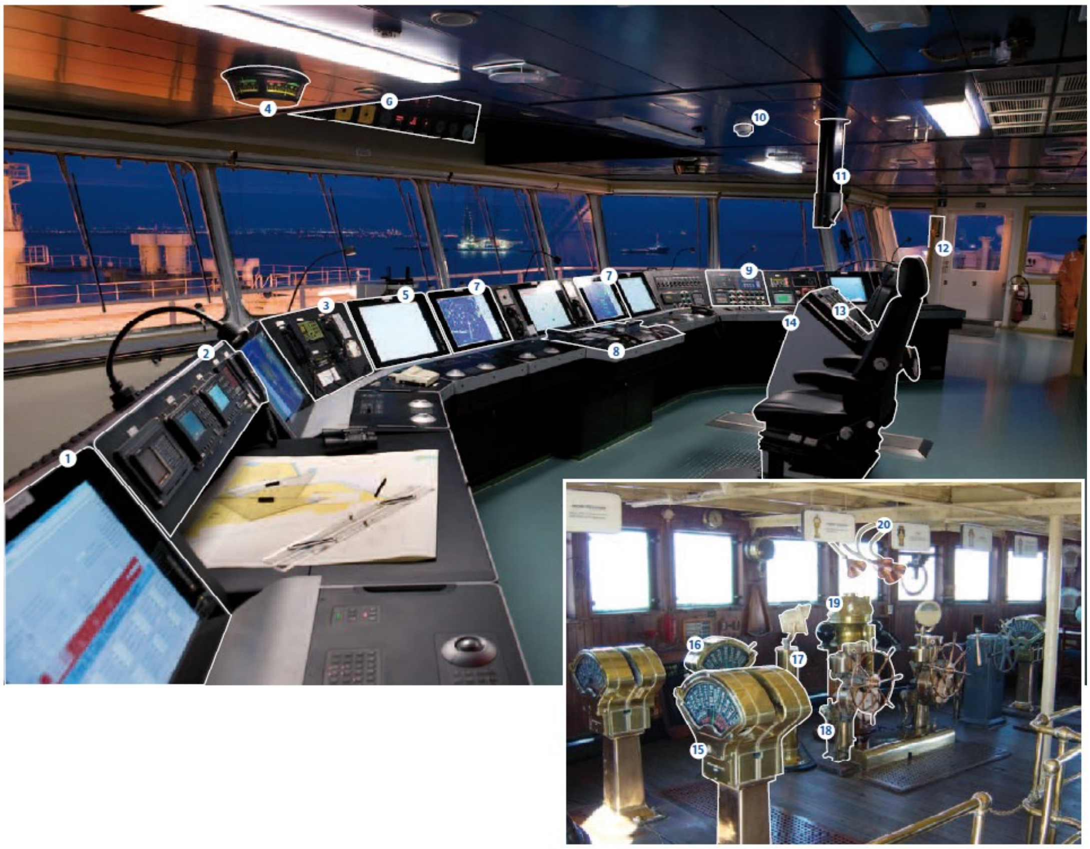
5.4. Bridge Technology

A ship's bridge is a platform or a designated place for command and control of the ship. On the bridge, there is a particular location for steering the ship's wheel called the wheelhouse, which is slowly disappearing over time because of the development of navigation technology. Nowadays only small vessels or boats have a wheelhouse. In the past, the ship's command was in the quarterdeck since ships were powered by wind (sailing ships). Subsequently, when the steam engine was developed, the paddle occupied the aft area, and the command location had to be moved above to give clear visibility to the master and more space for the engineering operations. Once the screw propeller was discovered and replaced the paddle wheel, the high command (bridge) remained in the same location.

The traditional bridge configuration was divided into two parts, one for navigation operations and the other for chart work. The command area contains the navigation equipment. In the past, the engine control was in the engine room and the captain had to give the thrust orders through an engine order telegraph from the wheelhouse. The captain would control the helm by giving orders to the helmsman to alter the ship's direction. The chart room is for nautical preparations, such as passage planning or updating of maritime charts and publications. **Error!**

eference source not found. shows the differences between classic and modern bridges.

Figure 5-5 Modern and traditional bridges (Fields, 2012)



Modern day bridge	**Traditional bridge** (*RMS Queen Mary* launched 1934)
1. Fire Detection Panel	**15.** Telegraph for port engines
2. GPS, AIS and Speed Log Display	**16.** Steering telegraph
3. VHF radio	**17.** Compass repeater
4. Rudder angle indicator	**18.** Steering stand for port rudder
5. Electronic Charts Display & Information System(ECDIS)	**19.** Magnetic compass
6. Clinometer, Anemometer, Tachometer, Echo sounder	**20.** Voicepipes
7. Radars (10 cm and 3 cm)	
8. Engine controls	
9. Switch panel (lighting etc.)	
10. Smoke alarm	
11. Magnetic compass display	
12. Search and Rescue transponder	
13. Gyro compass	
14. Steering stand	

The modern navigation bridge contains both parts in the same area sometime divided by a curtain. Modern ships have the ability to control the thrust and the direction from the bridge, as shown in Figure 5-6. Unlike the airplane cockpit that has similar design, there are no obvious standards on ship bridge equipment and layout to enhance the human-system integration. Currently, shipping companies are using more integrated bridge systems for the purpose of centralising the monitoring and controlling of different navigation equipment (Figure 5-7). With this system, the OOW can manage the steering, access information, communicate and control the thrust from the same location. The SOLAS regulations states that integrated bridge systems must be designed in a way that allows the OOW to immediately recognise the breakdown of any sub-system via sound and visual alarms, and this should not lead to the failure of additional sub-systems. Furthermore, each sub-system should be able to be operated separately in the case of the malfunction of an individual element of the integrated navigational system.

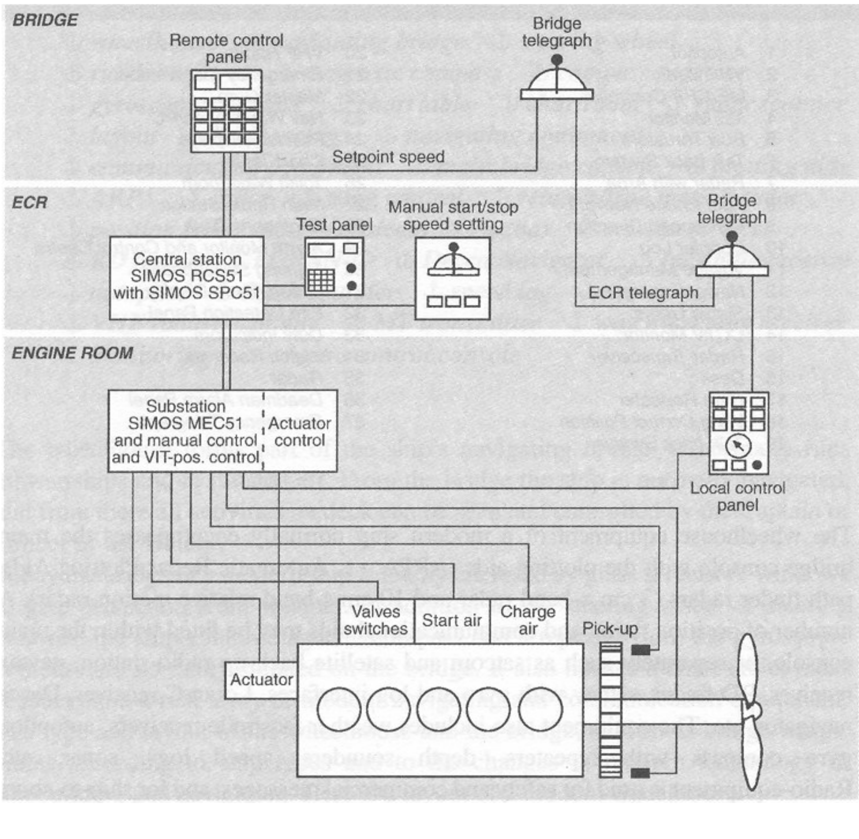


Figure 5-6 Engine control system from the bridge (University.of.Rijeka, 2013).

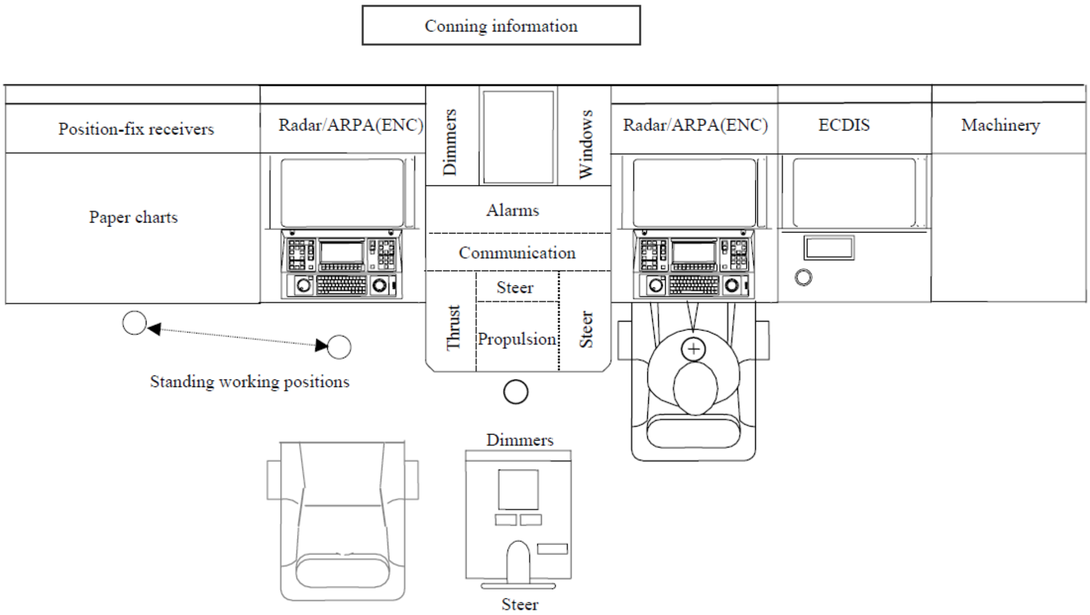


Figure 5-7 Example of principles for location of main equipment in a centre console (IACS, 1992)

5.4.1 Bridge Regulations and Requirements

The bridge design and technology should reach the minimum standards of the international maritime organisation for shipping safety and environment protection. Good ergonomics and design process are required for optimal bridge working performance. The bridge configuration, console arrangement and equipment position should all allow the OOW to execute their navigational mission and other assigned tasks along whilst sustaining a good lookout from a suitable location on the bridge (IACS, 1992). When navigating a ship the OOW must be able to perform different functions at the same time, such as lookout, monitoring the chart and the radar, and communicating by VHF while maintaining situational awareness (ICS, 1998). Besides, when the OOW is required to leave the bridge to the wing, he must be able to monitor the wheel and the engine indicators. All equipment requires testing and approval before use onboard a ship. During operation, all the bridge technology must continue to be tested periodically.

The International Convention for the Safety of Life at Sea (SOLAS) is a convention that was developed to ensure that vessels under a state flag are obeying the minimal safety requirements for ship construction, equipment and operation. SOLAS Chapter V came into force on 1 July 2002 and it covers the minimum standards for the safety of navigation, including bridge designing, technology, operation safety and manning. From these measures, the classification societies established standards and recommendations to be followed by ship owners and designers. It is important that the bridge design allows the operators (pilot or officer) to make a full appraisal of the situation for navigating the vessel safely in all conditions, improves bridge resource management, provides continuous access to essential information in a convenient manner, and reduces the risk of human error and fatigue.

The SOLAS convention discusses the importance of good visibility from the bridge and establishes minimum standards. The visibility must be clear at all times, showing not less than 225° of the horizon, and must not be affected by the cargo or the gears. The windows must provide good visibility by having the upper edge and lower edges as far apart as possible and they must able to avoid reflections and stay clear during all weather conditions.

The bridge system relies on the navigation equipment to provide navigation efficiency and safety. The equipment performs varying tasks, such as navigation, weather forecasting and communication, to create an efficient working environment. The navigation technology is described in Figure 5-8. (See APPENDIX E for the discretion of the bridge equipment).

Figure 5-8 Navigation technology on a modern ship's bridge

5.5. Summary

This section of the research work represents the first step of the safety and resilience integration model that describes the bridge operation system onboard ship. It shows the development of the bridge system during recent years. The elements of the bridge operation system (procedure, human and technology) were explained distinctly and individually. The procedure development of the navigation bridge shows definite improvement after the establishment of the ISM code and the safety management system. The voyage planning is an essential factor for the safety of the navigation and must be conducted according to the SOLAS convention requirement. There are different types of Navigation methods relating to the sailing area. The critical bridge navigation duty that must be performed by the bridge team is operating the ship safely and transferring the cargo on time and in perfect condition, which required following the collision avoidance regulation under the International Regulations for Preventing Collisions at Sea, 1972 (COLREGS). The Vessel traffic services (VTS) is a navigation facilitator that functions within the harbour approach water to control and monitor shipping traffic as well as to enforce safe navigation and environmental protection. Shipping companies facilitate their ships with a safety management system, which includes emergency procedures that must be followed by OOW such the emergency checklists in the case of an event. Fatigue onboard a vessel includes a crew member feeling exhausted or tired for working long hours which is regulated by the STCW to provide a rest system. The bridge human element is all people who are working on the navigation bridge. Minimum standard regulations of safe manning have to be applied to create the appropriate level of safety for each vessel According to the SOLAS Convention. The bridge design and technology should reach the minimum standards of the international maritime organisation for shipping safety and environmental protection.

Chapter 6. Second step of the Model: the Risks Analyses of Navigation Bridge Operation

6.1. Introduction

Maritime transportation has had a continuous improvement in its safety record through regulations and design improvements. Nonetheless, mishaps continue to occur and with the increasing size of passenger and cargo vessels, the outcomes of not handling the incidents optimally might become critical (EuropeanCommission, 2016). The European Maritime Safety Agency, EMSA (2015) recorded 9180 incidents between 2011–2014, with reported damage of two thirds of the ships, 390 fatalities and 3250 injuries. EMSA believes that human error contributes to 67% of these accidents. Mate (2012) (from Charles Taylor shipping insurance) stated that the greatest hazard that a ship owner faces is navigational accidents as claims of incompetent navigation are the highest single reason for shipping insurance claims. The Standard club's experience provides sufficient proof of that, with 85 claims cost more than $1 million of which over 50% were directly linked to navigational cases (Mate, 2012).

Analysis of marine accidents and statistics prepared by different agencies show only the general trend of the deficiencies. Many maritime agencies from the public and private domains are working hard to reduce shipping accidents by reporting, analysing and making recommendations after marine mishaps. Because of the high cost of this process, specific maritime regions in the world have the accident investigation capability. The European Maritime Safety Agency (EMSA), for instance, develops an annual overview of marine casualties and incidents that is updated every year. The EMSA reports show the general statistics of all types of accidents, causes, ships type and impacts in EU waters. These efforts are very valuable to the shipping industry. However, shipping accidents still occur, as (EMSA) reported 3399 ships were involved in accidents in 2014.

In this research, in-depth analyses of ship accidents were carried out with the focus on navigation. The navigation bridge is the head of the ship's operation and its safety relies on the correct decisions of the bridge team. Accordingly, the bridge must be observed more carefully to investigate the deficiencies and how they reflect on the accidents. The bridge consists of three aspects (human, technology and procedure) that operate together to provide a safe navigation. Humans are the operators and controllers of the bridge tasks, and their performance depends on their knowledge and experience. The technology helps to increase the safety and the efficiency of the navigation, but it requires familiarisation and tests. The bridge procedures are developed to deliver coherence to the operation process, but they need commitment by the bridge team in terms of following the procedures and the teamwork. The relations between these aspects (human, technology and procedure) are not investigated in the existing accident analyses. The aim of this work is to examine accidents that occurred because of operational failures in ship's bridge. The intention is to discover further details about the causes and organise them in a way that helps to develop solutions for the problems.

The officer of the watch (OOW) performs various tasks to operate the ship's bridge. The failure of one of these tasks could place the vessel in great danger. The tasks could fail because of various factors, which the OOW is accountable for. The consequences of bridge navigation problems fall under three different categories according to what the ship collides with. When one vessel hits another it is a collision, when it run over the seafloor it is a grounding, and when it hits a different object is a contact. The impacts of these events could destroy the assets, injure or kill people, and harm the marine environment. A competent and ready OOW is able to mitigate the impact of a strike by following the proper emergency procedures.

The MAIB (Marine Accident Investigation Branch) records marine accidents that occur in the United Kingdom territory and incidents involving UK flag state vessels. Incident records are highly significant tools for the evaluation of the maritime industry safety and environment protection performance, which can be harnessed to examine and analyse the mishap cases to identify the problems (MEPC, 2008). The accident data provide warning about the area that require more attention or new method for controlling the risk, such as design, operation and training. The bridge related accident analyses are examined by studying incident reports produced by MAIB between 2010 and 2015.

The structure of examining the MAIB accident reports was as the following:

1- It focused on the accident that occurred purely due to a failure with bridge (navigation) operation. The source of the accident analyses is the result of examining the MAIB reports, which also includes the UK ships accident or the accident in the British waters.

2- Identify the failed tasks (function) that lead to the operational (navigational) deficiencies. This step is important for the resilience performance analyses, which focus on the functions' performance and their integration together.

3- Identify the sub-factors that affect the bridge (navigation) tasks which could take different form of human error, technology negligent and organisation violation. It is important to understand the internal influences which help to provide solution and suggest resources to the safety management to prevent the risk.

4- Organising and terming the sub-factors was done according to the Taxonomy that developed by the Seahorse project. The Taxonomy is in-line with the Marine Accident investigation Branch (MAIB) which is a common reporting system that compatible with European Maritime Safety Agency (EMSA). Also it has the largest database in this field.

5- Recognise the impact of the deficiencies which help to define the severity and the form of the events.

6- Identify the mitigation elements that help to reduce or diminish the critical condition after the operational (navigational) tasks failed.

7- Find the solutions and recommendations, which were suggested after the accident by the experts, maritime organisation, and maritime authority. It helps for constructing the solutions and selecting the required resources to improve the safety and resilience of the bridge operation.

6.2. Maritime Accidents

During these 5 years, 127 events were recorded, and this research found that 56 of them were related to the navigation bridge. The selected sample is associated with commercial ships over 100 gt.

Table 6-1 Summary of Accident analysis from MAIB database reports between 2010- 2015

Type of Bridge Task Failure	Repetition	19 Collisions	17 Groundings	20 Contacts
Misjudgement	**43**	19	8	16
Inadequate Emergency Response	**28**	10	9	9
Inadequate Situational Awareness	**24**	6	12	6
Poor Lookout	**19**	10	9	0
Poor Alarm Management	**14**	2	11	1
Poor Leadership	**9**	0	2	7
Ineffective Passage Planning	**9**	1	5	3
Poor Learning	**8**	2	2	4
The total	**154**	50	58	46
Impacts of 56 Events	Damage: 52 Sinkage: 2 Pollution: 7 Injury: 7 Fatality: 15 No effect: 4	Damage:19 Pollution:4 Injury: 4 Fatality:15 Sinkage: 2	Damage:15 Pollution:2 No affect: 2	Damage:18 Pollution:1 Injury: 3 No affect: 2

Bridge task failure (cause of accident) is the inability to perform one or more task(s) of bridge operation by the officer of the watch (OOW), which generates an event. As a result of accident analysis eight underlying factors related to Navigation Bridge are identified (Table 6-1) and listed as misjudgement, Inadequate emergency response, Inadequate situational awareness, Poor lookout, Poor alarm management, Poor leadership, ineffective Passage Planning and Poor learning. analysis of reports identified 20 Sub-factors that lead to task deficiencies. The tasks failures were repeated 154 times between 2010 and 2015. Misjudgement occurred most frequent underlying sub-factor (43 times) whilst Poor learning was the least frequent underlying sub factor with 8 times. The Figure 6-1 presents the progression of the sub-factors together with the impact.

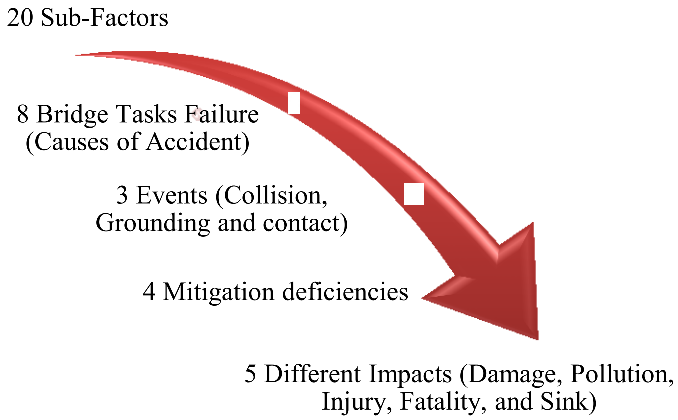


Figure 6-1 Failure escalation of bridge operation

An event can develop into a critical situation because of a failure to perform a bridge operation task by the crew. Critical situation may take three different forms: collision, grounding and contact. An event may have different impacts, namely harming assets, the environment and people. The effects on maritime businesses may not be economical, but may also involve fatalities, pollution to the environment and end of trading (SwedishClub, 2011).

According to EMSA (2015), a collision is damage when a vessel hits another vessel or being hit by a different vessel, whether they are sailing, anchoring or berthing. It is a critical event that may result from human or technological failure. A collision can harm the construction of the ship, which may generate injury, fatality, loss of assets and marine pollution. According to the Swedish Club (2011), the average cost of a bulk ships collision in the last decade was US$1,400,000 and for grounding is US$900,000. This research analysed 19 ship collisions between 2010 and 2015. The analysis revealed that 20 Sub-factors (Table 6-2) contributed to eight task failures, which caused damages to 19 ships, 9 cases of pollution, 4 injuries, 15 fatalities and 2 ships sinking. The Figure 6-2 presents the impacts of the events.

Ship grounding is a result of running over several things, such as the seafloor, the coast, and sunken wrecks, which may be under crew control or drifting after losing control (EMSA, 2015). Seventeen grounding cases took place between 2010 and 2015. The ships were grounded because of 15 Sub-factors that cause eight task failures and situational awareness was the most common cause, occurring 12 times. The impact of the risky events was distributed between 15 damages and two pollution cases.

According to EMSA (2015), the ship contact is damage made by striking another object, in which the object may take different states such as drifting, flying and fixed objects, but touching the seafloor is not counted as a contact. The bridge accident analysis found 20 contact events that occurred between 2010 and 2015 due to bridge operation deficiencies. The results show 14 sub-factors affecting seven bridge operation tasks that caused the contact events. The impact of the contacts can be summarised as 18 damaged ships, one pollution case and 3 injuries.

Damage can be defined as harm to the ship's construction that affects its performance features and demands restoration or element replacement (EMSA, 2015). 52 ships were damaged because of bridge operation faults(or errors). In some circumstances, the damaged ship would sink, which is not the total loss of the vessel, but it means that the ship cannot float. The analysis found that two vessels sunk after the collisions. A ship accident could cause injury to a person on board or a fatality that ends the person's life. Seven injuries and 15 fatalities were recorded. After the accident, the main concern that threatens marine life is pollution, which is usually caused by the ship's bunker. Seven pollution cases were recorded during the analysis period.

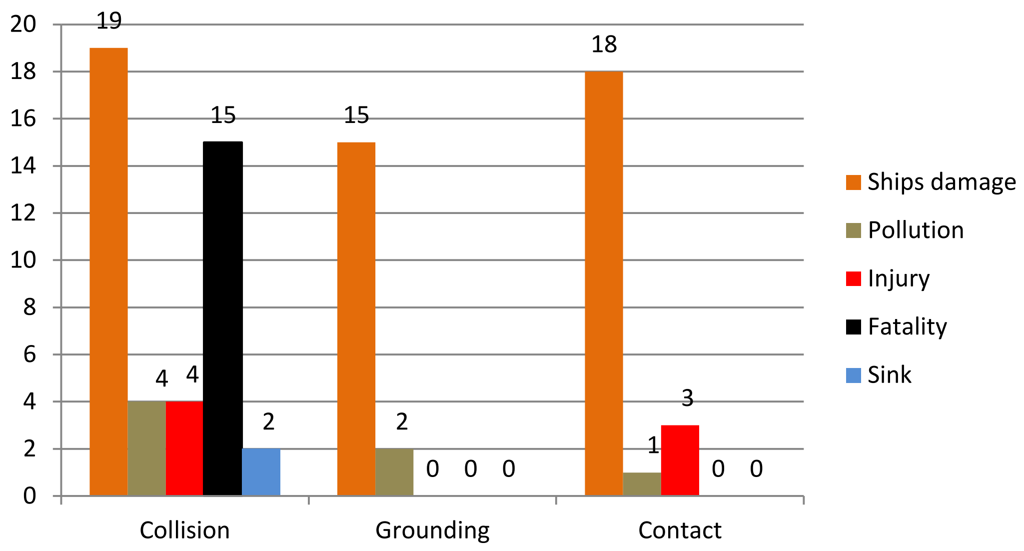


Figure 6-2 the impacts number of the events

6.3. Bridge Tasks Failure

Operating the ship's bridge requires several tasks to be performed by the crew to insure the safety and quality of navigation. The tasks demand knowledge, experience and crew readiness. Marine companies provide procedures to their ships to control the activities. In some occasions, the OOW or the ratings do not follow the bridge procedures, which expose the ship to the risk of a mishap. The bridge accident analysis revealed failures of eight main operational tasks on the bridge that resulted in 56 different accidents between 2010- 2015. The Table 6-2 shows the analysis result of the bridge tasks failure (Causes of Accident). The failed tasks are misjudgement, inadequate emergency response, inadequate situational awareness, Poor lookout, Poor alarm management, poor leadership, ineffective Passage Planning and Poor learning. Figure 6-3 presents the tasks failure numbers.

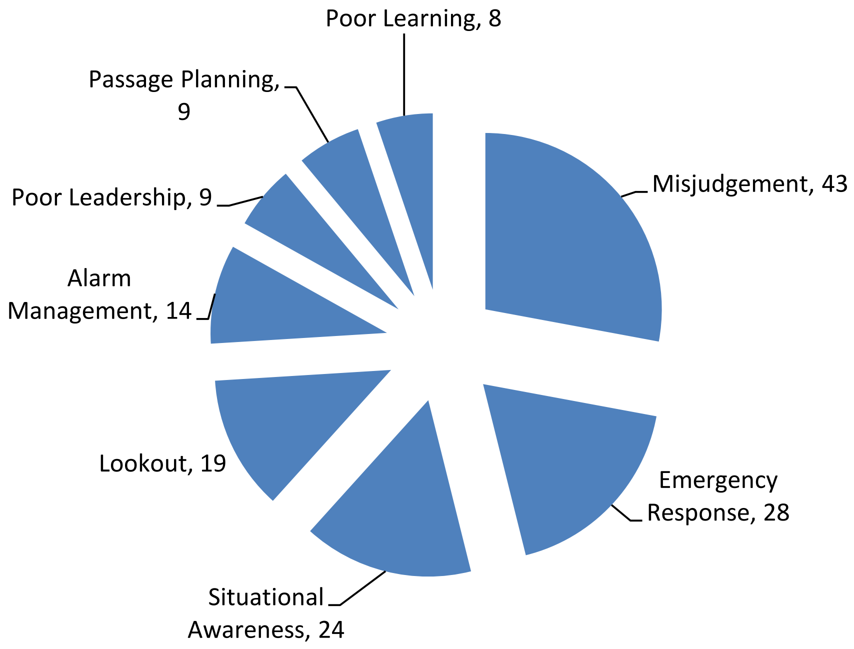


Figure 6-3 Tasks Failure numbers

Table 6-2 Analysis result of bridge tasks failure (Causes of Accident)

Tasks Failure	Sub-Factors and recurrence number	Events and recurrence number	Impact and recurrence number
Misjudgement	2- Inadequate ship behaviour Perception: 2 4- Inadequate traffic risk perception: 13 10- Abandoned bridge: 4 11- Inadequate utilisation of technology: 8 15- Violation of COLREG: 4 18- Violation of Pilotage procedures: 1 19- Diminished motivation: 1 20- Lack of vision: 1	Collisions: 19	Damage: 17 Pollution: 4 Injury: 2 Fatality: 14 Sink: 2
	2- Inadequate ship behaviour Perception: 4 5- Fatigue & vigilance: 1 9- Violation of Passage Planning procedures: 1 10- Abandoned bridge: 2 13- Violation of forecast procedures: 1 18- Violation of Pilotage procedures: 1 19- Diminished motivation: 1	Groundings: 8	Damage: 7 Pollution: 1
	2- Inadequate ship behaviour Perception: 9 9- Violation of Passage Planning procedures: 2 13- Violation of forecast procedures: 3 17- Excessive work load: 1 18- Violation of Pilotage procedures: 1	Contacts: 16	Damage: 14 Pollution: 1 Injury: 3

	19- Diminished motivation: 5 20- Lack of vision: 1		
Inadequate Emergency Response	1- Violation of emergency procedures: 6 11- Inadequate utilisation of technology: 1 15- Violation of COLREG: 2 16- Violation of Call Master procedures: 3	Collisions: 10	Damage: 9 Pollution: 2 Fatality: 12 Sink: 1
	1- Violation of emergency procedures: 9	Groundings: 9	Damage: 7
	1- Violation of emergency procedures: 9 16- Violation of Call Master procedures: 1	Contacts: 9	Damage: 17 Injury: 1
Inadequate Situational Awareness	5- Fatigue & vigilance: 3 17- Excessive work load: 1 18- Violation of Pilotage procedures: 1	Collisions: 6	Damage: 6 Pollution: 1
	5- Fatigue & vigilance: 7 10- Abandoned bridge: 1 14- Alcohol use: 3 17- Excessive work load: 1	Groundings: 12	Damage: 10 Pollution: 1
	5- Fatigue & vigilance: 2 15- Violation of COLREG: 1 17- Excessive work load: 2	Contacts: 6	Damage: 5 Injury: 1
Poor Lookout	3- Sole on bridge: 8 15- Violation of COLREG: 2	Collisions: 10	Damage: 9 Pollution: 1 Fatality:11 Sink: 1
	3- Sole on bridge: 7 8- Lack of communication or coordination: 1	Groundings: 9	Damage: 8 Pollution: 1
Poor Alarm Management	7- Violation of watch Alarm:2	Collisions: 2	Damage:2 Pollution: 1
	7- Violation of watch Alarm: 8 12- Inadequate equipment alarms: 3	Groundings: 11	Damage: 11 Pollution: 1
	12- Inadequate equipment alarms: 1	Contacts: 1	Nell
Poor leadership	8- Lack of communication or coordination: 2	Groundings: 2	Damage: 1
	8- Lack of communication or coordination: 7	Contacts: 7	Damage: 5
Ineffective passage Planning	9- Violation of Passage Planning procedures: 1	Collisions: 1	Damage: 1
	9- Violation of Passage Planning procedures: 5	Groundings: 5	Damage: 4
	9- Violation of Passage Planning procedures: 3	Contacts: 3	Damage: 1
Poor learning	6- - Lack of familiarisation and training onboard: 2	Collisions: 2	Damage:2 Injury: 1
	6- - Lack of familiarisation and training onboard: 2	Groundings: 2	Damage:2 Pollution: 1
	6- - Lack of familiarisation and training onboard: 4	Contacts: 4	Damage: 4

6.3.1 Misjudgement

According to the Cambridge dictionary , "misjudgement" is to form an idea or view about an individual or object that is unfair or incorrect. The accident analysis shows the negative aspects that influence the decisions of the master and the OOW (Figure 6-4), which led to the accidents. The failure of the judgment task was repeated 43 times between 2010 and 2015. Operating the ship's bridge requires up-to-date information about the present situation and what can be expected in the future. A shortage of information can happen for several reasons. Ignoring the navigation aids or relays in some cases might cause misjudgement. Reliance on external advisors such as pilots or the vessel traffic service without challenging the information or being involved in the decisions may result in unsafe actions. Standing in an inappropriate position on the bridge prevents the officer from perceiving the full condition of the operation. Fatigue limits the ability of the crew to understand the situation clearly and reduces the motivation for work. Inadequate recognition of their own ship behaviour or Traffic risk because of a shortage of experience or motivation affects the decisions of crew. Leaving the bridge without replacement by the officer on duty exposes the ship to great danger. Not following the bridge procedures increases the chance for misjudgement. Failing to prepare for unexpected situations, such as forecasting the weather can decrease the probability of taking the correct decision. The failure of the judgement task caused 19 collisions, eight groundings and 16 contacts. The events resulted in 38 damaged ships, six pollution cases, five injuries, 14 fatalities and two sunken ships (Figure 6-5).

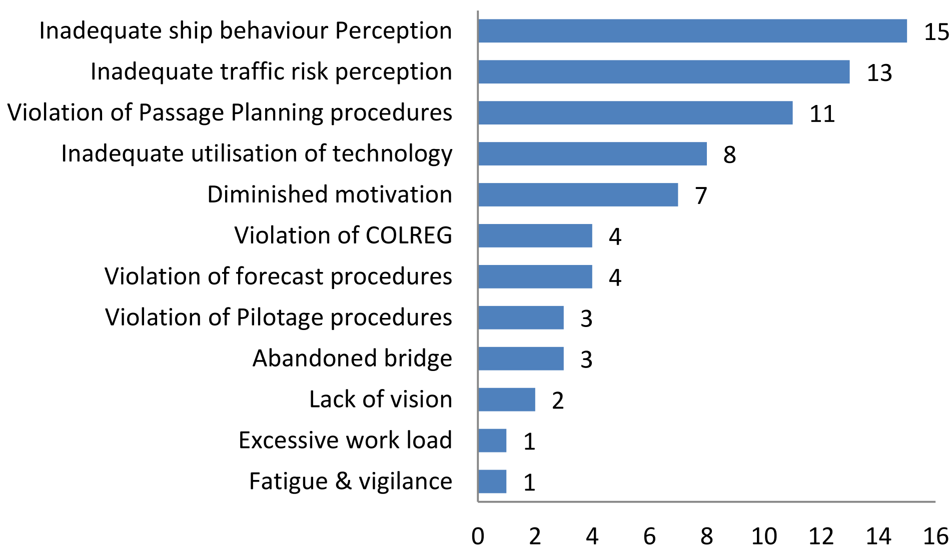


Figure 6-4 The Bridge sub-Factors that caused misjudgement

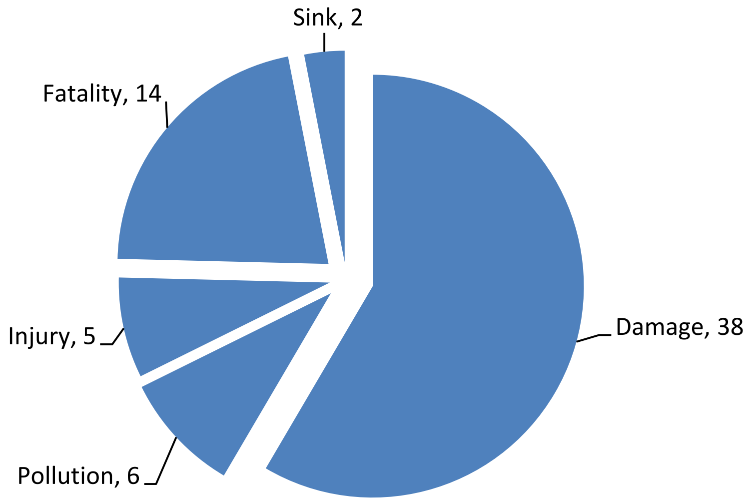


Figure 6-5 the impact of the misjudgement

6.3.2 Inadequate Emergency Response

The emergency response is an action that the in-charge officer on the bridge must take to prevent an accident from taking place or to reduce the impact after an accident. The shipping company supports all their vessels with an emergency procedure to be followed during critical times. It also requires the crew to perform emergency drill to prepare them to take the correct actions to reduce the probability of a catastrophe. The accident analysis defines four main reasons for failing the emergency action task (Figure 6-6). Not following the emergency procedure after an event, such as not using the emergency checklists which can worsen the impact of the event. In some occasions, the ship may encounter a highly hazardous condition, for instance restricted visibility that demands extra caution by following the COLREG regulation to prevent an accident. The analysis shows that not calling the Captain during the critical condition caused various accidents. In some cases, the in-charge officer neglected to set the Voyage Data Recorders (VDR) after the mishaps, which negatively affected the accident investigation. Failure of the emergency action task was recorded 28 times during the investigation period, resulting in 10 collisions, nine groundings and nine contacts. The impact of the accidents was 33 damaged ships, two pollution cases, one injury, 12 fatalities and one sunken ship (Figure 6-7).

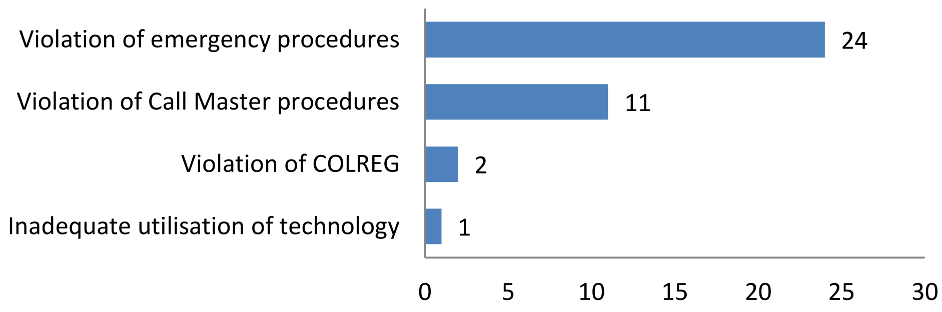


Figure 6-6 the sub-factors caused failure in emergency response

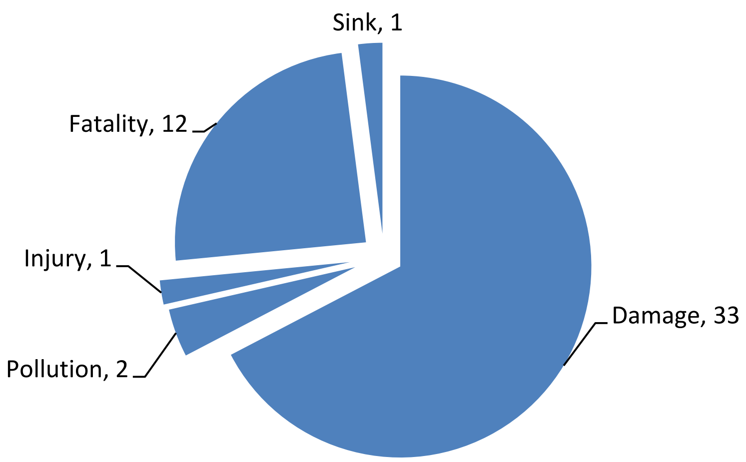


Figure 6-7 The impact of the inadequate emergency response

6.3.3 Inadequate Situational Awareness

Situational awareness is the capacity to recognise, process and understand the important factors affecting the team regarding their tasks (U.S.CoastGuard, 2014). Lacking of situational awareness means that the navigation officer is not entirely aware of the elements that impact the ship during the watch period (Swedish Club, 2011). The US coast guard states that loss of situational awareness caused 40% of their accidents. The bridge accident analysis found that the crew's situational awareness was affected by six factors that presented in the Figure 6-8. Fatigue was an important reason for the accidents, in some cases causing the OOW to fall asleep during the watch. Breaking the company procedures and leaving the bridge unattended was the second reason that prevented the officer from having the full picture of the situation. Alcohol consumption is a risky factor that prevents the crew from understanding the operation demanding clearly, and might lead to sleep. Not following the COLREG procedures, which help the bridge team to be prepared for the unexpected safety critical situations and recognise the information about the external situation, caused several mishaps. During the critical moment, the master and the mate are exposed to a mentally overloaded state, which affects their situational awareness and caused some accidents. The reliability on external support, such as the pilot, without challenging or involving on decisions cause the bridge team to not following the operational process and resulted several undesirable events. Losing situational awareness was reported 24 times during the analysis period and caused six collisions, 12 groundings and six contacts, which resulted in 21 damaged ships, two cases of pollution and one injury (Figure 6-9).

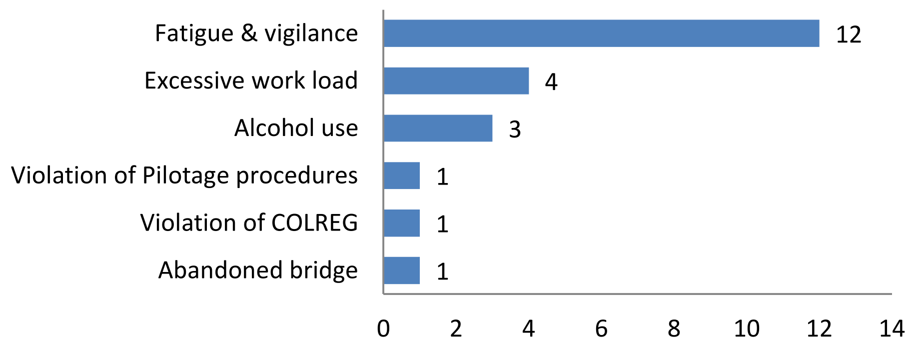


Figure 6-8 the sub-factors caused loss of situational awareness

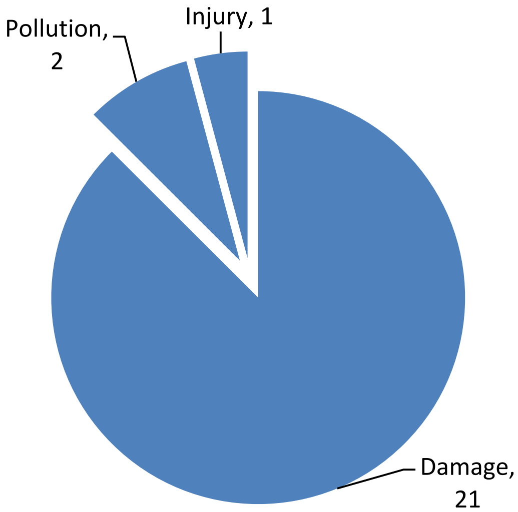


Figure 6-9 The impact of the inadequate situational awareness

6.3.4 Poor Lookout

The lookout is a seafarer who is assigned to the bridge to observe any risk that may counter the vessel and report what he observes to the OOW. Rule five of the COLREG (1972) convention requires that "*every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision*." A significant number of mishaps could be avoided with a well-trained lookout. Mate (2012) mentioned that inadequate lookout leads to poor decisions, which is a combination of several elements where the navigation officer does not observe the sea or there is not a hired crew member to perform this task (SwedishClub, 2011). Our analysis found three aspects that lead to the failure of the bridge lookout task (Figure 6-10). For economic reasons, some ship's owners hire the minimum number of crew on board their vessels, and with the high work demand it becomes very hard to assign an extra person as a lookout on the bridge. Another factor is keeping the OOW solely on the bridge, which limit the officer from receiving the full navigation condition in a way that form poor lookout. The COLREG requires using a lookout during critical conditions, such as restricted visibility. The bridge accident analysis showed that ignoring the lookout during critical conditions caused several accidents. One of the critical BRM (bridge resources management) procedures is the communication between the lookout and the bridge team. A number of accidents have been documented because the lookout does not communicate efficiently with the OOW. The failure of the lookout task caused 10 collisions and nine groundings, which resulted in damage to 17 ships, two cases of pollution, 11 fatalities and the sinking of one ship (Figure 6-11).

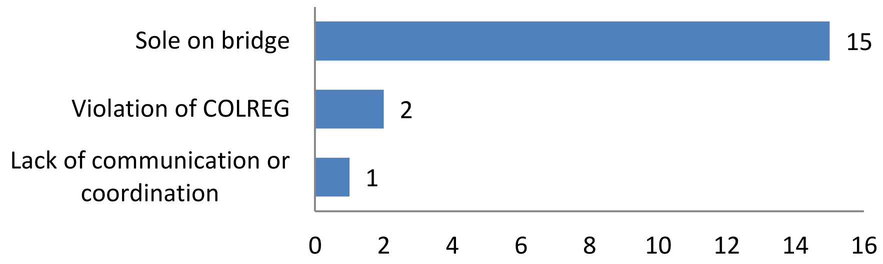


Figure 6-10 the sub-factors caused lookout failure

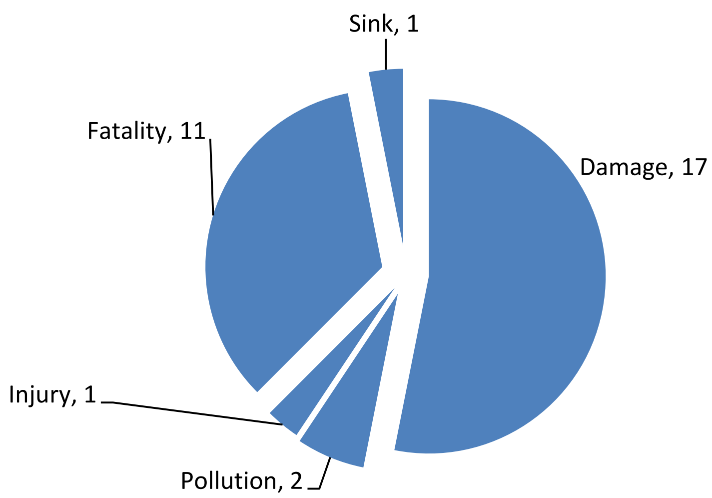


Figure 6-11 the impact of poor lookout

6.3.5 Poor Alarm Management

According to the IMO Code on Alerts and Indicators (2009), the alerts (on board ship) are divided into four types according to their priorities : emergency alarms, alarms, warnings and cautions. Unlike the emergency alarm that requires immediate action to save human life or the ship, the alarms demand immediate attention and action to preserve the safe navigation and operation of the vessel (IMO, 2009). The bridge accidents analysis found that the mishaps are caused by mistakes in the alarm type which is the level two relating to the priorities. The Figure 6-12 shows the sub-factors caused the alarm management failure. Important cause of accidents is ignoring the Bridge Navigational Watch Alarm System (BNWAS). Resolution MSC 128 (75) (2002) states that the BNWAS helps to monitor the bridge activities and detect the OOW's inability to perform the duty, which might cause maritime accident. The device can send an alarm to the master or another mate for assistance (IMO, 2002). Another factor that caused the failure of the alarm task is if the bridge officer turns the alarms or the sound of the navigational equipment off, which prevents the risk warning to be detected. Failure to manage the alarms on the bridge was repeated 14 times and produced two collisions, 11 groundings and one contact, which resulted in damage to thirteen ships and two cases of pollution (Figure 6-13).

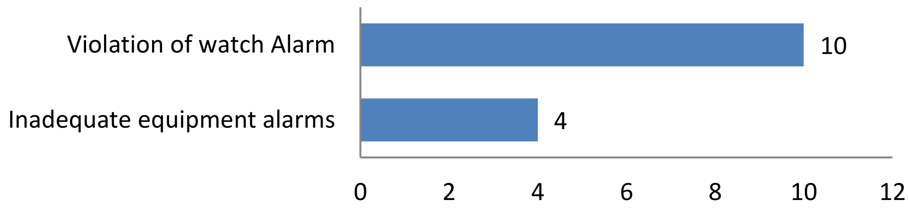


Figure 6-12 the sub-factors caused alarm management failure

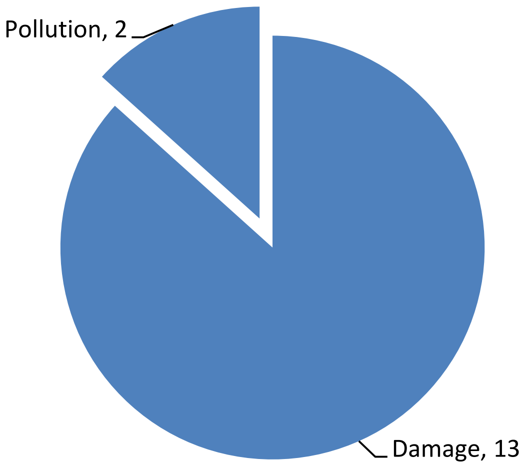


Figure 6-13 the impact of poor alarm management

6.3.6 Poor Leadership

Our research found one of the main reasons for accidents is the poor leadership elements, which is significant part in the bridge resources management. The leadership task is influenced by the quality of the communication or coordination among the bridge team which is part of the Bridge Resources Management (BRM). O'Connor (2011) stated that BRM is similar to crew resources management, which was formed to develop the communication between the master and the pilot and then shortly changed to cover the safety, the human factors and the conduct of the seafarers. It includes several subjects, such as leadership, ship manoeuvring, cultural awareness, communication, authorities, workload, stress, decision-making, crisis management and pilotage. In a high number of navigational accidents, the entire bridge team were highly qualified in BRM, and there is substantial proof that these training courses were not performed adequately and their results are poor (Mate, 2012). The failure of this task caused two ships to be grounded and seven others to contact, which resulted in damage to six ships.

6.3.7 Ineffective Passage Planning

According to the IMO (1999), passage planning is the framing of a plan for a voyage, along with the constant monitoring of the ship's performance and location during the execution of the plan, which is critical for human and ship safety, marine environment protection and effectiveness of navigation. Passage planning process has four stages:

1: the appraisal, which is gathering all information as possible relating to the voyage;

2: planning the detail of the entire voyage from berth to berth;

3: carrying out the voyage plan according to the guideline; and

4: monitoring of the vessel's progress and position.

In our bridge accident analysis we found that not following the passage planning procedures led to several accidents. The impact of the mishaps was one ship collision, five groundings and three contacts, which resulted in damage to six vessels.

6.3.8 Poor Learning

The learning task on bridge could be affected by the familiarisation and training onboard which influence the competence quality of crew onboard ship. The Professional familiarisation is essential part of the crew performance as the minimum that seafarers must have to execute as part of the bridge watch keeping duty. It has become clear that inexperienced crew are a problem since it is hard for the maritime companies to recruit experienced seafarers and finding seafarers with the right qualifications; the shipping company should also make sure that the crew are trained to understand the real job tasks demanded (SwedishClub, 2011). Our analysis discovered that a number of accidents took place because of the inadequate familiarisation and onboard training. The failure of this task caused two collisions, two groundings and four contacts, which resulted in eight damages, one injury and one case of pollution.

6.4. Sub-Factors

The sub-factors are actions or behaviours of the crew that affect the quality of the navigation tasks in a way that put the ship at risk of accident. The bridge study found 20 different sub-factors (Figure 6-14). They can take many forms, such as lack of knowledge and experience, breaking procedures and the lack of ability of the OOW. It is critical to recognise the root cause of the accident as the direct reason is possibly only a part of a larger deterioration in the operation (Swedish Club, 2011).

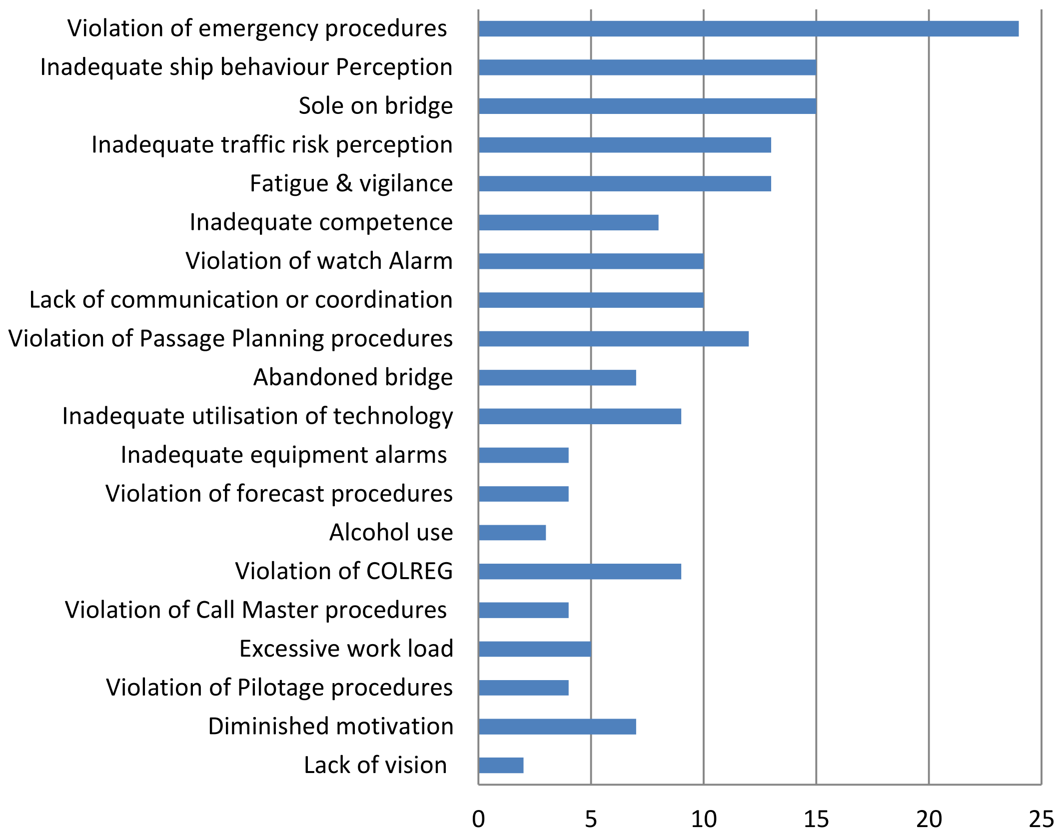


Figure 6-14 the Sub-factors

Table 6-3 Bridge operation Sub-Factors, Action and Recommendation by authority and maritime organisation

Sub-Factors	Aspect	Action and Recommendation by Authority and Maritime organisation
1- Violation of emergency procedures	Emergency Familiarization	-Training crew for emergency response - Use sound signal, emergency Checklist and VDR during drill -Drills in Correct Response To Propulsion System Failures
	Emergency Competence	- Clarify readiness procedures - Use engine or drop anchor for emergency stop (collision avoidance) - Timely warning for people
2- Inadequate ship behaviour Perception	External Effect Knowledge	-Training on Bank effect -Reduce Speed for Squat Affect - Ask for tug assistant
	Safety Procedure	-Ensure using ECDIS and monitor ship Position - Assess the speed risk -Test propulsion system in departure or arrival -Use distance measuring devices
	Perception Abilities	-Ensure about repetitive voyage effect - Ensure about main tasks not affect by other tasks
3- Sole on bridge	Lookout Procedure	- Maintaining a good lookout all time -Lookout remains at night and in reduced visibility -Spot checks by telephone to confirm the lookout -A revised SMS for the use of lookouts
4- Inadequate traffic risk perception	Collision Avoidance Knowledge:	- Provide OOW collision avoidance and risk assessment courses include simulator training -Training in navigation during restricted visibility -Computer based training of COLREGS & navigation -Training on defect reporting system
	Safety Procedure	- Act early for accident avoiding - Use distance measuring devices
5- Fatigue & vigilance	Fatigue Procedure	- Review vessel manning to ensure crew take rest hours -Crew changes to minimise impact on master workload -Provide guidance on fatigue management in SMS -Support masters' decision about delay sailing for safety -Implement procedures for records rest hours
6- Lack of familiarisation and training onboard	Competence	- Ensure all crew licences -Ensure all crew have experience related their tasks
	Language Skills	-Ensure crew communication language
	Technical Knowledge	-Ensure crew have bridge equipment familiarisation - Familiarisation procedures for vessel manoeuvring and control systems -Develop training for junior officer (assessed by master) -Require master to observe and validate officers skills
7- Violation of watch Alarm	Procedure	-The sole OOW must use BNWAS -Use BNWAS in night watch -Develop Master Standing Order to include BNWAS -Connect the BNWAS to autopilot with password -A revised SMS for the use of BNWAS
8- Lack of communication or coordination	Procedures	- Ensure bridge crew not breakdown during emergency -Pre-Departure and arrival briefing -Ensure bridge crew are Communicating -Ensure the master communicate his attention -Navigational briefing of manoeuvring plan

		-Ensure best use of the available crew resources -Master/Pilot information exchange checklist
	Knowledge	- Bridge resource management training
9- Violation of Passage Planning procedures	Procedures	- Ensure calculate safe water limit, tide and UKC - Check ECDIS: route, depth ,cross track, chart scale and safety contour depth -The OOW must calculate the tidal affect before the watch -Ensure following the passage planning steps: appraised, planned, executed and monitored -Update SMS for routes & restrict depth limits
	Knowledge	-Educate crew about squat -Navigation audits for ship's crew -Training all OOW On ECDIS -Provide training for the Crew in passage planning
10- Abandoned bridge	Procedures	- The OOW not leave without replacement -Update SMS about bridge manning requirement
11- Inadequate utilisation of technology	Technical Knowledge	-Training on bridge equipment utilisation - Use both 'S' and 'X' band Radars during sailing - Awareness about AIS system's capabilities and limitations and not Rely it - Don't Ignoring the AIS and Keep it on and updated all the time
12- Inadequate equipment alarms	Design	- Install double bottom bilge alarm - Reconnected ECDIS to BNWAS - Ensure all ships are similar in alarms
	Procedures	- Ensure recognise all radar alarms -Ensure recognise all ECDIS alarms -Ensure recognise echo sounder alarm -Ensure alarms sound are on
13- Violation of forecast procedures	Procedure:	-Develop Windage assessments and manoeuvring limits -Aware about the repetitive voyage affect
14- Alcohol use	Procedures	- Improve SMS about alcohol -Warn the crew about the punishment (may received custodial Sentence) -Introduced random alcohol testing on board
15- Violation of COLREG	Knowledge	- Training and testing for COLREGS
	Procedure	- Audit the ship for COLREG validation -Review SMS: not use VHF for collision avoidance - The minimum safe passing - The passing agreement -Restricted visibility preparation: lookout, Safe Speed, Use Fog Signals
16- Violation of Call Master procedures	Procedure	- Include default calling master -Call master in traffic or in restricted visibility -Update master standing order (when to call master)
17- Excessive work load	Procedure	- Ensure OOW or Master not distracted by others crew -Ensure take correct action after emergency situation -Ensure VHF communication not affect the watch task
18- Violation of Pilotage procedures	Procedure	-The master and the OOW must not rely on pilot - Keep communicating With the pilot and challenge his decisions - Exchange Information

19- Diminished motivation	Procedure	- Potential for low arousal -Aware about the repetitive voyage affect -Aware about not relax after pilot left the bridge
20- Lack of vision	Knowledge	- The OOW and the master must consider the Bridge visibility
Mitigation after the events	Procedure	-Use Sound Signal -Set the VDR to save data -Check Other Ship Safety after collision -Inspection After An Accident (Use Emergency Checklist) -Inform People On Board to avoid injury -Inform Authority to mitigate pollution -Damage Assessment after grounding and before re-float

The Inadequate knowledge and experience could affect the safety of the bridge operation. The ship's company is responsible for examining the seafarers qualification before placing them on-board. The crew must have licences, job experience and communication skills. The ships' master is in charge of familiarisation of the OOW with the bridge equipment, vessel manoeuvring and control systems. He is responsible for testing and observing the validation of the OOW skills, especially the junior officer. The analyses found that 20 Sub-factors contribute to the unsuccessful eight navigation tasks. The Table 6-3 presents bridge operation Sub-Factors, action and recommendation by authority and maritime organisation. The violation of bridge emergency procedures was the most repeated factor between 2010- 2015 by 24 times. Inadequate ship behaviour Perception and Sole on bridge factors are next factors by frequencies of 15 times each. For 13 reoccurrence each the inadequate traffic risk perception and Fatigue & vigilance took place. The violation of Passage Planning procedures was repeated 12 times, and the Violation of watch Alarm and lack of communication or coordination are each one of them were recurrent 10 times. Inadequate utilisation of technology and Violation of COLREG were repeated nine times separately. The Lack of familiarisation and training onboard sub-factor occurred eight times, the abandoned bridge and the diminished motivation occurred seven times each that affected the navigation tasks. The bridge operation was defected five times by the excessive work load of the bridge team and inadequate equipment alarms, violation of forecast procedures, violation of call master procedures and violation of Pilotage procedures were detected four times each. Finally, the navigation quality was affected which cause several events by the alcohol use in three times and the lack of vision in two occasions.

In the accidents analyses, it was found that the OOWs could not recognise their own ship's behaviour because of the poor preparation for external effects, ignoring the safety procedures and personal error. The external effects which require training are the bank effect and the squat effect, and asking for a tug to assist the ship in manoeuvring. The OOWs are responsible for following the bridge safety procedures to ensure that the ship's behaviour is controlled. Insufficient understanding or not complying with the COLREGS is likely the primary cause of the collisions, and there is substantial confirmation from several navigational accidents analyses in the public domain and the Standard Club suggests that many bridge teams including masters have lack of understanding or ignoring of the COLREGS (Mate, 2012). Several accidents occurred because the OOW could not recognise other ship's behaviour and distance. The OOW must act early for accident avoidance and use distance measuring devices. They could be avoided by following the collision avoidance procedure. The company is responsible for providing bridge watch keeping collision avoidance and risk assessment courses, simulator training on navigation in restricted visibility, COLREGS and a defect reporting system.

The bridge analysis found that some important procedures were not followed, causing a number of accidents. The Electronic Chart Display and Information System (ECDIS) was not used to monitor the ship's position, the speed risks were not assessed and the propulsion system was not tested before departure or arrival. Personal errors caused mishaps because of the repetitive voyage effect or the minor tasks affected the major ones. The study shows that the passage-planning process was not followed as it should be, which caused important planning elements to be missed as a result of ignoring the procedures or a lack of knowledge. Forecasting the weather at the beginning of any watch is a vital factor, which was disregarded in many cases.

Bridge technology exists to enhance navigation safety, and not utilising it properly reduced the chance of avoiding a few accidents. For example, not using the radar in manoeuvres as it should be or using the X-band radar without the S-band are some of the deficiencies identified in accident reports. The Swedish Club states that when the radar technology was presented to the shipping industry, it was assumed that it would end vessel collision at sea, yet unfortunately, that is not the situation. The Swedish Club adds further that despite the current ships are facilitated with various instruments and technology to prevent the vessels from colliding or going aground, sadly casualties still occur. Our analysis found that many accidents took place because the OOW was not able to utilise the bridge technology. The absence of alarm management for the bridge navigational equipment and the BNWAS places the ship in an unsafe state and prevents the OOW from recognising the risks and taking simple actions, which could have prevented several accidents. The shipping companies support their ships with AIS (Automatic Identification System) technology to increase navigation safety. In some accidents, it was found that the OOW was relying only on the AIS or not using it at all. The ideal ergonomic design helps the navigation officer to utilise the bridge equipment and observe the external environment clearly. It was found that inadequate bridge layout and ergonomics caused several accidents, since poorly positioned equipment could affect the crew’s situational awareness.

The analysis found that several incidents occurred because the OOW was so fatigued that in some occasions he fell asleep. In the future, the fatigue factor will become a hotter subject because it is a booming obstacle on board ships and is recognised by the Australian Maritime Safety Authority (AMSA) as a primary distress (Swedish Club, 2011). To avoid fatigue, ships should ensure that crew take rest hours, crew changes minimise the impact on master workload, provide guidance on fatigue, support masters’ decision about delaying sailing for safety, and implement procedures for recording rest hours accurately. Another factor that results in accidents is when the master or OOW is overloaded, which affects the mentality and prevents them from perceiving the risks properly. The bridge team must ensure that the bridge operation in critical situations is not preventing them from recognising the risks. The lack of motivation also causes the OOW not able to focus on his/her duty, which resulted in a few accidents. The company should consider the potential for low arousal, repetitive voyages and relaxing after piloting. Another failure factor that affects situational awareness is alcohol consumption, which has been recorded as a factor in a few accidents.

The bridge accidents analysis found that many bridge procedures were not followed. It is obvious that several collisions occurred as a result of ignoring the organisation’s SMS and the navigation procedures. Emergency action after a risky event is vital for reducing or preventing the impact after the accident, which can harm people, assets and the environment. The lack of emergency response can happen because of the lack of emergency procedure familiarisation, such as using the emergency checklist after an accident. The OOW’s preparation for emergency action after a critical condition is beneficial, for instance, dropping the anchor for an emergency stop or using the engine for an emergency stop. Calling the master is an essential procedure that brings an expert person onto the bridge to deal with a critical sailing condition. The analysis indicates that a number of OOWs ignored this practise. Numerous events occurred in restricted visibility; nevertheless, the core reason is not the poor visibility actually the bridge team did not perform the required procedures, such as assess the speed risk during critical conditions.

When two ships collide, the first reason could be that they did not follow the COLREGs (Swedish Club, 2011). Economic aspects may affect the ship’s safety by not hiring enough people, which forces the OOW to work alone on the bridge or to leave it without a replacement. Mate (2012) states that accidents occur frequently and often result from the officer of the watch falling asleep without having a lookout AB on the bridge.

The pilot needs to be integrated with the bridge crew and not to be regarded as a replacement, as many examples give proof that several accidents happen during pilotage, which indicates that the practice of the master and the officers relaxing while a pilot is on the bridge needs to perform the tasks (Mate, 2012). The reliance on the pilot without challenging its decisions could lead to risky results. According to the Swedish Club (2011), between 2000 and 2010, 277 collisions occurred and in 109 of them the pilot was on board, which shows that the pilot did not effectively communicate with the crew. Breaking the bridge resources management (BRM) procedure by ignoring the safety procedure or the shortage of BRM knowledge negatively affect the safety of the navigation. Attending the BRM course is important but applying what was learned is a different story. Quality of BRM training should also be looked into to make sure that they delivered the quality, understanding and the competence that are required in case of safety critical situation. The analyses show inadequate application and poor courses caused several accidents.

According to the Oxford English Dictionary (2017), the mitigation is "*the action of reducing the severity, seriousness, or painfulness of something*". The mitigation phase comes after a risky event has taken place, such as collision, grounding and contact. These events have serious impacts, which are damage, pollution, injuries, fatalities and ship sinking. The mitigation should prevent or minimise the impacts if it is carried out at the right time. The SMS on the bridge has several mitigation procedures and the OOW is responsible for following them in the case of a risky event. The bridge accidents analysis found that many mitigation procedures were ignored, which caused or increased the impact. The alarm signals cover all areas on the ship from the bridge to the engine room to warn the people about an emergency situation. The research found that the OOWs did not use the alarm signal or inform the people on board about the dangerous situation, which resulted in several injuries and fatalities. After a grounding or hard accident affects the ship's hull, the crew must carry out an emergency inspection and make sure there is no water ingress to the vessel. It was recorded that different crew in various ships ignore this procedure, which causes harmful impact on their vessels or places them in a hazardous condition. In some situations, the crew disregarded performing a damage assessment after the grounding and before the refloating process, which caused the vessel to sink after the procedure. Communication is a vital task that must be done after a mishap. It takes two forms: one is to check the other ship's safety and the other is to inform the authority about the accident. The analysis found several cases in which the crew did not perform one or both of the communications, which caused a number of fatalities because the other vessel sunk without noticing.

6.5. Summary

This study intended to establish an accidents analysis that focuses on navigation bridge deficiencies that created marine misfortunes. The analysis found eight main bridge operational tasks that were ignored or were not performed as the safety procedures stated. The neglected bridge tasks could cause a collision, grounding or contact. The miscarried tasks are misjudgement, inadequate emergency response, inadequate situational awareness, poor lookout, poor alarm management, poor leadership, ineffective passage planning and poor learning. The study also observed that failure of the tasks occurred 56 times between 2010 and 2015.

Behind the breakdown of these tasks, 20 sub-factors, which are wrong, incompetent or lack of actions or behaviours performed by the bridge team, spoil the safety of the navigation bridge tasks and position the vessel in risk of an accident. They take many forms, such as lack of knowledge, experience shortage, procedures breaking and absence of OOW capacity. All these factors were reported several times. After an accident occurs, there are mitigation procedures that must be implemented, which help to reduce or prevent the impact. The bridge accidents analysis recognises that several mitigation procedures were ignored.

There are five different impacts after an accident, which are damage, pollution, injury, fatality and sinking. 52 vessels were damaged and two of them sunk because of errors during bridge operation. Seven injuries and 15 fatalities occurred. The marine environment also was not protected from these accidents and it was polluted on seven different occasions.

The outcome of the analysis verifies that human deficiencies are the main reason for the mishaps since the bridge team was unsuccessful at performing the correct action before or after the risky events. Besides, they repeated the same bridge failure factors that led to the failure of the operational tasks. The ship’s owner is blamed for not hiring enough people, not checking crew qualifications and not providing training. The ship's masters are responsible for not familiarising the bridge team, not testing their ability and not communicating with them. Finally, the lack of standards of actions after the events by the owners were recognisable, because it was very diverse between generate large number of policies to just simply changing the ship’s flag state.

Chapter 7. Case Study: Preventing the Failure of Alarm Management Tasks

7.1. Introduction

The commercial ships rely on a set of procedure to ensure safe navigation. Several accidents investigation records documented a significant number of maritime events, which were experienced by different vessels, which applied high safety standard procedures. This study presents a novel application of barrier management to improve the ship safety by enhancing the resilience of the bridge operation. This section aims to illustrate the process of developing resilient safety management system. The model is applied on eight failed tasks which are misjudgement, inadequate emergency response, inadequate situational awareness, Poor lookout, Poor alarm management, poor leadership, ineffective Passage Planning and Poor learning. The alarm management task of navigation bridge is selected as an example to demonstrate the process application of the method and given in this chapter. Remaining application cases are provided in Appendix A.

From the accident reports investigation in Chapter 5 it was found that the Alarm Management task failed 12 times between 2010 to 2015 that caused grounding and collision to Britain's merchant fleet and the ships were sailing in the UK water. The events resulted in several ships damage and marine pollution. The failed tasks (Alarm Management) are the navigation hazards must be prevented from occurring by planning barriers system contains safety elements and resilience resources. These barriers should prevent the sub-factors from fail the Alarm Management task, and if the task failed the mitigation barriers should be effectively functioning to avoid or minimise any impact.

The first step of the model is the description of the critical function which is in this case is alarms management of the navigation bridge. Second, define the likely risks that could affect the performance of the alarm management system. Next, development of the risk scenarios by applying the fault and event trees analyses. The outcome of the analyses helps to develop the Bow-tie and the Functional Resonance Analysis methods. The results of the application are guidelines and recommendations to create or improve the standard operating procedure of navigation bridges.

7.2. Description of Alarm Management System on Navigation Bridge (Critical Function)

The first stage in the model requires a description of the alarm system on ship's bridge as a critical function, and its failure could result in a catastrophic event. According to SOLAS convention, if an alarm system sends a sound and visual warning, it indicates a condition that demands attention. The key task of the bridge alarm system is to reduce the navigational risk by recognising such a risk, monitoring and raising alarm, immediately for the bridge staff and the pilot to decide and take suitable action in timely manner (SOLAS-V/15, 2009). The IMO demanded that a bridge alarm management system should be divided into two groups, based on whether the alarm is affecting the navigation safety or not. Table 7-1 presents the alarms that influence the safety of navigation onboard commercial ships.

Table 7-1 presents the key alarms related to safety of navigation (SOLAS-V/15, 2009)

Critical Bridge Navigation Alarms
- operator disability (if detection system is installed)
- danger of collision
- heading deviations
- deviations from the route
- danger of grounding
- propulsion failure
- steering gear failure
- bridge navigational watch alarm system (BNWAS)
- heading information system
- heading / track control system
- position-fixing systems
- electronic chart system
- radar with electronic target plotting functions
- relevant machinery alarms for early warning

According to the IMO Code on Alerts and Indicators (2009), the alerts (on board ship) are categorised into four categories based on their priorities: 1- emergency alarms, 2- alarms, 3- warnings and 4- cautions. The emergency alarm (first category) demand immediate response to save human life or the vessel safety. The second type alarm (is the focus of this process) requests immediate attention and action to secure the safe navigation and operation of the vessel (IMO, 2009). The main alarm on the ship' s navigating bridge is the Bridge Navigational Watch & Alarm System (BNWAS). It is a monitoring system that notifies other officers or captain, in the case of the duty officer is not active on the bridge or is not response to the watch alarm for a safety critical situation that might cause a risk of accident. The ship's bridge also accommodates other several navigational alarm systems that installed as required by the IMO and classification requirements and guidelines. For example, the Electronic Chart Display and Information System (ECDIS) contains different alarms relating to the voyage routes. the ECDIS possesses five mandatory alarms that require attention which are crossing safety contour, deviation from route, positioning system failure, approach to a critical point, and different geodetic datum (Weintrit, 2009).

7.3. Risks analyses of Poor Alarm Management

The second step in the model requires identification of risks that affect the alarm system of ship's bridge. The navigation bridge accidents analysis (refer to chapter 5) determined the sub-factors that caused the task of alarm management to fail (Figure 7-1). The first sub-factor caused the task failure is the negligence of the Bridge Navigational Watch Alarm System (BNWAS) by the bridge team. The BNWAS helps to monitor the bridge activities and detect the OOW's disability to perform the watchkeeping, which may cause ship accident (MSC 128/75 (2002). The system has the ability to send an alarm to the captain or another officer for assistance (IMO, 2002) in the case of OOW is not active on bridge. Another sub-factor that produced the failure of the alarm task is the inadequate of using the navigational equipment alarms by turning the alarms or the sound off, which hinders the hazard warning to be noticed. Failure to manage the alarms on the bridge was repeated 14 times (Figure 7-1) and produced two collisions, 11 groundings and one contact, which resulted in damage to thirteen ships and two cases of pollution (Figure 7-2). Table 7-2 presents poor alarm management sub-factors, action and recommendation by authority and maritime organisation.

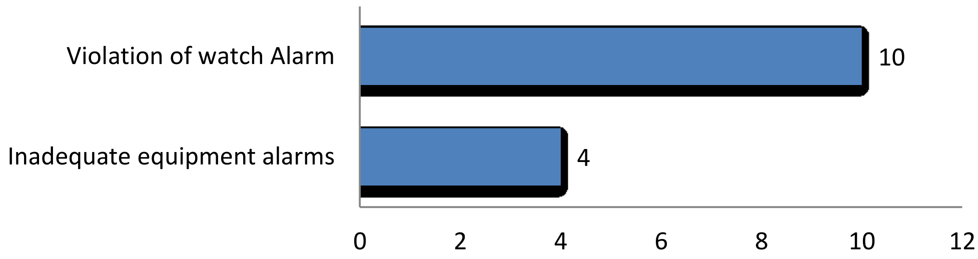


Figure 7-1 the sub-factors caused alarm management failure

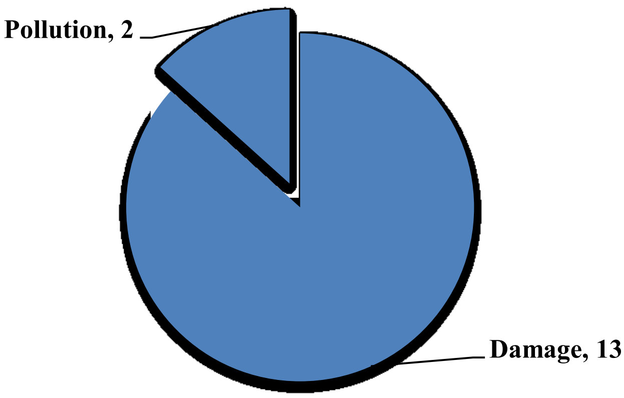


Figure 7-2 the impact of poor alarm management

Table 7-2 presents poor alarm management sub-factors, action and recommendation by authority and maritime organisation

Sub-Factors	Aspect	Action and Recommendation
1- Violation of watch Alarm	Procedure	-The sole OOW must use BNWAS -Use BNWAS in night watch -Develop Master Standing Order to include BNWAS -Connect the BNWAS to autopilot with password -A revised SMS for the use of BNWAS
2- Inadequate equipment alarms	Design	- Install double bottom bilge alarm - Reconnected ECDIS to BNWAS - Ensure all ships are similar in alarms
	Procedures	-Ensure recognise all radar alarms -Ensure recognise all ECDIS alarms -Ensure recognise echo sounder alarm -Ensure alarms sound are on

7.4. Building risk scenarios

The third step in the model is building risk scenarios, which requires performing cause analysis via the fault tree (FTA) and mitigation analysis by using the event tree (ETA). The results of the FTA and ETA analyses will be connected on a common platform (Figure 7-3) in order to demonstrate both sides of the bow tie to represent the scenario of the top event between accident causes and mitigation.

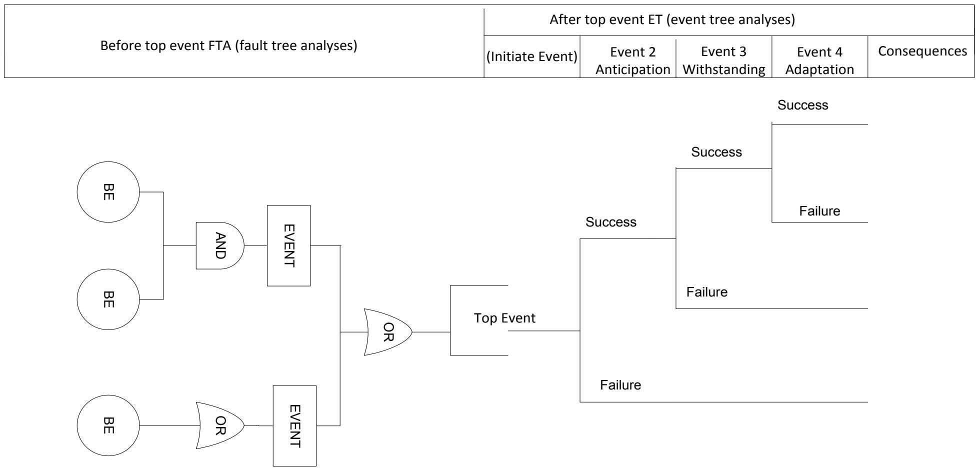


Figure 7-3 Generic Bow-tie Illustration include FTA and ETA

7.4.1 Poor Alarm Management FTA

The poor alarm management failure occurred 14 times causing two collisions, 11 groundings and a contact. There are two sub-factors which influenced the alarm management task on the ship's bridge and created the events. The root causes of each sub-factor were analysed by the application of FTA (Figure 7-4). The violation of watch alarm sub-factor was reported 10 times as a result of ignoring the bridge navigation watch alarm system (BNWAS). The inadequate equipment alarms sub-factor occurred on four occasions. They took place due to not utilising the alarms or switching the sound off and losing an important safety monitoring resource via not receiving a danger warning, which caused inadequate alarm management.

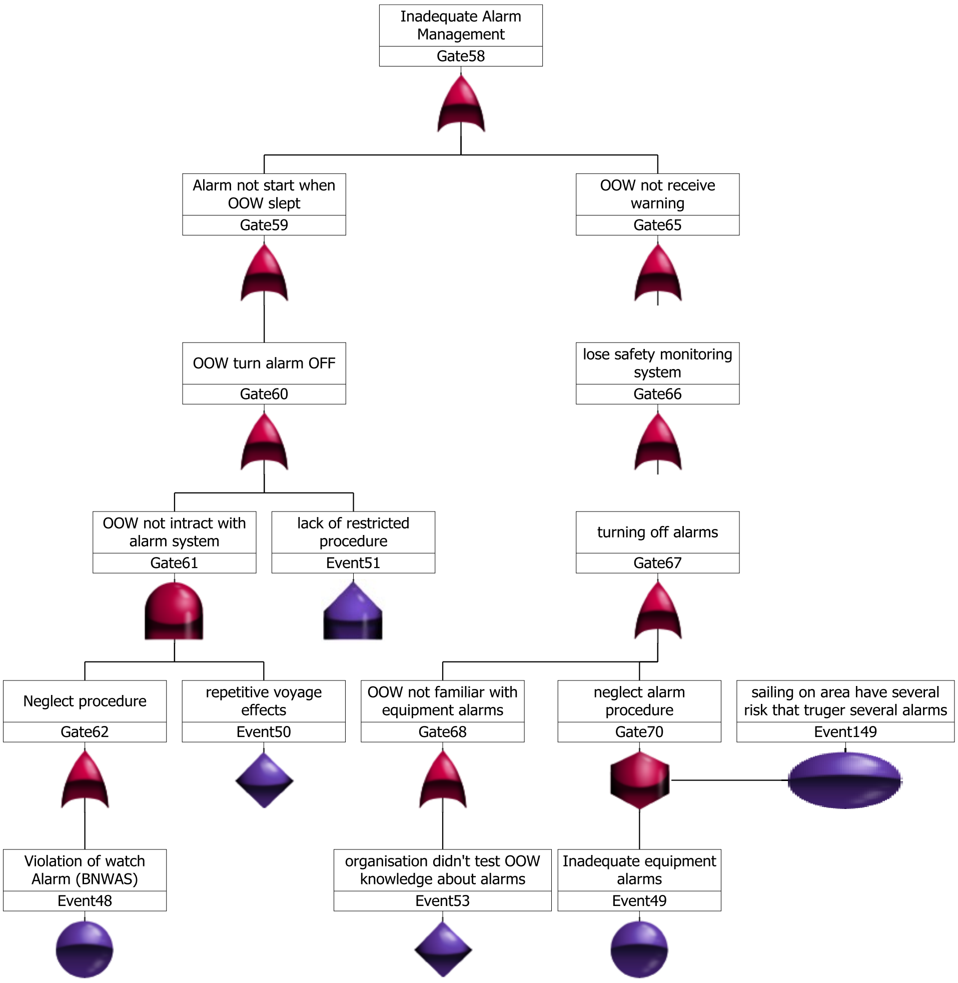


Figure 7-4 Poor alarm management FTA

7.4.2 Poor Alarm Management ETA

Figure 7-5 presents the Poor alarm management ETA that shows three levels of mitigation so as to avoid the impacts. The accident analyses conducted in Chapter 5 recorded 13 instances of ship damage because of poor alarm management. The accident and damage could be prevented by implementing the following processes: in the first step, the OOW should utilise all of the navigation technology on the bridge, e.g. the ECDIS and the radar equipment (including the repeaters). Next, the OOW should use all of the navigation alarms for monitoring, and ensure that they are switched on. Finally, the OOW must call the master for support in the case of any doubt.

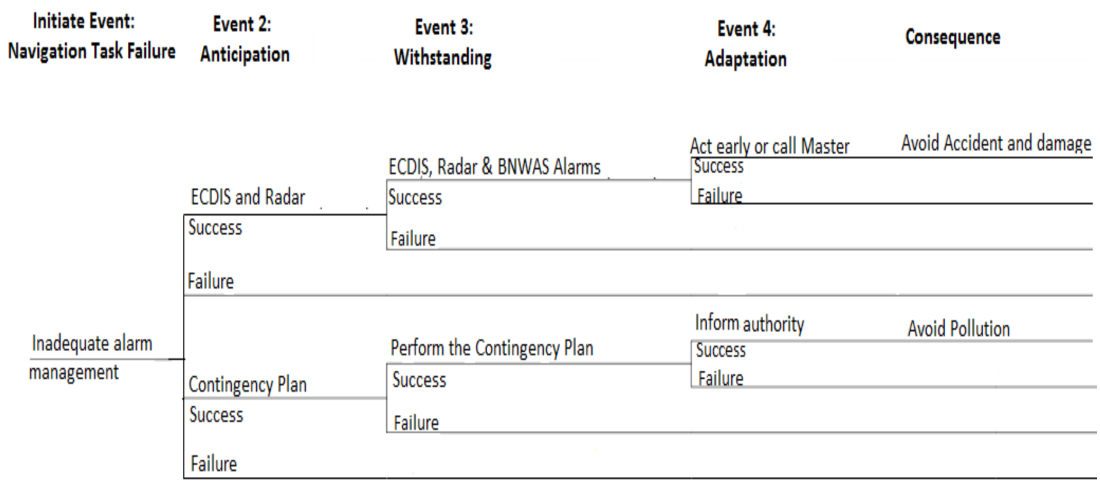


Figure 7-5 Poor alarm management ETA

The pollution impact could generate irreversible damage to the environment, so it must be mitigated as soon as possible. The accident investigation recorded 2 pollution cases because of poor alarm management. The event analyses (Figure 7-5) demonstrated three levels of mitigation barriers to eliminate the consequence. Firstly, the ship's company must provide a contingency plan for each ship. Secondly, the organisation must ensure that the crew have the knowledge and the ability to perform the plan as the regulation requires to prevent/mitigate the damage. Finally, the state authority must be informed so as to be prepared and provide support in the case of pollution presence.

7.5. Designing the system of Resilient Safety Barrier

Fourth stage of the model aims to plan the broad lines of the system by selecting the critical functions that require control and defining solutions for the risks which include safety performance and resilience enhancement. From the accident analysis in Chapter 5, it was found that the task of alarm management was failed because of two sub-factors which are violation of watch alarm and inadequate equipment alarms. The impacts of the failure are ships damage and marine pollution. The failed tasks are the navigation hazards which must be prevented from taking place by designing barriers from safety elements and resilience resources. These barriers must prevent the consequences of the sub-factors and after the task has failed, mitigation barriers should be functioning effectively to avoid or minimise any impact.

The notion of barriers needs to be explained through set of definitions of barrier functions, barrier elements, and other correlated terms. Risk should be controlled by the specific solution, which represents human, procedural and technological resources. The work process includes defining safety performance and developing resilience enhancement. Safety performance includes barrier purposes, functions and elements. Resilience enhancement contains resilience ability, resources and control. This work discusses the prevention of sub-factors violation of watch alarm (BNWAS) and inadequate equipment alarms, in addition to the mitigation from ship accident that cause damage and pollution impacts.

7.5.1 Defining Safety Performance

Planning the safety performance include defining the barrier functions. In this case, there are two types of functions;

a- Preventive functions of capacity error, performance error, lack of communication and unsafe act

b- Mitigating functions of unsafe act, unnoticed risky cause, event acceleration and confusion after an event took place.

For each function, there are selected elements such as technology, procedure and human. The elements were developed from recommendations of maritime authorities after the accidents, action done by shipping organisation after events (Table 7-2), and best practice of navigation that recommended by maritime experts.

7.5.2 Defining Resilience Enhancement

Designing the resilience enhancement require adapting four different resilience abilities for the preventive function, which are Anticipation, Monitoring, Learning, and response. The mitigation functions also need another four abilities which are Plan/Prepare, Absorb, Recover and Adapt. Each ability requires allocated resource(s) according to its type and defines control technique that could take different forms such as training and procedure.

Table 7-3 planning process of resilient safety system to prevent violation of watch alarm

Safety Performance			Resilience Enhancement		
Purpose	**Barrier type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
Prevent violation of watch alarm (BNWAS)	Prevent capacity error	Follow night watch alarm procedure	Anticipation (Knowing what to expect)	OOW must be familiar with the night watch procedure	Procedure: organisation validate OOW knowledge
	Prevent performance error	Use BNWAS (especially in the sole lookout)	Monitoring (Knowing what to look for)	Ensure using the BNWAS in the night watch and become mandatory during the sole lookout watch	Procedure: watch checklist Method: Connect the BNWAS to autopilot with password
	Prevent lack of communication	Interact with the BNWAS alarms	Learning (Knowing what has happened)	Ensure the BNWAS is part from the watch process	Procedure: watch checklist
	Prevent unsafe act	OOW doesn't acknowledge an alarm unless he is fit for the watch	Responding (knowing what to do)	Ensure the OOW can find assistant in the case of night and sole lookout watch	Procedure: Master's standing orders

Table 7-3 shows the method of preventing the violation of watch alarm sub-factor failure in order to improve the safety and enhance the resilience of alarm management task. The safety performance side of the table tries to define four preventative functions: capacity error, performance error, a lack of communication, and an unsafe act. The resilience enhancement side of the table attempts to determine four resilience abilities: anticipation, monitoring, learning and responding. Both safety performance function and resilience abilities are developed in a parallel perspective. For example, the preventative capacity error function and elements are in line with the development of the anticipation ability, including its resources and control.

The processes of preventing the violation of watch Alarm (Bridge navigation watch alarm system –BNWAS) sub-factor include the following:

1. It is vital to prevent the capacity error by providing the organisational element of "Follow night watch alarm procedure". This function and element require the resilience ability of anticipation that is demanding the resource of "OOW must be familiar with the night watch procedure" and the control of "Procedure: organisation validates OOW knowledge".
2. Preventing the performance error requires the element of "Use BNWAS (especially in the sole lookout)", which requires the resilience ability of monitoring that demands the resource of "Ensure using the BNWAS in the night watch and become mandatory during the sole lookout watch" and the control of "Procedure: watch checklist and Method: Connect the BNWAS to autopilot with password".
3. Preventing the lack of communication requires the element of "Interact with the BNWAS alarms", which needs the resilience ability of learning that demands the resource of "Ensure the BNWAS is part from the watch process" and the control of "Procedure: watch checklist".
4. Preventing an unsafe act requires the element of "OOW doesn't acknowledge the alarm unless he is fit for the watch", which needs the resilience ability of responding that demands the resource of "Ensure the OOW can find assistant in the case of night and sole lookout watch" and the control of "Master's standing orders".

Table 7-4 planning process of resilient safety system to prevent inadequate equipment alarms

Safety Performance			Resilience Enhancement		
Purpose	**Barriers Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Poor alarm management) **Inadequate equipment alarms**	Prevent capacity error	OOW should utilise all navigation technology alarms	Anticipation	Ensure OOW are familiar with bridge technology alarms	Procedure: organisation validate OOW knowledge Method: Ensure all ships have similar alarms
	Prevent performance error	Set the navigation technology alarms and sound on	Monitoring	Ensure recognise all alarms	Procedure: watch checklist
	Prevent lack of communicati on	OOW must receive warning alarms and validate it before press acknowledge button	Learning	Ensure to develop alarms management procedure	Procedure: provide guideline for bridge alarms Training: alarms management
	Prevent unsafe act	OOW should know how to respond to the received alarm or call captain	Responding	captain ensure OOW will not hesitate to call him	Method: friendly encouraging environment for communication

Table 7-4 shows the method of preventing the violation of watch alarm sub-factor failure in order to improve the safety and enhance the resilience of alarm management task. The safety performance side of the table tries to define four preventative functions: capacity error, performance error, a lack of communication, and an unsafe act. The resilience enhancement side of the table attempts to determine four resilience abilities: anticipation, monitoring, learning and responding. Both safety performance function and resilience abilities are developed in a parallel perspective. For example, the preventative capacity error function and elements are in line with the development of the anticipation ability, including its resources and control.

The processes of preventing the inadequate equipment alarms sub-factor include the following:

1. It is vital to prevent the capacity error by providing the organisational element of "OOW should utilise all navigation technology alarms". This function and element require the resilience ability of anticipation that is demanding the resource of "Ensure OOW are familiar with bridge technology alarms" and the control of "Procedure: organisation validate OOW knowledge and Method: Ensure all ships have similar alarms".
2. Preventing the performance error requires the element of "Set the navigation technology alarms and sound on", which requires the resilience ability of monitoring that demands the resource of "Ensure recognise all alarms" and the control of "Procedure: watch checklist".
3. Preventing the lack of communication requires the element of "OOW must receive warning alarms and validate it before press acknowledge button", which needs the resilience ability of learning that demands the resource of "Ensure to develop alarms management procedure" and the control of "Procedure: provide guideline for bridge alarms and Training: alarms management".
4. Preventing an unsafe act requires the element of "OOW should know how to respond to the received alarm or call captain", which needs the resilience ability of responding that demands the resource of "captain ensures OOW will not hesitate to call him" and the control of "Method: friendly encouraging environment for communication".

Table 7-5 planning process of resilient safety system to Mitigate from accident and damage

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
Mitigate from Accident and damage	Mitigate unsafe act	Utilise bridge navigation technology (ECDIS/ radar)	Plan /prepare	Bridge team familiar with navigation technology	Procedure: organisation and master validate the knowledge
	Mitigate from unnoticed risky cause	Use navigation technology alarms	Absorb	OOW able to deal with alarms	Training: alarm system
	Mitigate from an event acceleration	Assess the situation to act early to avoid or call master	Recover	Navigation risk assessment and able to take action	Training: simulator Method: (E.g. drop anchor ready , emergency stop)
	Mitigate from confusion after an event took place	actions must be taken after an accident	Adaptation	provide a guidance of the actions must be taken after an accident	Procedure: guidance (event checklist) Training: check the guidance during emergency drills

The failure of the alarm management task caused collisions, groundings and contacts, which resulted in damaged ships and pollution. For that all the mitigative barriers must include safety performance elements and resilience enhancement abilities. **Error! Reference source not found.** shows the processes of mitigating he inadequate alarm management task failure that lead to Accident and damage include the following:

1. It is vital to mitigate the unsafe act error by providing the organisational element of "Utilise bridge navigation technology". This function and element require the resilience ability of Plan /prepare that is demanding the resource of "Bridge team familiar with navigation technology" and the control of "Procedure: organisation and master validate the knowledge".
2. Mitigating the unnoticed risky cause error requires the element of "Use navigation technology alarms", which requires the resilience ability of absorbing that demands the resource of "OOW able to deal with alarms" and the control of "Training: alarm system".

3. Mitigating the event acceleration requires the element of "Assess the situation to act early to avoid or call master", which needs the resilience ability of Recovery that demands the resource of "Navigation risk assessment and able to take action" and the control of "Training: simulator and Method: (E.g. drop anchor ready, emergency stop)".
4. Mitigating the confusion after an event took place requires the element of "actions must be taken after an accident", which needs the resilience ability of adaptation that demands the resource of "provide a guidance of the actions must be taken after an accident" and the control of "Procedure: guidance (event checklist) and Training: check the guidance during emergency drills".

Table 7-6 planning process of resilient safety system to Mitigate the Pollution

Safety Performance			Resilience Enhancement		
Purpose	**Barriers Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
Mitigate from Pollution	Mitigate unsafe act	Provide Shipboard Marine Pollution Emergency Plan (SOPEP)	Plan /prepare	Develop and update the SOPEP regularly and provide SOPEP equipment, the emergency drills onboard ship must cover different types of pollutions	Procedure: organisation validate shipboard personnel knowledge Training: using SOPEP in drill
	Mitigate from unnoticed risky cause	After an accident (collision, grounding and contact) the bridge team must check every allegation of pollution	Absorb	Ensure the collision, grounding and contact checklists cover the pollution aspect and searching for pollution signs (E.g. ship both sides and the engine room bilges)	Procedure: checklist Training: using the checklist during emergency drills
	Mitigate from an event acceleration	The shipboard personnel must perform the SOPEP	Recover	Ensure the response is quick and the communication is unambiguous with maintaining the BRM	method: develop assessment system for emergency drills performance
	Mitigate from confusion after an event took place	Master must be familiar with the actions must be taken after a pollution event	Adaptation	organisation must provide guidance of pollution response (E.g. inform authority, organisation, collect sample)	method: guidance Training: check the guidance during emergency drills

The failure of the alarm management task caused collisions, groundings and contacts, which resulted in damaged ships, pollution, injuries, fatalities, and sunken ships. For that all the mitigative barriers must include safety performance elements and resilience abilities resources. **Error! Reference source not found.** shows the rocesses of mitigating the inadequate alarm management task failure that lead to pollution include the following:

1. It is vital to mitigate the unsafe act error by providing the organisational element of "Provide Shipboard Marine Pollution Emergency Plan (SOPEP)". This function and element require the resilience ability of Plan /prepare that is demanding the resource of "Develop and update the SOPEP regularly and provide SOPEP equipment, the emergency drills onboard ship must cover different types of pollutions" and the control of "Procedure: organisation validate shipboard personnel knowledge and Training: using SOPEP in drill".
2. Mitigating the unnoticed risky cause error requires the element of "After an accident (collision, grounding and contact) the bridge team must check every allegation of pollution", which requires the resilience ability of absorbing that demands the resource of "Ensure the collision, grounding and contact checklists cover the pollution aspect and searching for pollution signs (E.g. ship both sides and the engine room bilges)" and the control of "Procedure: checklist and training: using the checklist during emergency drills".
3. Mitigating the event acceleration requires the element of "The shipboard personnel must perform the SOPEP", which needs the resilience ability of Recovery that demands the resource of "Ensure the response is quick and the communication is unambiguous with maintaining the BRM" and the control of "method: develop assessment system for emergency drills performance".
4. Mitigating from confusion after an event took place requires the element of "Master must be familiar with the actions must be taken after a pollution event such", which needs the resilience ability of adaptation that demands the resource of "the organisation must provide in guidance for pollution response (E.g. inform authority, organisation, collect sample)" and the control of "method: guidance and Training: check the guidance during emergency drills".

7.6. Bow Tie Framework and FRAM Model

Figure 7-6 below presents the development of the resilience system of safety barrier by using the Bow-tie technique and the Functional Resonance Analysis Method (FRAM). This step in the model focuses on designing both sides of the bow tie that demonstrate safety performance function and elements. It is a useful tool, which helps to present the scenario of an event in a simple way that initiates by the causes and end with the impacts and consequences.

Figure 7-7 below shows the FRAM model application that provides an explanation to the relations among the safety functions and elements and the resilience enhancement. The resilience abilities are demonstrated in different colours which are the Anticipate and Plan/prepare are brown, Monitor and Absorb is purple, Learn and Recover are blue and response and Adapt are green. The red elements in the model represent the bridge alarm management task (critical function) and the failure impacts (accident/damage and pollution). The resilience abilities take different forms to improve the functionality of the safety elements such as resources, precondition and control.

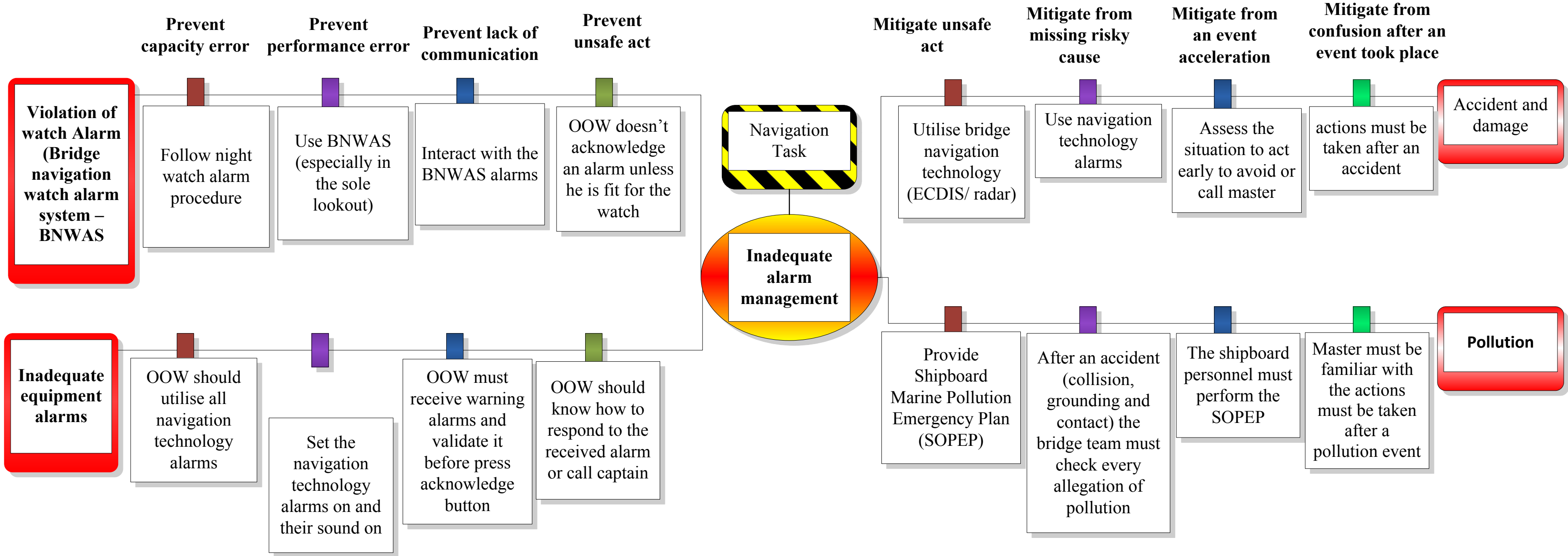


Figure 7-6 Inadequate alarm management Bow-tie

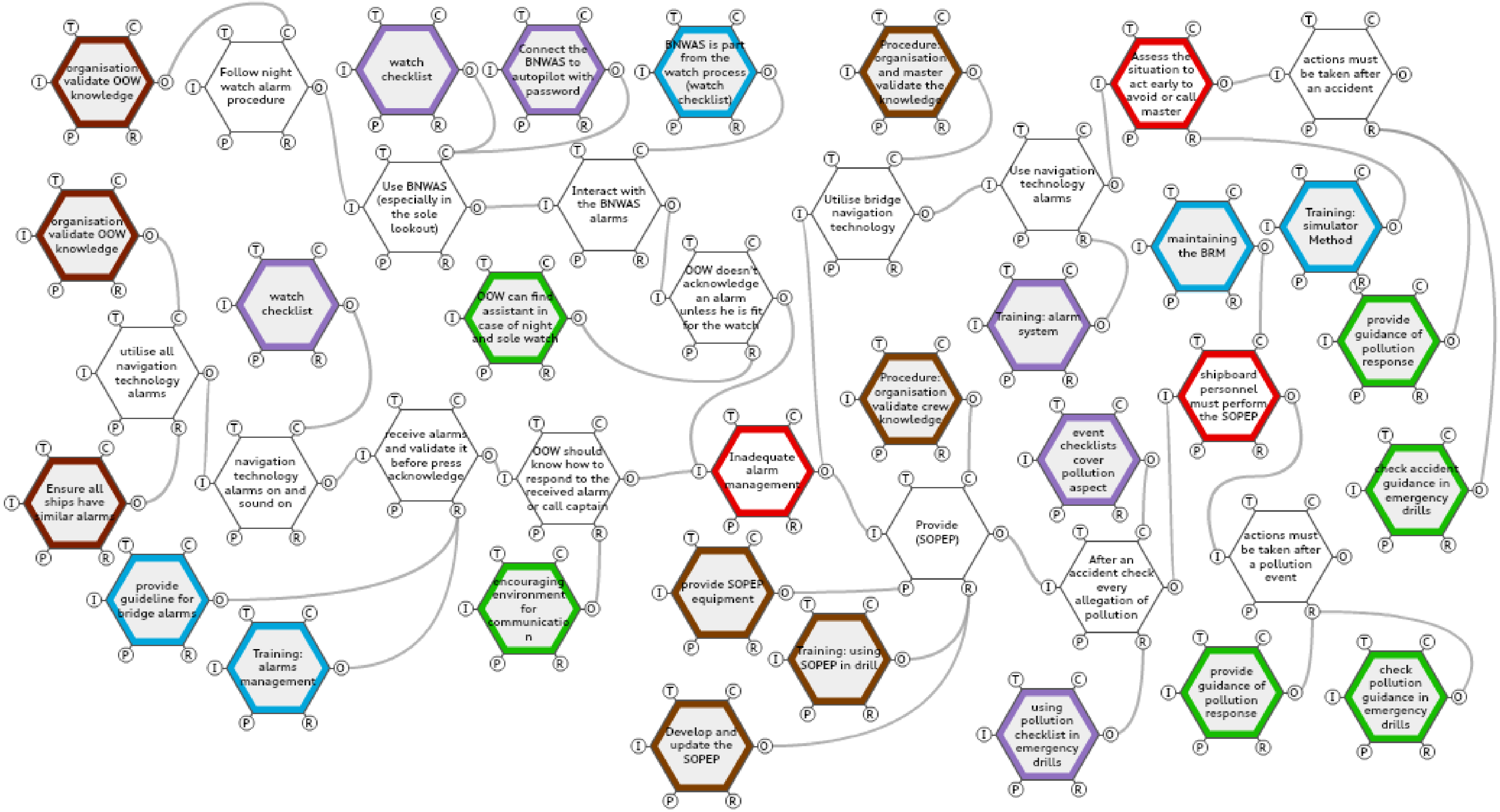


Figure 7-7 Inadequate alarm management FRAM

7.7. Guidelines and Recommendations after Applying the Method

To improve the alarm on the navigation bridge:

1- The shipping organisation should provide procedure to validate the knowledge of OOW about night watch procedure and bridge technology including alarms system.

2- Ensure utilising BNWAS on night watch and become mandatory during sole lookout watch and include this requirement to bridge procedure (watch checklist). It is recommended to connect BNWAS to the autopilot with a password to ensure the operation of the watch alarm.

3- Adding the use of the bridge technology alarms to the watch checklist.

4- Ensure BNWAS is part of the watch process, and OOW should interact with it (watch checklist).

5- The organisation should develop alarms management procedure and training to ensure OOW know how to respond to the received alarm

6- OOW does not acknowledge an alarm unless he is fit for the watch. Ensure OOW can find an assistant in the case of night and sole lookout watch (Master's standing orders).

To improve the Mitigation

1- The shipping organisation should provide procedure to validate the knowledge of OOW about bridge technology including alarms system.

2- Organisation should improve OOW risk assessment and action via simulator training (E.g. drop anchor ready, emergency stop).

3- Captain must be familiar with the actions that must be taken after an accident event. The organisation must provide guidance on accident response. The guidance should be checked during emergency drills.

4- Provide or develop Shipboard Marine Pollution Emergency Plan (SOPEP), ensure it is regularly updated, and provide SOPEP equipment. The emergency drills onboard ship must cover different types of pollutions and using the SOPEP. The organisation validates shipboard personnel knowledge about the SOPEP.

5- After an accident (collision, grounding and contact) the bridge team must check every possible scenario for pollution. Ensure the collision, grounding and contact checklists cover the pollution aspect and searching for pollution signs (E.g. ship both sides and the engine room bilges). The bridge team must use the checklists during emergency drills to help bridge team to be familiar with their use.

6- The shipboard personnel must perform the SOPEP and ensure their response is quick and their communication are unambiguous with maintaining the BRM. Develop assessment system for emergency drills performance.

7- Captain must be familiar with the actions that must be taken after a pollution event. The organisation must provide guidance on pollution response (E.g. inform authority, organisation, collect sample). The guidance should be checked during emergency drills (pollution prevention).

7.8. Summary

Integrating the principles of resilience engineering with the concept of barrier management is a novel approach for the operation of the ship's bridge. The intention is to improve the safety and reliability of the navigation operation by utilising the barriers effectively. This chapter demonstrated the process of developing resilient safety management system. The model is applied on eight failed tasks which are misjudgement, inadequate emergency response, inadequate situational awareness, Poor lookout, Poor alarm management, poor leadership, ineffective Passage Planning and Poor learning (See Appendix A). The alarm management task of navigation bridge is selected as an example to show the process application of the method. The application of the method shows optimistic improvement to the barrier management system by explaining the relations among the functions. It also includes the resources and control to enhance the resilience of the function. The classic barrier management method forms passive functions and elements to prevent or mitigate events. The resilience abilities have proactive characters that improve the operation quality. The anticipation, monitoring, learning, and responding become part of the system, which plays different roles than the common barriers. The model provides an in-depth monitoring function that helps to recognise risks in the early stage. The resilience engineering elements improve the strength of the bridge operation system by recognising the anticipation solutions and implement them for future risk prevention. The navigation bridge becomes flexible in accepting new codes of behaviour or procedure, since it is open to learning. The responding function can become more effective because of the accumulation of resilience function.

Chapter 8. Case study: Navigation Simulator Experiments for Evaluating the New Resilience Based Bridge Procedures

8.1. Introduction

The safety record of the maritime transportation domain has had a continuous development over the years. Nevertheless, accidents continue to happen and with the expanding size of passenger and cargo vessels, the consequences of not handling the incidents optimally would become critical (EuropeanCommission, 2016). The European Maritime Safety Agency, EMSA (2015) recorded 9180 incidents between 2011 to 2014, that resulting damage to two-thirds of the ships, 390 fatalities and 3250 injuries. EMSA assumes that human error contributes to 67% of these events. Mate (2012) stated that the most significant hazard that a shipowner faces is navigational mishaps as claims of incompetent navigation are the biggest single reason for shipping insurance claims which are relating to the cost. The Standard club's experience gives enough evidence of that, with 85 claims of higher than $1 million were of which over 50% directly associated to navigational cases (Mate, 2012).

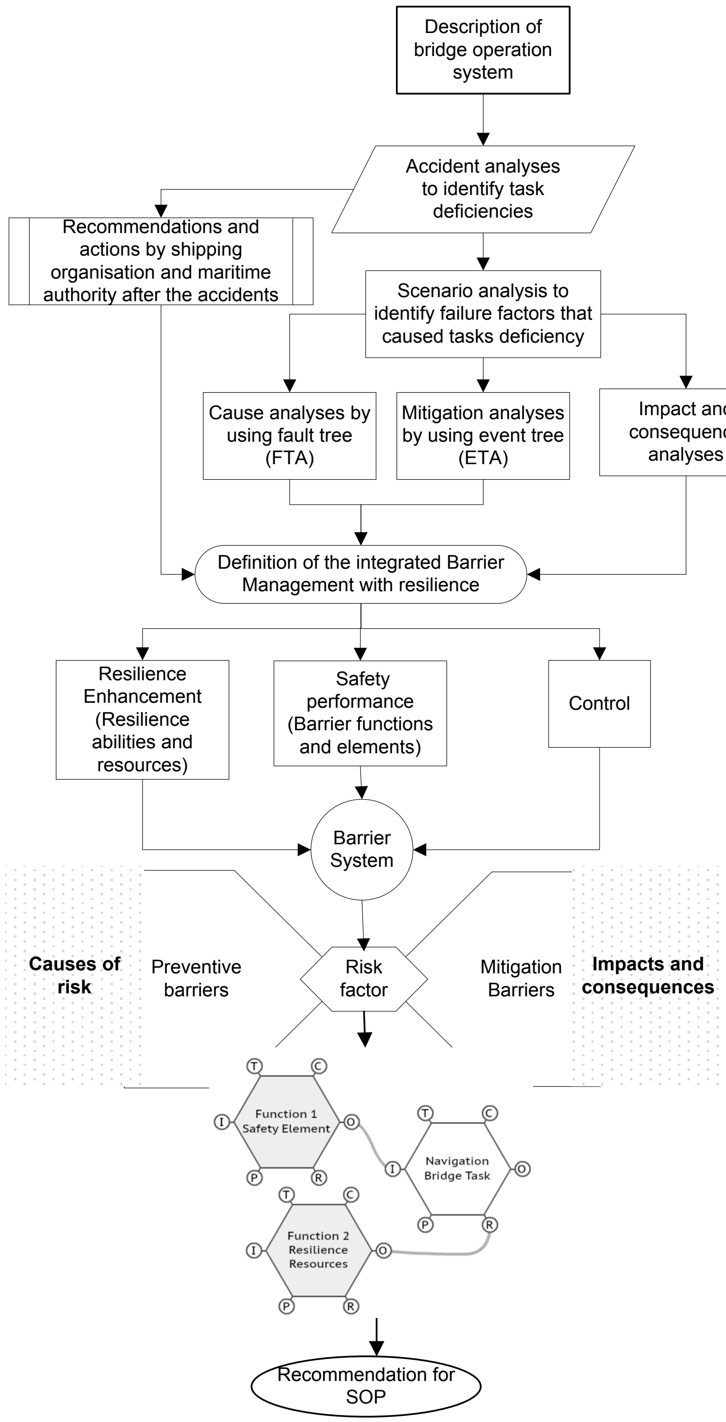


Figure 8-1 System diagram of building a bow-tie framework

This fact demonstrates the need to improve the safety standards of the navigation bridge. Figure 8-1 presents a new approach of barrier management for the execution of the navigation bridge system which was developed in a framework that combines the principles of resilience engineering to enhance shipping safety. The work process contains the risk analysis, the definition of the barriers including fundamental resilience, developing application methods and a design scheme to control and maintain the barriers. The approach introduces resilience elements: anticipation, monitoring, learning, and responding.

Table 8-1 Summary of the Accidents Analysis between 2010- 2015 (MAIB)

Tasks Failure	Sub-Factors and recurrence number	Events and recurrence number	Impact and recurrence number
Misjudgement	- Inadequate ship behaviour Perception: 15 - Inadequate traffic risk perception: 13 - Fatigue & vigilance: 1 - Violation of Passage Planning procedures:3 - Abandoned bridge: 6 - Inadequate utilisation of technology: 8 - Violation of forecast procedures: 4 - Violation of COLREGs: 4 - Excessive workload: 1 - Violation of Pilotage procedures: 3 - Diminished motivation: 7 - Lack of vision: 2	Collisions: 19 Groundings: 8 Contacts: 16	Damage: 38 Pollution: 6 Injury: 5 Fatality: 14 Sink: 2
Inadequate Emergency Response	- Violation of emergency procedures:24 - Inadequate utilisation of technology: 1 - Violation of COLREGs: 2 - Violation of Call Master procedures: 4	Collisions: 10 Groundings: 9 Contacts: 9	Damage: 33 Pollution: 2 Injury:1,Fatality: 12 Sink: 1
Inadequate Situational Awareness	- Fatigue & vigilance: 12 - Abandoned bridge: 1 - Alcohol use: 3 - Violation of COLREGs: 1 - Excessive workload: 4 - Violation of Pilotage procedures: 1	Collisions: 6 Groundings: 12 Contacts: 6	Damage: 21 Injury: 1 Pollution: 2
Poor Lookout	- Sole on bridge: 15 - Lack of communication or coordination: 1 - Violation of COLREGs: 2	Collisions: 10 Groundings: 9	Damage: 17, Pollution:2 Fatality: 11, Sink: 1
Poor Alarm Management	- Violation of watch Alarm:10 - Inadequate equipment alarms: 4	Collisions: 2 Groundings: 11 Contacts: 1	Damage: 13 Pollution: 2
Poor leadership	- Lack of communication or coordination: 9	Groundings: 2 Contacts: 7	Damage: 6
Ineffective passage Planning	-Violation of Passage Planning procedures: 9	Collisions: 1 Groundings: 5 Contacts: 3	Damage: 6
Poor learning	- Lack of familiarisation and training onboard: 8	Collisions: 2 Groundings: 2 Contacts: 4	Damage: 8 Injury: 1 Pollution: 1

Table 8-1 shows the result of examining ships accident that resulted owing to operation failures on the navigation bridge. Deficiencies on a navigation bridge lead to three types of accidents: collision, grounding and contact. The outcome of the accidents analysis found that 56 out of 127 ship accidents caused by navigation failures on the bridge that occurred between 2010 and 2015. The Marine Accident Investigation Branch (MAIB, 2016) was the source of the collected data. This research found eight main causes attributed to 20 sub-factors, with five possible consequences.

Table 8-2 shows an example of navigation task and resilience resources

Judgment		
Operation elements	**Resilience ability**	**Resources/ Control**
Dealing with Excessive workload (master not communicate with crew)	Anticipation	Captain/ OOW must by familiar with bridge resource management Training: BRM
	Monitoring	brief crew about manoeuvring Procedure: departure and arrival checklists
	Learning	Ensure two ways communication Procedure: departure and arrival checklists
	Responding	Out loud thinking Procedure: departure and arrival checklists

The application of the method produced solutions to improve the resilience of the navigation bridge, which are incorporated into the navigation bridge procedure. Table 8-2 shows an example of navigation task and resilience resources. The case study aims to validate the implementation of the resilient solutions. The maritime simulator helps to perform the defined scenarios to assess the quality of the bridge team performance. The experiment includes two groups and each bridge team contains 1 Officer of the watch (OOW), 1 Lookout and 1 helmsman. The first team will perform the scenarios by applying the traditional procedures and checklists, which is used by the ships that involved in the accidents that discussed above. The second group implement the new developed procedure and checklists that includes resilience solutions. Both teams perform the tasks without knowing the scenarios' details, which give more genuine and random action to their behaviours. The experiment includes five different scenarios which are normal navigation, passing agreement, restricted visibility, shallow water effect, and pilot onboard. The resilience abilities (anticipation, monitoring, learning and responding) of the two groups will be assessed according to these indicators: 1- Ability for Judgment, 2- Emergency preparation, 3-Situation awareness, 4-Lookout quality, 5-Alarm Management, 6-Leadership, 7-Passage planning, 8- Learning environment on bridge.

8.2. The experiment elements

8.2.1 People

The number of people who volunteer to join the experiment in the full mission simulator is 6. Four of them have seafaring background and qualification. The remaining two come from different maritime background. All of them are PhD candidates and working in several maritime subjects but generally are relating to the safety and human factors. The volunteers are divided into two groups A and B, and each one has 1 OOW, 1 Lookout and 1 helmsman. The scenarios to be tested will not be known by both groups and they will be instructed only on the day of the simulator tests and they take part only once.

8.2.2 Navigation Bridge

The experiment location was in *the City of Glasgow College* campus. TRANSAS 360° full mission Navigation bridge simulator (Figure 8-2) was used to perform the scenarios. It has the capacity of training and skill assessment such as familiarisation, watch-keeping, emergency preparation and bridge resources management. It has variety of navigation technology equipment that exist on the commercial vessels, for instance, radar, ECDIS, VHF, GMDSS, echo sounder, GPS, off-course alarm, etc. The simulator provides different operation conditions including several weather conditions. It also has the ability to imitate the navigation of bridge of different type of ships, such as Tanker, tug, supply boat etc. The external environment contains diversity of traffic and weather conditions which can apply to various maritime locations to offer real manoeuvring situation. For the experiment 3 different vessels were used which are a container vessel 4000TEU, an Offshore Supply vessel and a panamax Bulk carrier.

Figure 8-2 Photo of TRANSAS 360° full mission Navigation bridge simulator

8.2.3 Documents

The bridge procedures are distributed to the bridge team to help them to perform their tasks during the bridge simulator scenarios. For the experiment purpose, there are two different documents are distributed to each group: Group A receive the classic bridge procedure that exists in the commercial ships. The group B receive the newly developed resilient based procedures, which are the result of the methodology application that includes the safety and resilience solutions (see APPENDIX B).

The developed resilient based procedures for group B included:

1- The sentences of the checklist elements are short and unambiguous as possible.

2- Focus on the safety elements that important for each manoeuvre condition in a way that improve the performance and not affect the safety.

3- The checklists included the sign ⊘ before some elements which meant that this step must be completed before going to the next step.

4- The checklists included the sign ☝ before some elements which meant that this step must be done by close communication methods (Plan, Execute and verify)

5- Bridge familiarisation checklist included small checklists for the critical equipment such as the Radar and ECDIS to provide extra details to improve the bridge familiarisation. It also covered more points about the alarms and the safety performance of the navigation.

6- The Departure checklist included:

- The master brief the bridge team about the manoeuvring plan
- The master asked the bridge team about their concern
- The Master or OOW must provide a briefing to the lookout about what he could expect
- The master is remind about the important of out loud thinking
- The master remind about the important of the two-ways communication

7- The restricted visibility checklist included:

- Check for the future risk on the chart
- The master or OOW must provide a briefing to the lookout about what he could expect
- The master remind about the important of the out loud thinking
- The master remind about the important of the two-ways communication

7- Pilot checklist included:

- Master and bridge team define what pilot must know about bridge condition
- Master and OOW understand that the pilot is part from the bridge team (inform pilot)
- OOW and master must communicate with the pilot and challenging his decisions
- OOW should perform normal watch as possible and remain active during piloting
- Master not leaves bridge before OOW is ready for the watch

8- Arrival checklist included:

- The master brief the bridge team about the manoeuvring plan
- The master asked the bridge team about their concern
- Master or OOW must provide a briefing to the lookout about what he could expect
- The master is remind about the important of the out loud thinking
- The master remind about the important of the two-ways communication

8.2.4 Evaluation forms

Evaluation forms are used to measure the bridge team safety and resilience performance. The two groups are assessed according to these indicators: 1- Ability for Judgement, 2- Emergency preparation, 3-Situation awareness, 4-Lookout quality, 5-Alarm Management, 6-Leadership, 7-Passage planning, and 8-Learning. Each indicator has elements which are the safety and resilience factors. The performance of the application of these factors will be measured during the observation of each scenario. For the evaluation standard the Likert scale is applied, which is common method, which is used to scale responses in survey research. In our case, it has five choices between 1 (extremely poor) to 5 (very good) (see APPENDIX C).

8.2.5 Reliability of scale analysis

Cronbach's Alpha method was presented by Lee Cronbach in 1951 to offer a measure of internal consistency of a scale (reliability), which is displayed as a number between 0 and 1. The 0.00 outcome indicates that there is no consistency in the measurement and 1.0 is the perfect consistency in the measurement. The 0.70 result determines that 70% of the variance in the scores is reliable variance and 30% is error variance. The benchmark of the reliable score is 0.7, and lower than that needs to be assessed again.

8.3. The process of the experiment

The experiment has 5 different scenarios:
1- Normal Navigation
2- Passing agreement
3- Restricted visibility
4- Shallow water effect
5- Pilot on board

At the beginning of the experiment, both groups received checklists which are part of the bridge procedures. First, the familiarisation takes place according to the different checklists. It covers the navigation technology and the bridge procedures. In this step, we try to measure the qualification of both groups to recognise if the new checklists improved the bridge team qualification performance. The bridge team is given half an hour for normal operation to familiarise them self with the navigation bridge. During this time they are going to pass through shipping traffic that helps to evaluate their seamanship and bridge technology utilisation. Second, the weather condition is changed that affect the bridge visibility, which is an important scenario to assess the emergency preparation of the crew. Third, the ship sails in shallow water that exposes the ship to the risk of grounding because the squat affect. In this stage, the performance of the bridge team is assessed according to their risk recognition. Later on, the pilot arrives on the bridge leading the ship to a port. During this manoeuvre the pilot will act unsafely (deliberately) and will use a shortcut passage which directs the ship to the risk of grounding. The bridge team also is assessed in terms of their reaction and actions while their response time is recorded. Both groups had no information about the scenarios which are going to navigate through. The scenarios help to assess the effectiveness of the resilience resources that was integrated into the bridge operation procedures. Reaction of crew in groups are compared to see the effect of resilience resources compared to standard procedures.

8.4. Group A & B Discussion

The first day of the experiment was on the 18th October 2017. Three people volunteered in the group A, which are: 1 Officer of the watch (OOW), 1 Lookout, and 1 Helmsman (Figure 8-3). At the beginning of the experiment, the group members received an explanation about the general requirements, such as their roles among the bridge team and they must act naturally during the scenario. Also, they received the bridge operation procedures that exist in the commercial ships.

Figure 8-3 The bridge team of group A

The second day of the experiment was on the 19th October 2017. Three people volunteered in group B, which are: 1 Officer of the watch (OOW), 1 Lookout, and 1 Helmsman (Figure 8-4). Before the experiment started, the group members received an explanation about their duties and the importance of acting naturally during the experiment. The bridge team received the newly developed resilience based bridge procedures (See APPENDIX C).

Figure 8-4 The bridge team of group B

Both days, the bridge was filmed recording both team actions in each scenario so that they can be watched and observed their behaviour comparatively.

On the 8th November 2017 a workshop organised involving experts panel to evaluate the behaviour of the bridge team in all scenarios of groups A and B. Evaluation forms were distributed which contains different questions for each scenario (see APPENDIX C). The meeting had 6 members who are working in different fields of maritime human factors (Figure 8-5). They watch the recorded videos of the scenarios and observe the bridge teams behaviour and reaction. The results of the experiment were discussed and analysed below.

Figure 8-5 the expert panel during the scenarios evaluation

8.5. First scenario: bridge familiarisation and normal navigation

The familiarisation of both groups will take place by using the checklists that are prepared specifically for each group. The group A is given the classic checklists that are generally used in the bridge of the commercial ships. Group B received the developed checklist that includes the resilience enhancement. Table 7 14 presents the improved elements of the group B procedure. In the beginning of the scenario, the simulator instructor familiarise each group about the bridge technology since he is the most suitable person, who has the experience of the navigation bridge simulator. After the familiarisation completed the bridge team have 30 minutes of free sailing which helps to improve their control over the bridge technology. A container vessel 4000TEU is used in this scenario. The departure checklist application is in Southampton port and after that the sailing is in the Southampton waters. During the execution of the scenarios several factors will be assessed:

1- Bridge team's ability to recognise the ship behaviour Perception (Judgement task).

2- Bridge team's familiarisation and training onboard (Learning task).

3- Communication or coordination which is the two-way communication between OOW and the lookout (Leadership and Lookout tasks).

4- Bridge team's ability of technology utilisation (Judgement task)

Group A: At the beginning of the scenario, the simulator instructor started the familiarisation process for group A by using the classic checklist. It was noticeable that the process was quick and in several occasions he asked the group if they understand the step and without waiting for their confirmation would pass to the next. No one asked question, made statement whether they understood the instructions or challenged the provided information. Before the ECDIS familiarisation initiated, he simply asked if they have studied it before and when they said yes the step was skipped. All the time he never asked for confirmation especially near to the end of the familiarisation. The familiarisation was completed after 14 minutes.

Group B: The simulator instructor performed the familiarisation process with group B by following the developed checklist. It was very obvious that the ⊘ sign in the beginning of the checklist steps prevented the instructor from going fast or skipping any steps and he had to allocate more time to provide extra clarification. The ☝ sign make the instructor ask the bridge team for confirmation, which allowed them to ask questions and insist for clarification. For example, the instructor did not know one of the familiarisation points but because the ⊘ sign he could not skip it. Each one of the new radar and ECDIS checklists took around 10 minutes. The familiarisation completed after 39 minutes. The time difference between both groups is 25 minutes. After the familiarisation competed, both groups had around 30 minutes of normal bridge operation. They were assessed during the navigation to evaluate the quality of the familiarisation procedure.

8.5.1 Analyses of assessments by experts panel

The 6 members of the expert panel evaluated the performance of groups A and B in each scenario after watching the recorded videos and observe the bridge team behaviours and reaction. They filled evaluation forms individually which contain different questions and indicators (See APPENDIX C).

8.5.2 Reliability of scale analysis

Table 8-3 presents the results of the reliability of scale analysis

Reliability of scale for Group A

Case Processing Summary

		N	%
Cases	**Valid**	6	100.0
	Excluded[a]	0	0.0
	Total	6	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
0.72	**4**

Reliability of scale for Group B

Case Processing Summary

		N	%
Cases	**Valid**	6	100.0
	Excluded[a]	0	0.0
	Total	6	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
0.70	**4**

The sample size which was included in the reliability of scale analysis is 6 people (Table 8-3). All of their answers are valid and there are no excluded items or missing values. Cronbach's Alpha measurement is 0.72 for group A and 0.7 for group B that means around 70% of the variance in that score would be considered true score variance or reliable internal consistency and reliable variance.

8.5.3 Statistical Analyses

Table 8-4 presents the statistics analysis result of the expert panel responses

Descriptive Statistics	N	Group A Mean	Group B Mean	Std. Deviation A	Std. Deviation B	Group B higher by
Q 1 Judgement task (ship behaviour perception)	6.0	2.0	4.2	0.89	0.75	**110%**
Q 2 Learning task	6.0	2.3	4.5	0.52	0.55	**96%**
Q 3 Leadership and Lookout tasks	6.0	1.8	5.0	0.75	0.00	**178%**
Q 4 Judgement task (technology utilisation)	6.0	1.8	4.0	0.75	0.63	**122%**
Average		**40%**	**89%**			**124%**

The Table 8-4 presents the statistics analysis result of the expert panel responses. In the normal operation scenario, the bridge teams of group A and B applied different procedures, and the safety and the quality of the operation were evaluated to find which procedure is beneficial. Table 8-13 presents the improved elements of the group B procedure. Performance of each group was measured by using the scale of (1 to 5) where 1 is considered extremely poor and 5 is very good. Application of the classical procedure for group A and the newly developed procedure for group B have different means. The mean of group A was between (1.8 to 2.3), and group B was between (4.2 to 5). From these means, we can understand that group B performed much better than group A. The standard deviations are almost same that is less than 1, which proves that the classical and the new procedure have same consistent responses according to the performance of each group. The odd response was Q3B which has 0 standard deviation and spread out data which means all the responses of the expert panel are same.

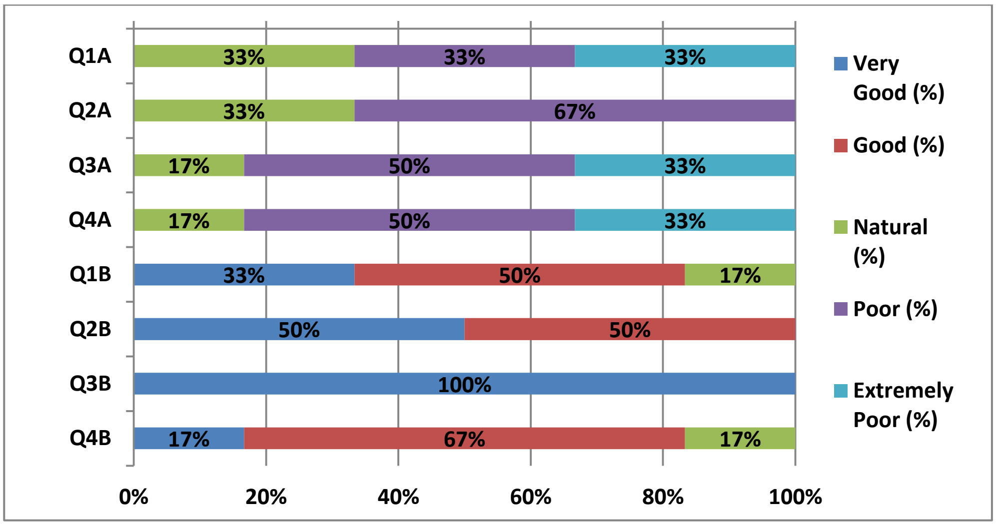


Figure 8-6 illustrates the frequency percentage distribution of the simulator experiment survey responses

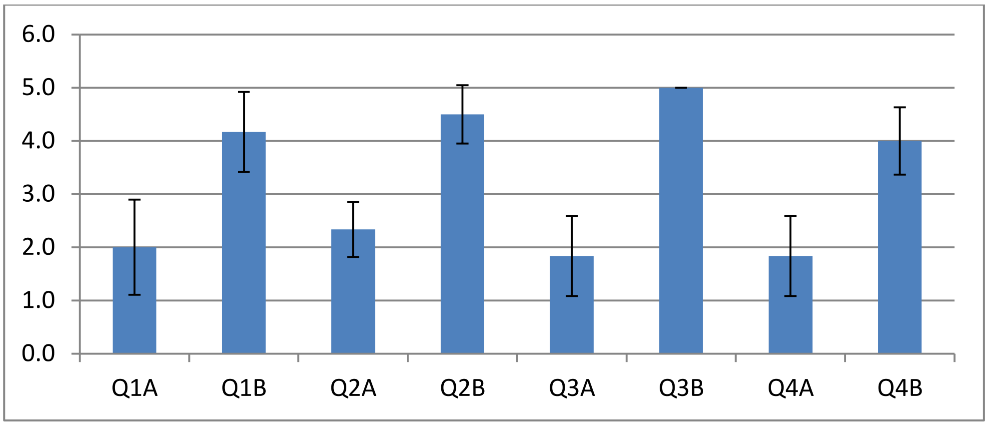


Figure 8-7 shows the comparison of the mean and the standard deviation of each group performance

The results clearly show that resilience based procedures improve Bridge team's performance significantly in some cases 178%.

Q1 Judgment task (ship behaviour Perception)

The judgment indicator was affected by the bridge team's ability to recognise the ship behaviour. The group A started the scenario with a lot of doubt. While the team B showed confident bridge operation. Based on the expert panel evaluation for the judgement task of both groups, the perception of bridge team A was between neutral to poor according to 67% of the responses, and the bridge team B was between very good to good according to the 83% of the answers (Figure 8-6). Q1 is related to the judgment task and it has a mean of 2.0 for group A and 4.2 for group B, which proved that the new procedure enhanced the judgment task of group B by 110% (Figure 8-7). The standard deviation of group A is 0.89 and B is 0.75 which shows close consistency of the responses. Understanding the ship behaviour requires information to be received from different sources such the technology and observing the sea state. The developed procedure for group B reinforced the technology utilisation which advances the OOW's ability for the identification of the ship conduct. The lookout reports were improved significantly after adding the key the two-ways communication in the procedure.

Q2 Learning task

The bridge team's learning task is impacted by the familiarisation and training onboard of the crew. The group A focused on the technology more than observing the sea. The bridge team of group B started the scenario in an organised manner, and each member was familiar with his duty. Based on the expert panel evaluation of the learning for both groups, the familiarisation of bridge team A was poor according to 67% of the responses, and the bridge team B was very good according to 50% of the responses and good by the remaining answers (Figure 8-6). Q2 is related to the learning, and it has a mean of 2.3 for group A and 4.5 for group B, which proved that the new procedure improved the learning performance of group B by 96% (Figure 8-7). The standard deviations of both groups are around 0.5 that shows close consistency of the responses. The developed familiarisation checklist includes two significant conditions that enhance group B's competence with regards to learning about the bridge. The first condition is adding block signs before some steps to demonstrate that these steps must be completed before going to the next. This step eliminates any possible shortcuts or incomplete tasks. Another additional resilience step is the close lop communication methods (Plan, Execute and verify) which allow the bridge team to ask and clarify about several points. Also, the small checklists of the ECDIS and radars provided extra detail to be understood by the team B.

Q3 Leadership and Lookout tasks

The communication and the coordination among the bridge team are important elements for the success of the leadership and the lookout tasks. The OOW of group A ignored the reports from the lookout in several times and did not communicate with the rest of the crew as it should be. The OOW of group B was showing his intention clearly through the out loud thinking. The bridge team members provided learning environment and two-way communications between OOW and the lookout. Based on the expert panel evaluation of the leadership and lookout tasks for both groups, the communication and coordination of bridge team A was rated as neutral to poor according to 67% of the responses, and the bridge team B was rates as very good according to 100% of the answers (Figure 8-6). Q3 is related to the lookout and leadership tasks, and it has a mean of 1.8 to group A and 5.0 to group B which demonstrated that the new procedure improved the performance of group B with regards to the lookout and leadership tasks by 178% (Figure 8-7). The standard deviation of group A is 0.75 and B is 0 which means that the consistent responses of B are perfect, and the highest score of group A was not even close to the score of group B. There are vital resilient elements added to the departure and restricted visibility checklists that improved the lookout and leadership tasks for group B. It is essential that the master brief the bridge team about the manoeuvring plan and asked them about their concern to enhance the unity and the awareness of all the team members. Another point added which is reminding the master about the importance of the out loud thinking to show his intention to the bridge team especially during safety critical conditions to create shared situational awareness. Another resilience element included in group B is the importance of the two-ways communication between the master (OOW) and the lookout to remind them about the teamwork.

Q4 Judgement task (technology utilisation)

The judgment of the bridge team is affected by the technology competence of the crew. Based on the expert panel evaluation of the judgement task for both groups, the technology utilisation of bridge team A was rated as neutral to poor according to 67% of the responses, and the bridge team B was rated as very good to good according to 67% of the answers (Figure 8-6). Q4 is related to the judgment task and it has a mean of 1.5 for group A and 4.0 for group B, which proved that the new procedure improved the judgment task of group B by 122% (Figure 8-7). The standard deviation of group A is 0.75 and B is 0.63 which show the responses are consistent. Developing the small checklists to utilise specific equipment such as ECDIS and radar improved the knowledge of group B about the technical details, which allow them to utilise the bridge technology much better than group A.

8.6. The Second Scenario, Passing agreement:

The International Regulations for Preventing Collisions at Sea (COLRG's) requires OOW to assess the passing risk of his and other ships by all possible navigation methods. In this scenario, different ships contact the bridge by the VHF radio to ask for passing agreement and which side should they pass. In the new procedure, a comment is added on the VHF for the group B which is instructed by the OOW not use the VHF radio for passing agreement. Beside they the applied the new familiarisation checklists and departure checklist that include the new procedure. Table 8-13 presents the improved elements of the group B procedure. A container vessel 4000TEU is used in this scenario to sail in the Southampton waters. From all these conditions several factors will be assessed:

1- The Bridge team's traffic risk perception (Judgement task).

2- Communication or coordination which is the two-way communication between OOW and lookout (Leadership and Lookout tasks).

3- Bridge team's ability of technology utilisation (Judgement task).

4- COLREG's application, OOW should avoid using VHF radio for collision avoidance and passing agreement (Judgement and Situational Awareness tasks).

5- OOW communicates with crew during excessive workload (Bridge team judgement and Situational Awareness tasks).

Group A: The passing agreement scenario is about sailing in different traffic condition to evaluate the bridge ability to assess the ships traffic status. They should use their knowledge and bridge technology to assess the situation. In the scenario, OOW of group A broke the COLREG's procedures in several occasions by using the VHF radio for passing agreement with other ships, which is the result of poor traffic perception. The communication among the bridge team was insufficient especially during the excessive workload. The lookout could not recognise the risk in several occasions, and the OOW was not showing his intention to the bridge team. The utilisation of the bridge technology was not sufficient enough for the normal bridge operation. The group A scenario was completed after 36 minute.

Group B: The traffic perception of group B was good. All the targets and the critical condition such as the low water depth were recognised by the OOW and the lookout. The working environment was pleasant which allows the team to communicate efficiently. The OOW was showing his intention by the out laud thinking and the lookout informed the bridge team about all the recognised risks followed by the OOW confirmation. The utilisation of the bridge technology was very good and the OOW identified all the targets and the encountered risks. One important resilience element of the developed procedure is to add a note on the VHF for avoiding using the radio for passing agreement, and it worked very well. Despite the fact that we added several dangerous crossing situations, the OOW did not use the VHF for passing agreement. During the excessive workload condition the bridge team showed good communication. The group B scenario was completed after 39 minutes.

8.6.1 The experts panel responses analyses

The 6 members of the expert panel evaluated the performance of groups A and B after for this scenario by watching the recorded videos and observing the bridge team behaviours and reaction. They use evaluation forms which contains different questions and indicators (See APPENDIX C)

8.6.2 Reliability of scale analysis

Table 8-5 presents the results of the reliability of scale analysis

Reliability of scale for Group A

Case Processing Summary

		N	%
Cases	**Valid**	6	100.0
	Excluded[a]	0	0.0
	Total	6	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
0.73	5

Reliability of scale for Group B

Case Processing Summary

		N	%
Cases	**Valid**	6	100.0
	Excluded[a]	0	0.0
	Total	6	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
0.75	5

The simple size included in the reliability of scale analysis is 6 people (Table 8-5). All of them are valid and there are no excluded items or missing values. Cronbach's Alpha measurement is 0.73 for group A and 0.75 for group B which are more than 70% of the variance. This means the score would be considered true score variance or reliable internal consistency and reliable variance.

8.6.3 Statistical Analyses

Table 8-6 presents the statistics analysis result of the expert panel responses

Descriptive Statistics	N	Group A Mean	Group B Mean	Std. Deviation A	Std. Deviation B	Group B higher by
Q 1 Judgement task (recognise traffic risk)	6.0	2.0	4.5	0.63	0.55	**145%**
Q 2 Leadership and Lookout tasks	6.0	2.5	4.3	1.22	0.82	**73%**
Q 3 Judgement task (technology utilization)	6.0	2.7	4.0	0.82	0.63	**50%**
Q 4 Judgement and Situational Awareness tasks (follow COLREG's)	6.0	1.5	4.0	0.55	0.63	**167%**
Q 5 Judgement and Situational Awareness tasks (communication during excessive workload)	6.0	1.8	4.7	0.75	0.52	**155%**
Average		**41%**	**86%**			**108%**

The Table 8-6 presents the statistical analysis result of the expert panel responses. The sample size is 6 people and all their responses are included in the statistical analysis. In the passing agreement scenario, the bridge teams of group A and B applied different procedures (Familiarisation checklists, departure checklists and adding notice of not use VHF radio for passing agreement to team B), and the safety and the quality of the operation were evaluated to find which procedure is more effective and beneficial. Table 8-13 presents the improved elements of the group B procedure. We measured the performance of each group by using the scale of (1 to 5) where 1 is considered extremely poor and 5 is very good. The application of the classical procedure of group A and the newly developed resilience based procedure of group B have different means. The means of group A were between (1.8 to 2.7), and group B were between (4.0 to 4.7). From these means, we can understand that group B performed much better than group A. The standard deviations are almost same which is around 1 or less, which proves that the classical and the new procedures have same consistent responses according to the performance of each group.

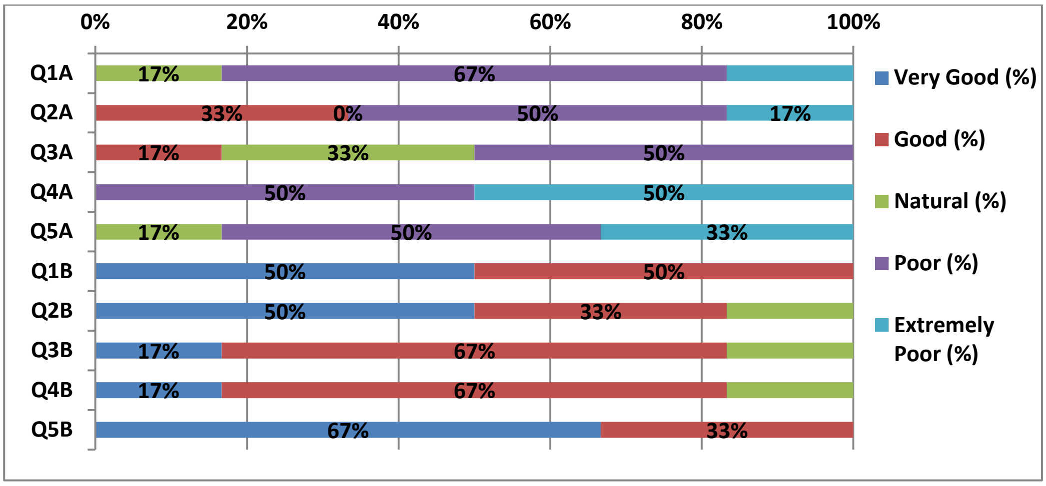


Figure 8-8 illustrates the frequency percentage distribution of the simulator experiment survey responses

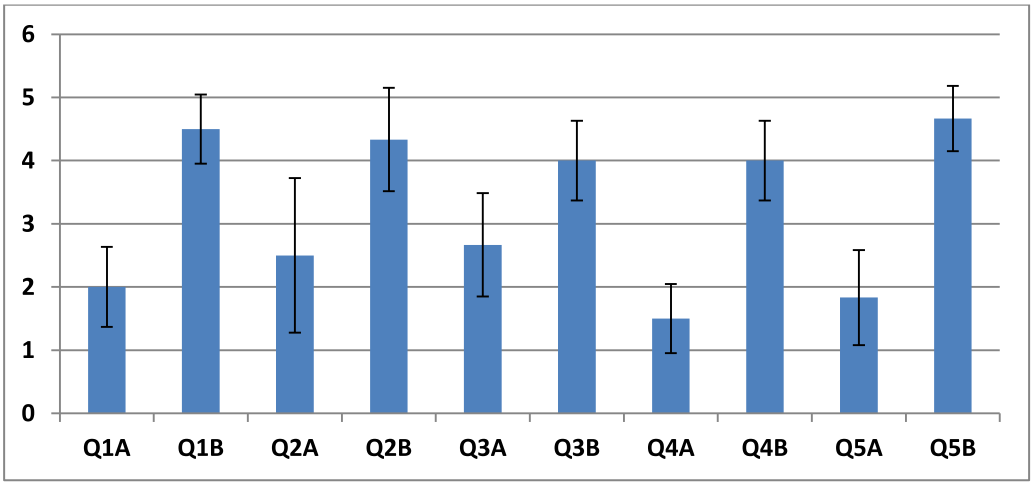


Figure 8-9 shows the mean and the standard deviation of the responses to each question

The results clearly show that resilience based procedures improve Bridge team's performance significantly in some cases 167%.

Q1 Judgment task (recognise traffic risk)

The quality of the judgment task is affected by the bridge team's ability to recognise the traffic risk. Based on the expert panel evaluation of the judgement task for both groups, the ability of the bridge team A to recognise the traffic risk was rated between neutral and poor according to 83% of the responses, and the ability of the bridge team B was rated between very good and good according to 100% of the answers (Figure 8-8). Q1 is related to the judgment task and it has a mean of 2.0 for group A and 4.5 for group B, which proved that the new resilient based procedure improved the judgment task of group B by 145% (Figure 8-9). The standard deviation of group A is 0.63 and B is 0.55 which shows consistent responses. Recognising the traffic risk requires good observation and receiving information from the lookout and the technology. The developed procedure for group B provided very effective and beneficial familiarisation process that helps the bridge team to be familiar with the technology which advanced their performance. Also, other resilience resources the two-ways communication and the out laud thinking provided positive cooperation environment between the OOW and the lookout.

Q2 Leadership and Lookout tasks

The achievement of the leadership and the lookout tasks relies on the communication and coordination among the bridge team. The OOW of group A ignored the lookout reports on several occasions and did not communicate with the rest of the crew as it should be. The OOW of group B was showing his intention clearly through the out loud thinking. The Bridge team members provided learning environment and two-ways communications between OOW and the lookout. Based on the expert panel evaluation of the leadership and the Lookout tasks for both groups, the communication and coordination of bridge team A was rated from poor to extremely poor according to 67% of the responses, and the bridge team B was rated from very good to good according to 83% of the answers (Figure 8-8) . Q2 is related to the lookout and leadership tasks, and it has a mean of 2.5 for group A and 4.3 for group B which demonstrated that the new procedure improved the leadership and lookout tasks of group B by 73% (Figure 8-9). The standard deviation of group A is 1.22 and B is 0.82 which mean that the consistent responses are slightly close to each other. What improved the leadership and lookout tasks for group B is the added major elements to the bridge procedure that enhanced the resilience of the system. Each bridge team member should be briefed about the manoeuvring plan and ensure they do not have any concern. The out loud thinking and the two-ways communication between the OOW and the lookout should apply on bridge.

Q3 Judgment task (technology utilization)

The judgment of the bridge team is affected by the crew's competence with technology. Based on the expert panel evaluation of the judgement task for both groups, the technology utilisation of bridge team A was rated between neutral and poor according to 83% of the responses, and the bridge team B was rated good according to 67% of the answers (Figure 8-8). Q3 is related to the judgment task and it has a mean of 2.7 for group A and 4.0 for group B, which proved that the new procedure improved the judgment task performance of group B by 50% (Figure 8-9) compared to Group A. The standard deviation of group A is 0.82 and B is 0.63 which show consistent responses. The familiarisation process of the developed procedure of group B allowed the team to learn more about the technology. The small checklist improved their understanding of the minor details of the navigation technology which gave them the advantage over group A.

Q4 Judgement and Situational Awareness tasks (follow COLREG's)

The Bridge team's ability to follow the COLREG's procedure is essential for the bridge team judgment and the situational awareness. OOW should avoid using the VHF radio for collision avoidance and passing agreement during crossing ships traffic. Based on the expert panel evaluation of the judgement and situational awareness tasks for both groups, the ability of bridge team A to follow the COLREG's procedure was between poor and extremely poor according to 100% of the responses. Ability of the bridge team B to follow the COLREG's procedure was good according to 67% of the answers (Figure 8-8). The mean of the responses for group A is 2.7 and for group B is 4.0 which demonstrated that the new procedure improved the judgment and situational awareness task of group B by 167%

(Figure 8-9). The standard deviation is 0.82 for group A and 0.63 for group B which show consistent responses. What gives the advantage to group B is adding a visual note on the VHF to ban the use of the VHF radio for passing agreement. Also, the two-ways communication among the bridge team helps the OOW to evaluate the passing situation of other ships. These additional elements provide significant enhancement in resilience of bridge team.

Q5 Judgement and Situational Awareness tasks (communication during excessive workload)

The judgement and situational awareness of the bridge team is affected by the reduction of the communication during the excessive workload condition. Based on the expert panel evaluation of the judgement and situational awareness tasks for both groups, the communication ability of bridge team A during excessive workload between was poor and extremely poor according to 83% of the responses. The communication ability of bridge team B during excessive workload was very good according to 67% of the answers (Figure 8-8). Q5 is related to the judgment and situational awareness tasks and it has a mean of 1.8 for group A and 4.7 for group B, which proved that the new procedure improved the judgment task of group B by 155% (Figure 8-9). The standard deviation of group A is 0.75 and B is 0.52 which show consistent responses. There are numbers of important resilient elements added to the bridge procedure to improve the judgement and situational awareness tasks. Reminding the OOW about the importance of the out loud thinking is critical to show his intention to the bridge team especially during a difficult condition. Another resilience solution included in the procedure is the two-ways communication between OOW and lookout which provide same situational awareness for all team members about the manoeuvring condition.

8.7. The Third Scenario, Restricted Visibility

In this scenario, the weather condition is changed to poor (fog effect), which affects the bridge visibility badly. Both groups must apply the restricted visibility preparation checklist. They should behave constructively to navigate the ship safely through this condition. Besides, the ship must enter a narrow channel, where there are other ships following the same route. Several fishing boats are working in the same location. An Offshore Supply vessel is used for this scenario and the sailing area is the Milford Haven. From all these conditions several factors will be assessed:

1- Bridge team's ability to recognise ship behaviour Perception (Judgement task).
2- Bridge team's traffic risk perception during restricted visibility (Judgement task).
3- Communication or coordination which is the two-way communication between OOW and the lookout (Leadership and Lookout tasks).
4- Bridge team's ability of using equipment alarms (Alarm Management task).
5- Call Master procedures during critical condition (Emergency Response task).
6- OOW communicates with crew during excessive workload (Bridge team judgement and Situational Awareness tasks).

Group A: The third scenario is about the sailing in restricted visibility condition. The group A demonstrated poor perception ability of the ship behaviour. They lost control and the ship was away from the passage plan course. In several occasions OOW decided to manoeuvre then to use the speed control for collision avoidance. The team ability about traffic perception was rated as neutral and they could not recognise a few targets. The communication level between the OOW and the lookout was also neutral, and the OOW was not showing his intention to the bridge team. Regarding the alarm management, it was hard to assess their ability, but generally they got neutral. The team recognised the restricted visibility after 4 minutes. The OOW called the master 7 minutes after the restricted visibility took place only after following the checklist for this condition. During the excessive workload, the OOW stopped communicating with the lookout which resulted in poor to neutral performance. The scenario was completed after 45 minutes.

Group B: The group B's perception ability about ship behaviour was between neutral to good performance, and OOW has effective speed control. The traffic risk perception was good and the team recognised the restricted visibility after 3 minutes. Bridge team B were in high alert state and motivated. The Lookout informed the OOW about the risk of grounding during the restricted visibility. The two-way communications between OOW and the lookout was good. Concerning the alarm management, it was difficult to measure their skill, but mostly they are rated neutral. The OOW called the Master after 6 minutes, but generally he used to call the master at any doubt which gives them good score. The OOW's communication during the excessive workload was neutral, since he stopped communication and did not care about the lookout reporting in several occasions.

8.7.1 The experts panel responses analyses

The 6 members of the expert panel evaluated the performance of groups A and B after watching the recorded videos and observing the bridge team behaviours and reaction. They used evaluation forms which contain different questions and indicators (See APPENDIX C).

8.7.2 Reliability of scale analysis

Table 8-7 presents the results of the reliability of scale analysis

Reliability of scale for Group A

Case Processing Summary

		N	%
Cases	Valid	6	100.0
	Excluded[a]	0	0.0
	Total	6	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
0.90	6

Reliability of scale for Group B

Case Processing Summary

		N	%
Cases	Valid	6	100.0
	Excluded[a]	0	0.0
	Total	6	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
0.70	6

The simple size included in the reliability of scale analysis is 6 people (Table 8-7). All of them are valid and there are no excluded items or missing values. Cronbach's Alpha measurement is 0.90 for group A and 0.70 for group B which mean 90% and 70% of the variance in that score would be considered true score variance or reliable internal consistency and reliable variance.

8.7.3 Statistical Analyses

Table 8-8 presents the statistics analysis result of the expert panel responses

Descriptive Statistics	N	Group A Mean	Group B Mean	Std. Dev A	Std. Dev B	Group B higher by
Q 1 Judgement task (recognise ship behaviour)	6.0	2.3	3.8	0.52	1.17	**64%**
Q 2 Judgement task (recognise traffic risk)	6.0	3.2	4.2	0.98	1.17	**32%**
Q 3 Leadership and Lookout tasks	6.0	3.2	4.0	1.17	0.89	**26%**
Q 4 Alarm Management task	6.0	2.8	3.3	0.98	0.82	**18%**
Q 5 Emergency Response task	6.0	3.5	4.2	0.84	1.17	**19%**
Q 6 Judgement and Situational Awareness tasks (communication during excessive workload)	6.0	2.7	3.2	1.21	1.33	**19%**
Average		**59%**	**76%**			**28%**

The Table 8-8 presents the statistical result of the responses by expert panel. The sample size is 6 people and all of their responses are included in the statistical analysis. In the restricted visibility scenario, the bridge teams of group A and B applied different procedures, and the safety and the quality of the operation are evaluated to determine whether the new procedure is beneficial. Table 8-13 presents the improved elements of the group B procedure. Performance of each group was measured by using the scale of (1 to 5) where 1 is considered extremely poor and 5 is regarded very good. The application of the classical procedure for group A and the newly developed resilient based procedure for group B have different means. The mean of the group A was between (2.3 to 3.5), and the mean of group B was between (3.2 to 4.2). From these means, we can understand that group B performed better than group A. The standard deviations are almost same which is around 1 or less, and this proves that the classical and the new procedure have same consistent responses according to the performance of each group.

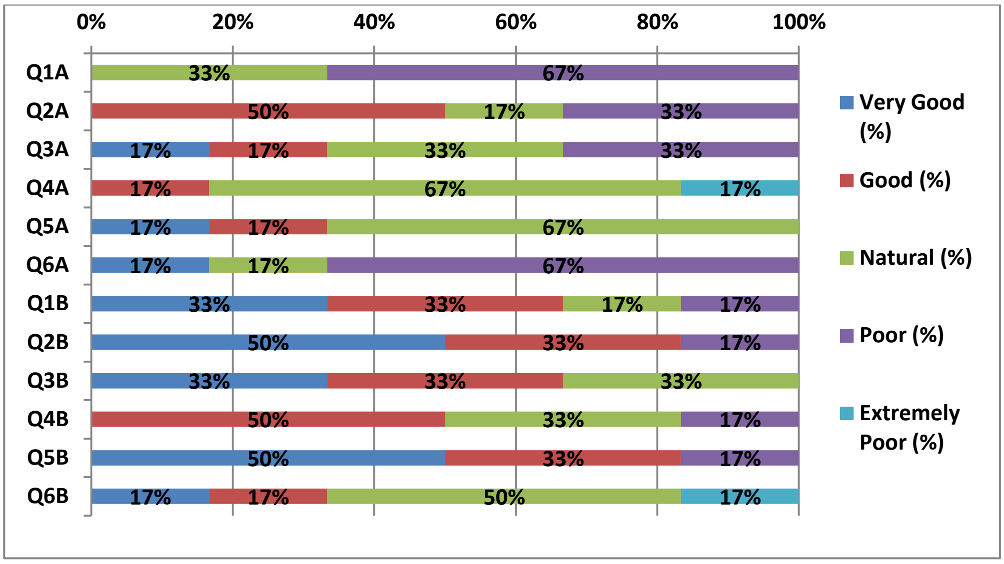


Figure 8-10 illustrates the frequency percentage distribution of the simulator experiment survey responses

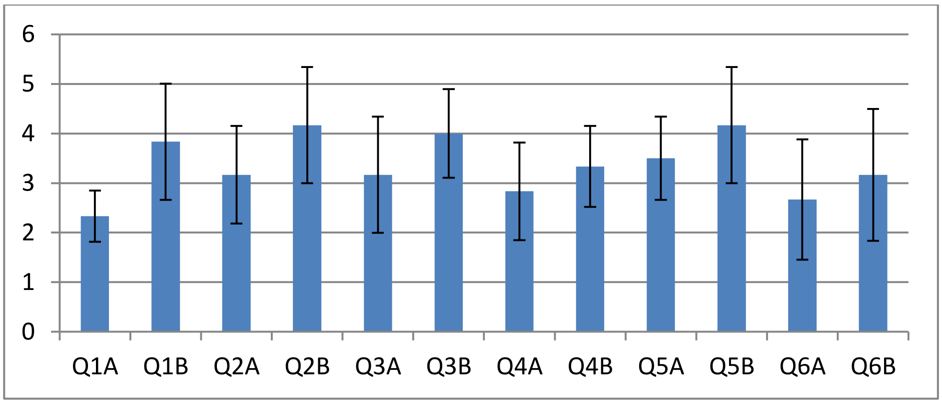


Figure 8-11 shows the mean and the standard deviation of the responses to each question

The results clearly show that resilience based procedures improve Bridge team's performance significantly in some cases 64%.

Q1 Judgement task (recognise ship behaviour)

The judgment indicator is affected by the bridge team's ability to recognise the ship behaviour. During the scenario, the OOW of group A lost the control of the ship. In several occasions he decided to manoeuvre than tried to use the speed control for collision avoidance which caused the vessel to drift away from the passage plan course. The OOW of group B showed positive control over the ship's speed. Based on the expert panel evaluation of the judgement task for both groups, the recognition ability of ship behaviour by the bridge team A was rated between neutral and poor according to 100% of the responses, while the bridge team B was rated between very good and good according to 67% of the answers (Figure 8-10). Q1 is related to the judgment task and it has a mean of 2.3 for group A and 3.8 for group B, which proved that the new procedure improved the judgment task of group B by 64% (Figure 8-11). The standard deviation is 0.52 for group A and 1.17 for group B which demonstrated that the team B has better consistent response. The new procedure included number of items to improve the ship behaviour perception. Understanding the ship requires information to be obtained by the OOW. The utilisation of the navigation technology and the two-way communication procedures enhanced the performance of bridge team B with regards to ability to receive and share information, which gives them the advantage over group A.

Q2 Judgement task (recognise traffic risk)

The quality of the judgment task is affected by the bridge team's ability to recognise the traffic risk. Based on the expert panel evaluation of the judgement task for both groups, the ability to recognise traffic risk by bridge team A was between good and neutral according to 67% of the responses, and the bridge team B was between very good and good according to 83% of the answers (Figure 8-10). Q2 is related to the judgment task and it has a mean of 3.8 for group A and 4.2 for group B, which proved that the new procedure improved the judgment task of group B by 32% (Figure 8-11). The standard deviation of group A is 0.98 and 1.17 for group B which show consistent responses. Recognising the traffic risk requires good observation and receiving information from the lookout and the technology. The new developed restricted visibility procedure based on resilience solutions for group B improved the lookout job and the communication in the bridge. The OOW's briefing the lookout about what he could expect made him more alert. The two-ways communications and the out loud thinking provided excellent team work during this condition.

Q3 Leadership and Lookout tasks

The achievement of the leadership and the lookout tasks rely on the communication and coordination among the bridge team. The OOW of group A ignored the lookout reports on several occasions and did not communicate with the rest of the crew as it should be. The OOW of group B was showing his intention clearly through the out loud thinking. The Bridge team members provided learning environment and two-ways communications between OOW and the lookout. Based on the expert panel evaluation of the leadership and the Lookout tasks for both groups, the communication and coordination of bridge team A was rated between neutral to poor according to 67% of the responses, and the bridge team B was rated between good to neutral according to 67% of the answers (Figure 8-10). Q3 is related to the lookout and leadership tasks, and it has a mean of 2.5 for group A and 4.3 for group B which demonstrated that the new procedure improved the lookout and leadership tasks of group B by 26% (Figure 8-11). The standard deviation of group A is 1.22 and 0.82 for group B which mean that the consistent response is slightly close. What improved the lookout and leadership tasks of group B is introducing important resilience elements to the bridge procedure. Each bridge team member should be briefed about the manoeuvring plan and ensure they do not have any concern (shared situational awareness). The out loud thinking and the two ways communication between the master and the lookout should be applied on the bridge.

Q4 Alarm Management Task

The quality of the alarm management task relies on the bridge team's ability of using the alarms function of the navigation equipment effectively. It was hard to assess the ability of both teams because during the scenario it was not clear which equipment was setting off the alarm and which type of alarm. Based on the expert panel evaluation of the alarm management task for both groups, the ability of using the equipment alarms by the bridge team A was rated neutral according to 67% of the responses, and the bridge team B was rated between good and neutral according to 83% of the answers (Figure 8-10). Q4 is related to the alarm management task and it has a mean of 2.8 for group A and 3.3 for group B, which show a slight improvement due to the new procedure by 28% (Figure 8-11). The standard deviation of group A is 0.98 and B is 0.82 which show close consistent responses. The alarm management required the bridge team to be familiar with the alarm functions of the bridge technology. The new procedure gives more emphasise and description to the use of alarms. The familiarisation procedure provides clear details by offering small checklists for the major equipment such as the ECDIS and radar. The restricted visibility procedure demanded to apply numbers of alarms during this critical conditions.

Q5 Emergency Response task

The emergency response task rely on how the OOW can ask for the master's help when it required. The quality of the emergency response task for both groups was similar. The OOW of group A called the master after 7 minutes after the restricted visibility took place and only after following the checklist for this condition. Based on the expert panel evaluation of the judgement task for both groups, the ability to use captain's helps by bridge team A was neutral according to 67% of the responses, and the bridge team B was rated between very good and good according to 83% of the answers (Figure 8-10). The OOW of group B called the master after 6 minutes after the restricted visibility occurred and by following the checklist. The mean of the Q5 is 3.5 for group A and 4.2 for group B, which shows a slight improvement for group B by 19% (Figure 8-11). The standard deviations of group A are 0.84 and 1.17 for group B which shows consistent responses. The first step in the developed restricted visibility procedure is to inform the captain and that what both groups did during the conditions.

Q6 Judgement and Situational Awareness tasks (communication during excessive workload)

The judgement and situational awareness of the bridge team is affected by the reduction of the communication during excessive workload conditions. The quality of the judgement and situational awareness for both groups were nearly the same since they stopped communicating with the lookout. The reason for that both teams have similar experience and competence. Based on the expert panel evaluation of the judgement and situational awareness tasks for both groups, the ability of the communication during excessive workload by bridge team A was rated between poor and extremely poor according to 67% of the responses, and bridge team B was rated between neutral and good according to 67% of the answers (Figure 8-10). Q6 is related to the judgment and situational awareness tasks and it has a mean of 2.7 for group A and 3.2 for group B, which show a slight improvement for group B by 19% (Figure 8-11). The standard deviation of group A is 1.21 and 1.33 for group B which indicates consistent responses. The judgment and the situational awareness require the OOW to be able to communicate during a critical condition. Even though the restricted visibility procedure demanded the OOW to show his intention by out loud thinking and to provide two way communications, he could not perform these during this period of time.

8.8. The Fourth Scenario, Shallow Water Effect

In this scenario, the ship is exposed to shallow water effect. The master enters the bridge and takes the command from the OOW. He commences his duty by sailing on safe water that has sufficient depth according to the passage plan. The master gave unsafe orders to the helmsman which causes the ship to proceed off the charted course. A navy vessel crossed in front of the ship to escalate the course changing toward the risky area. There is a buoy on the waterway to show that the ship is off the channel. The bridge team should recognise the risk of the ship grounding. If they performed the passage planning process according to the best practice, the grounding can be avoided. The OOW should utilise the ECDIS alarms and observe the ship location. He also must report to the master about the danger of grounding. The Lookout is expected to show some concern and raise it with the OOW. The bridge team should be active during the manoeuvring. A panamax Bulk carrier is used for this scenario and the sailing area is the Singapore Strait. From all these conditions several factors will be assessed:

1- Bridge team's ship behaviour Perception (Judgement task).

2-Bridge team's traffic risk perception during restricted visibility (Judgement task)

3- Bridge team's familiarisation and training onboard (Learning task).

4- Communication or coordination which is the two-way communication between OOW and the lookout (Leadership and Lookout tasks).

5-Following passage planning procedure include the preparation for shallow water effect (passage Planning task).

6- Bridge team's ability of technology utilisation (Judgement task).

7- Bridge team's ability of using equipment alarms (Alarm Management task).

8- OOW communicates with crew during excessive workload (Judgement and Situational Awareness tasks).

9- Bridge team understanding of diminished motivation effect which leads to neglecting watch responsibility (Judgement task).

<u>Group A:</u> The fourth scenario is about how each group behaved during the sailing in shallow water. The group A's perception ability about ship behaviour was rated between poor and neutral since they recognised the risk but not challenged the captain about it which caused the grounding of the ship. The traffic risk perception was neutral. The competence of bridge team reduced when the master took the bridge command. The communication among the crew was poor with full of hesitation. They did not care about the captain's deviation from the safe course of the passage plan. The bridge team performance was neutral when it came to the technology utilisation. Regarding the alarm management, it was hard to assess their ability, but generally tit was neutral. They show poor communication during the excessive workload conditions. The motivation was diminished which led to negligence about the watch duty.

<u>Group B:</u> The bridge team B's perception ability about ship behaviour was good. The lookout kept observing and reporting to the captain. The OOW was performing his duty as normal. The perception of the traffic risk was very good since the team were alert and recognised all the ships and the land marks around. OOW noticed the risk of grounding but he informed the master with hesitation. The bridge team competence was good and not much affected by the captain having the bridge command. The bridge team communication was generally very good since the OOW and the lookout reported clearly what they observed. The OOW noticed the deviation from the passage plan and the risk of the sailing area. The OOW utilised the technology very well. Concerning the alarm management, it was difficult to measure their skills, but mostly it was neutral. The OOW and the lookout communication during the excessive workload was neutral. The bridge team show good motivation when the captain was in command.

8.8.1 Analyses of the experts panel's responses

The 6 members of the expert panel evaluated the performance of groups A and B after watching the recorded videos and observing the bridge team behaviours and reactions. They use evaluation forms which contain different questions and indicators (See APPENDIX C).

8.8.2 Reliability of scale analysis

Table 8-9 presents the results of the reliability of scale analysis

Reliability of scale for Group A

Case Processing Summary

		N	%
Cases	**Valid**	6	100.0
	Excluded[a]	0	0.0
	Total	6	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
0.91	9

Reliability of scale for Group B

Case Processing Summary

		N	%
Cases	**Valid**	6	100.0
	Excluded[a]	0	0.0
	Total	6	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
0.83	9

The simple size included in the reliability of scale analysis is 6 people (Table 8-9). All of them are valid and there are no excluded items or missing values. Cronbach's Alpha measurement is 0.91 for group A and 0.83 for group B which means 91% and 83% of the variance in that score would be considered true score variance or reliable internal consistency and reliable variance.

8.8.3 Statistical Analyses

Table 8-10 presents the statistical analysis result of the expert panel responses

Descriptive Statistics	N	Group A Mean	Group B Mean	Std. Deviation A	Std. Deviation B	Group B higher by
Q 1 Judgement task (recognise ship behaviour)	6.0	2.5	4.2	1.05	0.75	**67%**
Q 2 Judgement task (recognise traffic risk)	6.0	3.0	4.7	1.10	0.52	**56%**
Q 3 Learning task	6.0	3.2	4.5	1.17	0.55	**42%**
Q 4 Lookout and leadership tasks	6.0	2.3	4.7	.82	0.82	**100%**
Q 5 Passage Planning task	6.0	2.0	3.8	1.10	0.98	**92%**
Q 6 Judgement task (technology utilisation)	6.0	2.7	4.2	.82	0.75	**56%**
Q 7 Alarm Management task	6.0	2.5	3.5	1.05	1.05	**40%**
Q 8 Judgement and Situational Awareness tasks (communication during excessive workloads)	6.0	2.2	3.8	0.75	0.41	**77%**
Q 9 Judgement task (avoid diminished motivation)	6.0	2.2	4.3	1.60	0.52	**100%**
Average		**50%**	**48%**			**67%**

The Table 8-10 presents the statistical analysis results of the expert panel responses. The sample size is 6 people and all of their responses are included in the statistical analysis. In the shallow water effect scenario, the bridge teams of group A and B applied different procedures, and the safety and the quality of the operation were evaluated to determine whether the new procedure is beneficial. Table 8-13 presents the improved elements of the group B procedure. Performance of each group was measured by using the scale of (1 to 5) where 1 is considered extremely poor and 5 is regarded very good. The application of the classical procedure of group A and the newly developed resilience based procedure of group B have different means. The mean of the group A was between (2.2 to 3.2), and the mean of the group B was between (3.5 to 4.7). From these means, we can understand that group B performed better than group A. The standard deviations are almost same which around 1 or less, which proves that the classical and the new procedure have similar consistent responses according to the performance of each group.

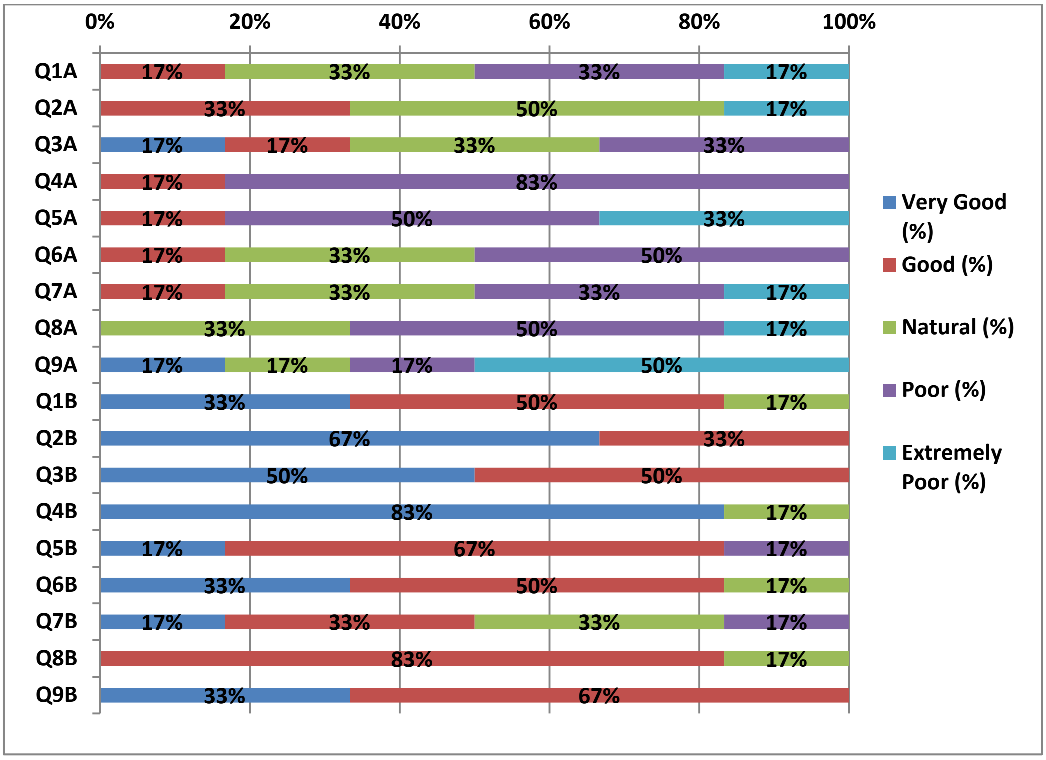


Figure 8-12 illustrates the frequency percentage distribution of the simulator experiment survey responses

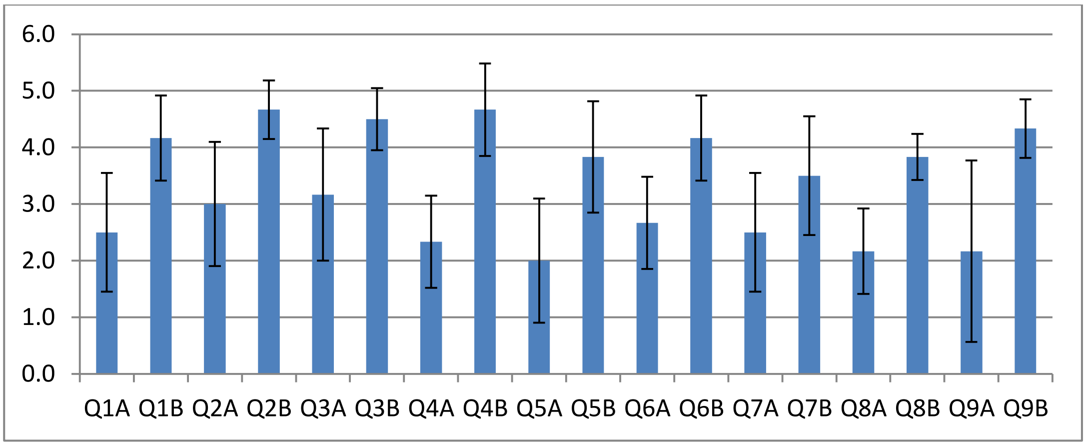


Figure 8-13 shows the mean and the standard deviation of the responses to each question

The results clearly show that resilience based procedures improve Bridge team's performance significantly in some cases 100%.

Q1 Judgement task (recognise ship behaviour)

The judgment indicator is affected by the bridge team's ability to recognise the ship behaviour. During this scenario, OOW of group A recognised the risk but did not challenge the captain about it which caused the ship grounding. The OOW of group B was performing his duties normally and the lookout kept observing and reporting to the master. Based on the expert panel evaluation of the judgement task for both groups, ability to recognise the ship behaviour by bridge team A was rated between neutral and poor according to 67% of the responses, and the bridge team B was rated between very good and good according to 83% of the answers (Figure 8-12). Q1 is related the judgment task and it has a mean of 2.5 for group A and 4.2 for group B, which proved that the new procedure improved the judgment task of group B by 67% (Figure 8-13). The standard deviation of group A is 1.05 and 0.75 for group B which showed consistent responses. Understanding the ship behaviour while captain is on command needs active engagement of the OOW and the lookout, which is critical for reporting the navigation information from different resources. The developed procedure for group B focused on the importance of the two-ways communication and the technology utilisation, which improved the bridge team's understanding of the ship's conduct.

Q2 Judgement task (recognise traffic risk)

The quality of the judgment is affected by the bridge team ability's to recognise the risk during the sailing in shallow water. During the scenario, the group A recognised the risk but not challenged the captain's decision which caused the ship grounding. The team B was alert and recognised all the ships and the landmarks around. OOW noticed the risk of grounding but informed the captain with hesitation. Based on the expert panel evaluation of the judgement task for both groups, the ability to recognise the shallow water risk by bridge team A was rated between good and neutral according to 83% of the responses, and the bridge team B was rated between very good and good according to 100% of the answers (Figure 8-12). Q2 is related to the judgment task and it has a mean of 3.0 for group A and 4.7 for group B, which proved that the new procedure improved the judgment task of group B by 56% (Figure 8-13). The standard deviation of group A is 1.10 and 0.52

for group B which demonstrated that the group B outcomes have better consistency. The traffic risk perception demands the OOW to be active while the captain is on the bridge. The new resilience based procedure requires the one, who is on command to show his intention through the out loud thinking. Also it enforced the two-ways communication to allow the bridge team member to speak during the sailing in the shallow water.

Q3 Learning task

The bridge team's learning task is impacted by the familiarisation and training onboard of the crew. During the scenario, the group A's performance decreased when the master was in command of the ship. The team B was organised, and each member was familiar with his duty and was not affected by the captain operating the bridge. Based on the expert panel evaluation of the learning for both groups, the familiarisation of bridge team A was rated between neutral and poor according to 67% of the responses, and the bridge team B was rated between very good and good according to 100% of the answers (Figure 8-12). Q3 is related to the learning, and it has a mean of 3.2 for group A and 4.5 for group B, which proved that the new procedure improved the familiarisation of group B by 42% (Figure 8-13). The standard deviation of group A is 1.17 and 0.55 for group B which demonstrated that group B had a better consistency. The learning requires competency of the team who run the navigation bridge. The new familiarisation procedure gave group B an advantage for learning about the navigation bridge more than group A. the checklists have block signs in some steps indicating that these steps must be completed before going to the next. Another point is the close loop communication methods (Plan, Execute and verify) which allow the bridge team to ask and clarify about several points. Also there are small checklists for each major equipment such as the ECDIS and the radar to provide more details and to enhance the effective use of the equipment.

Q4 Leadership and Lookout tasks

The achievement of the leadership and the lookout tasks rely on the communication and coordination among the bridge team. During the scenario, group A did not show any concern about the captain's deviation from the safe course of the passage plan which led to the ship grounding. The group B reported clearly what they recognised to the master. The OOW of group B noticed the deviation from the passage plan and he perceived the risk of the sailing area but did not challenge the captain about it. Based on the expert panel evaluation of the leadership and the Lookout tasks for both groups, the communication and coordination of bridge team A was poor according to 83% of the responses, and the bridge team B was very good according to 67% of the answers (Figure 8-12). Q4 is related to the lookout and leadership tasks, and it has a mean of 2.3 for group A and 4.7 for group B which demonstrated that the new procedure improved the leadership and lookout tasks of group B by 100% (Figure 8-13). The standard deviation of both groups is 0.82 which means that the responses are consistent and identical. What improved the leadership and lookout tasks of group B is the added essential resilience elements in the bridge procedures. Each bridge team member should be briefed about the manoeuvring plan and ensure they do not have any concern. The out loud thinking and the two-ways communication between the master and the lookout should be applied on the bridge.

Q5 Passage Planning task

The quality of the passage planning task relies on following its procedures strictly which in our case the preparation for the shallow water effect. During the scenario, the group A did not recognise the deviation from the passage plan, and they were not concerned about fixing the ship's position. While group B was active in defining the ship's position and they informed the master about the deviation from the safe water but did not challenge his decision. Based on the expert panel evaluation of the judgement task for both groups, the ability of following the passage planning procedures of bridge team A was rated between neutral and poor according to 83% of the responses, and the bridge team B was rated good according to 67% of the answers (Figure 8-12). Q5 is related to the passage planning task and it has a mean of 2.0 for group A and 3.8 for group B, which proved that the new procedure improved the passage planning task of group B by 92% (Figure 8-13). The standard deviation of group A is 1.10 and B is 0.98 which show consistent responses. The passage planning relies on several procedures to be completed to ensure the safety of the navigation. There are numbers of elements, which were added or improved in the new procedure. The voyage plan must be clearly defined before the sailing, and the master should brief the bridge team about the manoeuvring plan. It also enforces the effectiveness of out laud thinking and the two-ways communication to improve the working environment.

Q6 Judgement task (technology utilisation)

The ability of the bridge team to utilise the navigation technology is vital for the judgment task. Based on the expert panel evaluation of the judgement task for both groups, the technology utilisation of bridge team A was rated between neutral and poor according to 83% of the responses, and the bridge team B was rated between very good and good according to 83% of the answers (Figure 8-12). The Q6 is related to the judgment task and it has a mean of 2.7 for group A and 4.2 for group B, which proved that the new procedure improved the judgment task of group B by 56% (Figure 8-13). The standard deviation of group A is 0.75 and 1.05 for group B which shows close and consistent responses. The familiarisation process of the developed procedure of group B allowed the team to learn better about the technology. The small checklists improved their understanding of the minor details of the navigation technology which gave them the advantage over group A.

Q7 Alarm Management Task

The quality of the alarm management task relies on the bridge team's ability of using the alarms function of the navigation equipment. It was hard to assess the ability of both teams because during the scenario it was not clear which equipment was setting off the alarm and which type of alarm. Based on the expert panel evaluation of the alarm management task for both groups, the ability of using the equipment alarms of bridge team A was rated neutral according to 67% of the responses, and the bridge team B was rated between good and neutral according to 67% of the answers (Figure 8-12). Q7 is related to the alarm management task and it has a mean of 2.5 for group A and 3.5 for group B, which shows an improvement for the application of the new procedure by 40% (Figure 8-13). The standard deviation of both groups is 1.05 which means that the responses are consistent. The alarm management requires the bridge team especially the OOW to be familiar with the alarm function of the bridge technology. The new procedure puts additional emphasise and description on the uses of the alarms. The familiarisation procedure provides clear details by offering small checklists for the major equipment such as the ECDIS and the radar.

Q8 Judgement and Situational Awareness tasks (communication during excessive workloads)

The judgement and the situational awareness of the bridge team is affected by the reduction of the communication during the excessive workload conditions. Based on the expert panel evaluation of the judgement and situational awareness tasks for both groups, the ability of communication during the excessive workload of bridge team A was rated between neutral to and according to 83% of the responses, and the bridge team B was rated good according to 83% of the answers (Figure 8-12). Q8 is related to the judgment and situational awareness tasks and it has a mean of 2.2 for group A and 3.8 for group B, which proved that the new procedure improved the performance of group B by 77% (Figure 8-13). The standard deviations of group A is 0.75 and 0.41 for group B which indicates similar and consistent responses. The judgment and the situational awareness requires the OOW to have the ability to communicate during difficult conditions. Even though the developed procedure demanded the OOW to provide two-ways communication, he could not communicate much during the excessive workload conditions.

Q9 Judgement task (avoid diminished motivation)

The judgment task relies on the bridge team awareness about the risk of the diminished motivation that causes negligence with regards to the watch duties while the master have the command. During the scenario, the group A’s motivation diminished when the captain runs the bridge and this led to neglection of the watch responsibility. On the other hand group B was active most of the time and performed their duties normally. Based on the expert panel evaluation of the judgement task for both groups, the ability to stay motivated and not neglecting the watch responsibility by bridge team A was rated between poor and extremely poor according to 67% of the responses, and the bridge team B was rated between very good and good according to 100% of the answers (Figure 8-12). Q9 is related to the judgment task and it has a mean of 2.2 for group A and 4.3 for group B, which proved that the new procedure improved the judgment task of group B by 100% (Figure 8-13). The standard deviation of group A is 1.6 and 0.52 for group B which shows consistent responses for group B. While the captain is on command, it is essential to maintain the motivation to sustain the awareness of the bridge team about the manoeuvring conditions. The developed procedure demands the master to brief the bridge team about his manoeuvring plan and ask about any concerns, which gives them the courage to be more engaged during the manoeuvring. The master should also be reminded about the importance of the out loud thinking and the two-ways communication to improve the information exchange among the bridge team.

8.9. Fifth Scenario, Pilot Onboard

In this scenario, the pilot joins the bridge team to take the ship to the port. The bridge team should exchange information with the pilot and inform about any deficiencies. Both groups must apply the pilot checklist. The simulator instructor plays the pilot role. He acted as an unstable person taking risky decisions. The ship will divert from the safe passage into an unsafe shortcut. He proceeds to shallow water which is shallower than the ship's draft. It is expected that the OOW communicate with the master, observe the passage and recognise the risk and report to the master. The lookout should observe the external situation and report to the bridge team. The master will leave the bridge and gives the command to the OOW. It is expected that the OOW shows some concern and communicate with the pilot and challenge his decisions. A panamax Bulk carrier is used in this scenario and the sailing area is the Singapore Strait. There are several factors is assessed in this scenario:

1- Bridge team's ship behaviour Perception (Judgement task).

2- Bridge team's familiarisation and training onboard (Learning task).

3- Communication or coordination which is part from the leadership task (OOW communicate with the pilot and challenge his decisions).

4- Follow the passage planning procedure including the preparation for shallow water effect (passage Planning task).

5- Bridge team's ability of following the Pilot procedures (inform the pilot about bridge condition) (Situational Awareness task).
6- Bridge team understanding of diminished motivation effect which leads to neglect watch responsibility (Judgement task).

Group A: The average performance of group A was rated poor in the evaluation scale. The bridge team's perception ability about the ship behaviour was rated less than neutral since they were totally relied on the pilot. They recognised the grounding after it took place which demonstrates their lack of awareness. Their competency were poor because of their reliance on the pilot. The OOW and the Lookout barely communicated or challenged the pilot's decisions. The OOW did not show any concern about the captain's deviation from the passage plan and taking unsafe shortcut. The bridge team were poor with regards to following the Pilot procedures, because they did not inform the pilot about the bridge condition. The motivation was diminished and this led to neglecting the watch responsibility.

Group A: The average performance of group B was rated good in the evaluation scale. The bridge team's perception ability about ship behaviour was neutral. Their competence not much affected by the pilot's presence, and generally the performance was good. The OOW and the lookout were communicating with the pilot and challenging his decisions but with hesitation. When the pilot deviated from the passage plan towards the shallow water, the OOW did not challenge the pilot even after recognizing the danger. The bridge team's ability of following the Pilot procedures were good since they informed the pilot about the bridge condition. Their motivation was neutral and they were too relax in some occasions leading to loss of focus.

8.9.1 The experts panel responses analyses

The 6 members of the expert panel evaluated the performance of groups A and B after watching the recorded videos and observing the bridge team behaviour and reaction. They use evaluation forms which contains different questions and indicators (See APPENDIX C).

8.9.2 Reliability of scale analysis

Table 8-11 presents the results of the reliability of scale analysis

Reliability of scale for Group A

Case Processing Summary

		N	%
Cases	**Valid**	6	100.0
	Excluded[a]	0	0.0
	Total	6	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
0.72	**6**

Reliability of scale for Group B

Case Processing Summary

		N	%
Cases	**Valid**	6	100.0
	Excluded[a]	0	0.0
	Total	6	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
0.70	**6**

The simple size included in the reliability of scale analysis is 6 people (Table 8-11). All of them are valid and there are no excluded items or missing values. Cronbach's Alpha measurement is 0.72for group A and 0.70 for group B which means more than 70% of the variance in that score would be considered true score variance or reliable internal consistency and reliable variance.

8.9.3 Statistical Analyses

Table 8-12 presents the statistics analysis result of the expert panel responses

Descriptive Statistics	N	Group A Mean	Group B Mean	Std. Deviation A	Std. Deviation B	Group B higher by
Q 1 Judgement task (recognise ship behaviour)	6.0	2.3	3.8	0.82	1.17	**64%**
Q 2 Learning task	6.0	2.3	3.8	1.03	0.41	**64%**
Q 3 leadership and Lookout tasks	6.0	1.7	4.0	0.82	0.63	**140%**
Q 4 Passage Planning task	6.0	1.8	3.5	0.75	1.05	**91%**
Q 5 Situational Awareness task	6.0	2.0	4.3	1.26	0.82	**117%**
Q 6 Judgement task (avoid diminished motivation)	6.0	1.8	3.7	0.75	0.82	**100%**
Average		**40%**	**77%**			**93%**

The Table 8-12 presents the statistical analysis of the expert panel's responses. The sample size is 6 people and all of their responses are included in the statistical analysis. In the passing agreement scenario, the bridge teams group A and B applied different procedures, and the safety and the quality of the operation are evaluated to determine if the new procedure is beneficial. Table 8-13 presents the improved elements of the group B procedure. We measured the performance of each group by using the scale of (1 to 5) where 1 is considered extremely poor and 5 is regarded very good. The application of the classical procedure of group A and the newly developed resilience based procedure for group B have scored different average ratings. The mean of group A was between (1.7 and 2.3), and the mean of group B was between (3.5 and 4.3). From these mean results, we can understand that group B performed better than group A. The standard deviations are almost same which is around 1 or less, which proves that the classical and the new procedure have similar consistent responses according to the performance of each group.

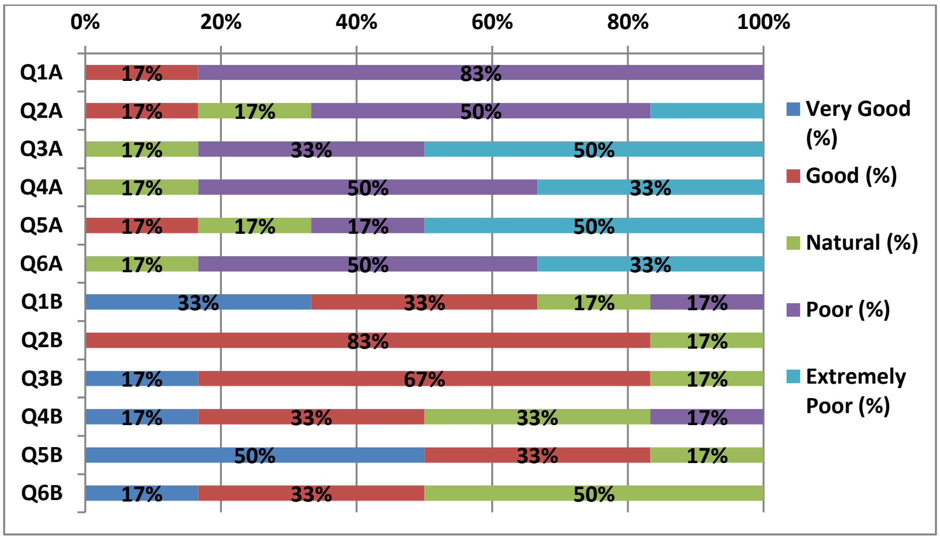


Figure 8-14 illustrates the frequency percentage distribution of the simulator experiment survey responses

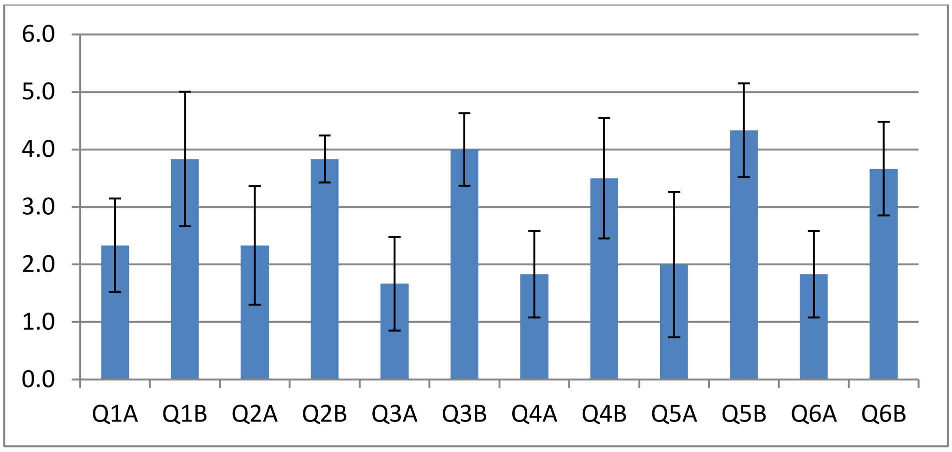


Figure 8-15 shows the mean and the standard deviation of the responses to each question

The results clearly show that resilience based procedures improve Bridge team's performance significantly in some cases 140%.

Q1 Judgement task (recognise ship behaviour)

The judgment task is affected by the bridge team's ability to recognise the ship behaviour. During the scenario, the group A entirely relied on the pilot which reflected negatively on their judgment. Group B was active during the pilotage and they recognised the ship's movements on different occasions. Based on the expert panel evaluation of the judgement task for both groups, the ship behaviour recognition ability of bridge team A was poor according to 83% of the responses, and the bridge team B was rated between very good and good according to 67% of the answers (Figure 8-14). Q1 is related to the judgment task and it has a mean of 2.3 for group A and 3.8 for group B, which proved that the new procedure improved the judgment task of group B by 64% (Figure 8-15). The standard deviation of group A is 1.03 and 0.41 for group B which shows consistency of responses. Understanding the ship behaviour requires information to be received from different resources. The developed pilot procedures of group B improved the judgment of group B by adding vital resilient elements. The pilot must become part of the bridge team to improve the unity of the information. OOW and master must communicate with the pilot and challenge his decisions to prevent the potential risks of wrong choices by the pilot. OOW should perform normal watch duties as expected and remain active during the pilotage to prevent the bridge team from being negligent of their duties.

Q2 Learning task

The bridge team's learning task is affected by the familiarisation and training onboard of the ship's crew. During the scenario, the group A relied on the pilot to operate the bridge and did not perform their duties. The group B was organised, and each member of the bridge team was familiar with their duties and not much affected by the pilot in charge of the bridge. Based on the expert panel evaluation of the learning for both groups, the familiarisation of bridge team A was rated between neutral and poor according to 67% of the responses, and the bridge team B was rated good according to 83% of the answers (Figure 8-14). Q2 is related to the learning, and it has a mean of 2.3 for group A and 3.8 for group B, which proved that the new procedure improved the competency of group B by 64% (Figure 8-15). The standard deviation of group A is 1.03 and 0.41 for group B which demonstrates that the group B results have better consistency. The learning requires competency by the bridge team. The new familiarisation procedure gives group B advantage of learning about the navigation bridge more than group A. The checklists have block signs in some steps to demonstrate that these steps must be completed before moving to the next step. Another point is the close communication methods (Plan, Execute and verify) which allow the bridge team to ask and clarify about several points. Furthermore, there are small checklists for each major technology such as ECDIS and radar that enhances the utilisation of technology effectively. The developed pilot procedure also included that the OOW should perform normal watch as possible and remains active during the pilotage. All these resilience resources enhances the performance of group B.

Q3 Leadership and Lookout tasks

The quality of the leadership and the lookout tasks depend on the communication and coordination among the bridge team. The OOW and the Lookout of group A were barely communicating or challenging the pilot's decisions. The group B demonstrated clear communication with the pilot and they challenged his decisions but with hesitation. Based on the expert panel evaluation of the leadership and the

Lookout tasks for both groups, the communication and coordination of bridge team A was rated between poor and extremely poor according to 83% of the responses, and the bridge team B was rated good according to 67% of the answers (Figure 8-14). Q3 is related to the lookout and leadership tasks, and it has a mean of 1.7 for group A and 4.0 for group B which demonstrated that the new procedure improved the lookout and leadership tasks of group B by 140% (Figure 8-15). The standard deviations of group A is 0.82 and 0.63 for group B which indicates similar and consistent responses. What improves the leadership and lookout tasks of group B is the added vital resilient elements in the pilot operation procedure. Master and OOW should understand that the pilot is part of the bridge team and the pilot must be informed about that. OOW and master must communicate with the pilot and challenge his decisions when necessary. OOW should perform normal watch as possible and remain active during the pilotage.

Q4 Passage planning task

The quality of the Passage Planning task relies on following the passage planning procedures during the pilotage. The OOW of group A did not show any concern about the captain's deviation from the passage plan and taking an unsafe shortcut. While group B team was active in defining the ship's position and when the pilot deviated from the passage plan towards the shallow water, the OOW recognised it but did not challenge the pilot's decision. Based on the expert panel evaluation of the judgement task for both groups, the ability to follow the passage planning procedures by bridge team A was rated between neutral and poor according to 67% of the responses, and the bridge team B was rated between good and neutral according to 67% of the answers (Figure 8-14). Q4 is related to the passage planning task and it has a mean of 1.8 for group A and 3.5 for group B, which proved that the new procedure improved the passage planning task of group B by 91% (Figure 8-15). The standard deviation of group A is 0.75 and 1.05 for group B which shows consistent responses. The passage planning task relies on several procedures to be completed to ensure the safety of the navigation. There are numbers of procedures which were added or improved in the new pilot checklist. The passage plan must be discussed with the pilot when he joined the ship. OOW and master must communicate with the pilot and challenge his decisions when necessary. OOW should perform normal watch as possible and remain active during the pilotage.

Q5 Situational Awareness task

The quality of the situational awareness task relies on the bridge team's ability to follow the pilot procedure which is in this case to inform the pilot about the bridge condition. Based on the expert panel evaluation of the situational awareness task for both groups, the ability to follow the pilot procedure of bridge team A was rated between poor and extremely poor according to 67% of the responses, and the bridge team B was rated between very good and good according to 83% of the answers (Figure 8-14). Q5 is related to the situational awareness task and it has a mean of 2.0 for group A and 4.3 for group B, which proved that the new procedure improved the judgment task of group B by 117% (Figure 8-15). The standard deviation of group A is 1.26 and 0.82 for group B which demonstrated that the group B results have better consistency. The situational awareness task relies on following the pilot procedure. The new pilot checklist included that the captain and bridge team should determine what the pilot must know about bridge condition and informs him when he joins the bridge team, in addition to the pilot card.

Q6 Judgement task (avoid diminished motivation)

The judgment task relies on the Bridge team awareness about the risk of the diminished motivation that causes negligence about the watch duty when the pilot is in command. The group A's motivation/concentration was diminished when the pilot took the command, which led to negligence about the watch responsibility. While group B was most of the time active during the scenario. Based on the expert panel evaluation of the judgement task for both groups, the ability to stay motivated and not to neglect the watch duty of bridge team A was rated between poor and extremely poor according to 83% of the responses, and the bridge team B was rated between good and neutral according to 83% of the answers (Figure 8-14). Q6 is related to the judgment task and it has a mean of 1.8 for group A and 3.7 for group B, which proved that the new procedure improved the judgment task of group B by 100% (Figure 8-15). The standard deviation of group A is 0.75 and 0.82 for group B which shows good consistent responses. The motivation attitude during the pilotage watch is necessary to maintain the awareness of the bridge team about the manoeuvring conditions. Adding the resilient elements (the OOW should perform normal watch as possible and remain active during the pilotage) to the new procedure improved group B's motivation.

8.10. The Resilience Resources Result

Table 8-13 Presents the results of the application of the resilience resources. They were assessed by experts panel after watching the five scenarios, which are normal navigation, passing agreement, restricted visibility, a shallow water effect, and a pilot on board, and each scenario include different bridge operation condition. The resilience abilities (anticipation, monitoring, learning and responding) of the two groups (A & B) were evaluated according to the following indicators: 1- Ability of Judgement, 2- Emergency Preparation, 3- Situational Awareness, 4- Lookout Quality, 5- Alarm Management, 6- Leadership, 7- Passage Planning, and 8- Learning. The purpose of this phase is to present the outcome in different way that shows the scores of the improvement of each resilience resource. Some scores are outcome of average calculation of the marks of several questions in different scenario but sharing same indicator.

Table 8-13 Presents the results of the application of the resilience resources

Resilience resources	Task / sub-factor	B higher than A by
• **Short Sentences, Focus on important safety elements, sign ⊘ before some elements which meant that this step must be completed before going to the next step** • **The sign ☝ before some elements which meant this step must be done by close communication methods (Plan, Execute and verify)** • **Small checklists for the critical equipment (and their alarms)** • **Ensure the bridge has learning environment that allow bridge team to ask and discuss**	2- Familiarisation (Learning task). (normal operation scenario) 4- Technology utilisation (Judgement task) (normal operation scenario) 1- Traffic risk perception (Judgement task). (Passing agreement scenario) 3- Technology utilisation (Judgement task). (Passing agreement scenario) 1- Ship behaviour Perception (Judgement task). (Restricted visibility scenario) 4- Using equipment alarms (Alarm Management task). (Restricted visibility scenario) 1- Ship behaviour Perception (Judgement task). (Shallow water scenario) 3- Familiarisation (Learning task). (Shallow water scenario) 5-Following pp procedure) (passage Planning task). (Shallow water scenario) 6- Technology utilisation (Judgement task). (Shallow water scenario) 7- Using equipment alarms (Alarm Management task). (Shallow water scenario) 2- Familiarisation (Learning task). (Pilot on board scenario	**96%** **122%** **145%** **50%** **64%** **18%** **67%** **42%** **92%** **56%** **40%** **64%** **71%**
Add note on the VHF "do not use VHF for passing agreement"	4- COLREG's (Judgement and Situational Awareness tasks). (Passing agreement scenario)	**167%**
Captain briefs bridge team about manoeuvring plan (Dep. checklist)	1- Ship behaviour Perception (Judgement task). (normal operation scenario) 1- Ship behaviour Perception (Judgement task) (Judgement task). (Shallow water scenario)	**110%** **67%** **89%**
Captain aske bridge team about their concern (Dep. checklist)	3- Communication or coordination (Leadership and Lookout tasks).	**178%**
Captain/ OOW brief lookout about what he could expect (Dep. checklist)	5- Communicates with crew (judgement and Situational Awareness tasks). (Passing agreement scenario)	**155%**
Out loud thinking (Dep. checklist)	5- Communicates with crew (judgement and Situational Awareness tasks). (Passing agreement scenario)	**155%**
Two-ways communication (Dep. checklist)	3- Communication or coordination lookout (Leadership and Lookout tasks). (normal operation scenario)	**178%** **73%**

	2- Communication or coordination lookout (Leadership and Lookout tasks). (Passing agreement scenario) 5- Communicates with crew (judgement and Situational Awareness tasks). (Passing agreement scenario)	**155%** **135%**
Check for the future risk on the chart (RV checklist)	4- Following PP procedure (passage Planning task). (Pilot on board scenario)	**91%**
Captain/ OOW brief lookout about what he could expect (RV checklist)	1- Ship behaviour Perception (Judgement task). (Restricted visibility scenario)	**64%**
Out loud thinking (RV checklist)	2- Traffic risk perception (Judgement task). (Restricted visibility scenario) 6- Communicates with crew (judgement and Situational Awareness tasks). (Restricted visibility scenario)	**32%** **19%** **26%**
Two-ways communication (RV checklist)	2- Traffic risk perception (Judgement task). (Restricted visibility scenario) 3- Communication or coordination (Leadership and Lookout tasks). (Restricted visibility scenario) 6- Communicates with crew (Judgement and Situational Awareness tasks). (Restricted visibility scenario)	**32%** **26%** **19%** **26%**
Define what pilot must know about bridge condition (Pilot checklist)	3- Communication or coordination (leadership task). (Pilot on board scenario) 5- Following Pilot procedures (Situational Awareness task). (Pilot on board scenario)	**140%** **117%** **129%**
Pilot is part of the bridge team (inform pilot) (Pilot checklist)	1- Ship behaviour Perception (Judgement task). (Pilot on board scenario) 3- Communication or coordination (leadership task). (Pilot on board scenario)	**64%** **140%** **129%**
Communicate with pilot and challenge his decisions (Pilot checklist)	3- Communication or coordination (Leadership task). (Pilot on board scenario)	**140%**
Perform normal watch as possible and remain active during piloting (Pilot checklist)	9- Diminished motivation effect (Judgement task). (Shallow water scenario) 1- Ship behaviour Perception (Judgement task). (Pilot on board scenario) 6- Diminished motivation effect (Judgement task). (Pilot on board scenario)	**100%** **64%** **100%** **88%**
Captain not leaves bridge before OOW is ready for the watch (Pilot checklist)	1- Ship behaviour Perception (Judgement task). (Pilot on board scenario)	**64%**

Captain brief bridge team about manoeuvring plan (Arrival checklist)	5- Communicates with crew (judgement and Situational Awareness tasks). (Passing agreement scenario)	**155%**
Captain asks bridge team about their concern (Arrival checklist)	3- Communication or coordination (Leadership and Lookout tasks). (normal operation scenario)	**178%**
Captain/ OOW brief lookout about what he could expect (Arrival checklist)	3- Communication or coordination lookout (Leadership and Lookout tasks). (normal operation scenario)	**178%**
Out loud thinking (Arrival checklist)	8- Communicates with crew (Judgement and Situational Awareness tasks). (Shallow water scenario)	**77%**
Two-ways communication (Arrival checklist)	4- Communication or coordination (Leadership and Lookout tasks). (Shallow water scenario)	**100%** **77%**
	8- Communicates with crew (Judgement and Situational Awareness tasks). (Shallow water scenario)	**89%**

The results of each resilience resource demonstrate that the performance of group B is improved after applying the newly prepared checklists. The advancement outcomes of team B were diverse when although they apply similar resilience resources in different sailing conditions. For example, the out loud thinking and the two ways communication techniques when they applied in the ship departure scenario was effective by 155% and 135%, while its implementation in the restricted visibility scenario resulted only in 26% improvement. The main reason for the large gaps between the two performances is the good competence of group A in such condition. The restricted visibility condition is given high priority by the maritime education and training, which is reflected positively in the scenario performance. The new checklists improve the performance of several tasks significantly, yet the result of the Alarm Management task during restricted visibility scenario improved by barely 18%. This outcome demonstrates that enhancing the alarm management task is required more than the checklists. It needs intensive practical training and assessment which could be performed in the maritime simulation. The details of the application, the resilience resources definition and the scores are discussed clearly above. The outcomes undoubtedly show that resilience based procedures improve Bridge team’s B performance significantly in some cases 178%.

8.11. Summary

The experiments regarding the application of the resilience resources being introduced into the bridge operation procedures demonstrated positive performance improvement. The goal of this study is to validate the implementation of resilience solutions. The purpose is to improve navigational operations by making it resilient to able to cope with challenges with respect to changing conditions. The full mission navigation simulator helps to accomplish the prepared scenarios so as to evaluate the quality of the bridge team’s performance. The experiments included two groups (A & B), with each group containing one Officer of the Watch (OOW), one lookout and one helmsman. Group A performed the watch by applying classic procedures and checklists, which were used by the vessels involved in the accidents. Group B used the developed procedures and checklists and performed similar scenarios. Group B's new developed resilience based procedures and checklists were smaller and included short and clear sentences. They also focused on the safety elements that are essential for each condition in a way that improves performance and does not affect the safety. To maintain the objectiveness of the experiment, the scenarios were anonymous to both teams. The case study included five different scenarios: normal navigation, passing agreement, restricted visibility, a shallow water effect, and a pilot on board. The resilience abilities (anticipation, monitoring, learning and responding) of the two groups were measured according to the following indicators: 1- Ability of Judgement, 2- Emergency Preparation, 3- Situational Awareness, 4- Lookout Quality, 5- Alarm Management, 6- Leadership, 7- Passage Planning, and 8- Learning.

The evaluation of the experiment's results showed a promising outcome for the new procedure. The assessment team included six members of the expert panel. The first scenario comprised bridge familiarisation and normal navigation conditions, and the analysis of the general performance of both groups demonstrated that the average performance of Group B was 124% higher than that of Group A. The second scenario comprised passing agreement, and the analysis of the general performance of both groups demonstrated that the average performance of Group B was 108% higher than that of Group A. The third scenario comprised the restricted visibility condition, and the analysis of the general performance of both groups demonstrated that the average performance of Group B was 28% higher than that of Group A. The difference with the results between both groups were small because their experience and competence are similar. Also the restricted visibility is very critical situation that considered very well by the maritime institutes. The fourth scenario comprised the shallow water effect, and the analysis of the general performance of both groups demonstrated that the average performance of Group B was 67% higher than that of Group A. The fifth scenario comprised the pilot being on board, and the analysis of the general performance of both groups demonstrated that the average performance of Group B was 93% higher than that of Group A.

Chapter 9. The Resilience Assessment Tool (RAT)

9.1. Introduction

Resilience is the core capability of a system to modify its activity before, during or after variations and disturbances, and it can maintain the required performance even following a great misfortune or the existence of continual stress (Nemeth et al., 2008). Unlike safety, resilience could not be designed merely through presenting further procedures, precautions and barriers — resilience engineering demands constant performance monitoring of a system in respect of how things are done (Hollnagel and Woods, 2006). The aim of this study is providing methods to assess the resilience of shipping organisations. This is very important as the company resilience whether in the organisation or onboard the ship should be promoted, assessed and improved using the same values, KPIs. Having a unified system will help developing the same shared understanding, values and commitment regardless of the management positions, locations and the operations in an organisation. This is the only way that we can link the resilience onboard ship and resilience within the organisation.

The Resilience Assessment Tool (RAT) was developed and validated by experts team of SEAHORSE project. The tool was applied first time to assess the resilience of commercial shipping company which is based in Saudi Arabia but operates globally. The company is one of the important providers of shipping services worldwide, covering six maritime activities include Oil, Chemicals, Logistics, Dry Bulk, Data and managing 90 ships. The application of the RAT tool shows beneficial capability of assessing four resilience abilities (anticipation, monitoring, learning and responding) for the multi levels of the system (multi-party, organisation, team and individual) in this company.

9.2. The Application Area:

The company is one of the world's leading transportation and logistics organisation, which plays a foremost role in the transformation and development of the international maritime industry. The company is one of the major providers of shipping services worldwide, which covers Oil, Chemicals, Logistics, Dry Bulk, Ship Management, and Data. The company is managing 90 ships that provide different services include shipment of crude oil, oil products, chemical, bulk and general cargo. The organisation maintains good safety and certificating records. The accidents and incidents including the near miss are accurately documented and periodically perform safety culture surveys.

9.3. The Procedure of collecting the Data

The period of the visit to collect the data was four days. The first day was familiarisation process which includes meeting different employees and observing the work of different departments. The remaining days were spend on meeting people working in senior level to conduct face to face interview and file up the resilience assessment questionnaire.

9.4. The Volunteers

There are 10 people from the management level participated to fill up the questionnaires. They have different background between engineering and navigation. The multi-parties level and organisation level questions were answered by safety managers and superintendents, and the team level and individual level were covered by x-captains are responsible for managing ships crew onboard.

9.5. Resilience Assessment Method

Ships owners need resilience assessment tool in order to recognise the deterioration of operation performance, which help them to look for solutions to maintain the system efficiency. The SEAHORSE Virtual Platform has been established with the ambitious goal to handle this demand. It demonstrates an innovative system for the shipping industry which means to provide maritime organisation with inclusive support in their route towards safety and resilience (Seahorse project, 2016).

The Resilience Assessment Tool (RAT) is a diagnostic method for shipping organisation. It intends to determine the strengths and weaknesses of a system with regard to resilience aspect. The functionality idea of the RAT developed for the assumption that shipping companies have to go beyond the normal safety abilities to another level that require monitoring and responding to what is going on (Seahorse project, 2016). The Resilience is important feature in the changing working environments, which helps shipping companies to develop and improve their anticipation of upcoming challenges and learning from what has gone right and wrong. The four abilities (anticipation, monitoring, learning and responding) characterise the foundations of the tool, and they intersected with multi resilience levels: multi-party, organisation, team and individual. The RAT relies on questionnaire method based on a structure that able to show the features that influence the function activities to achieve a set goal. Figure 9-1 shows the main components of the RAM.

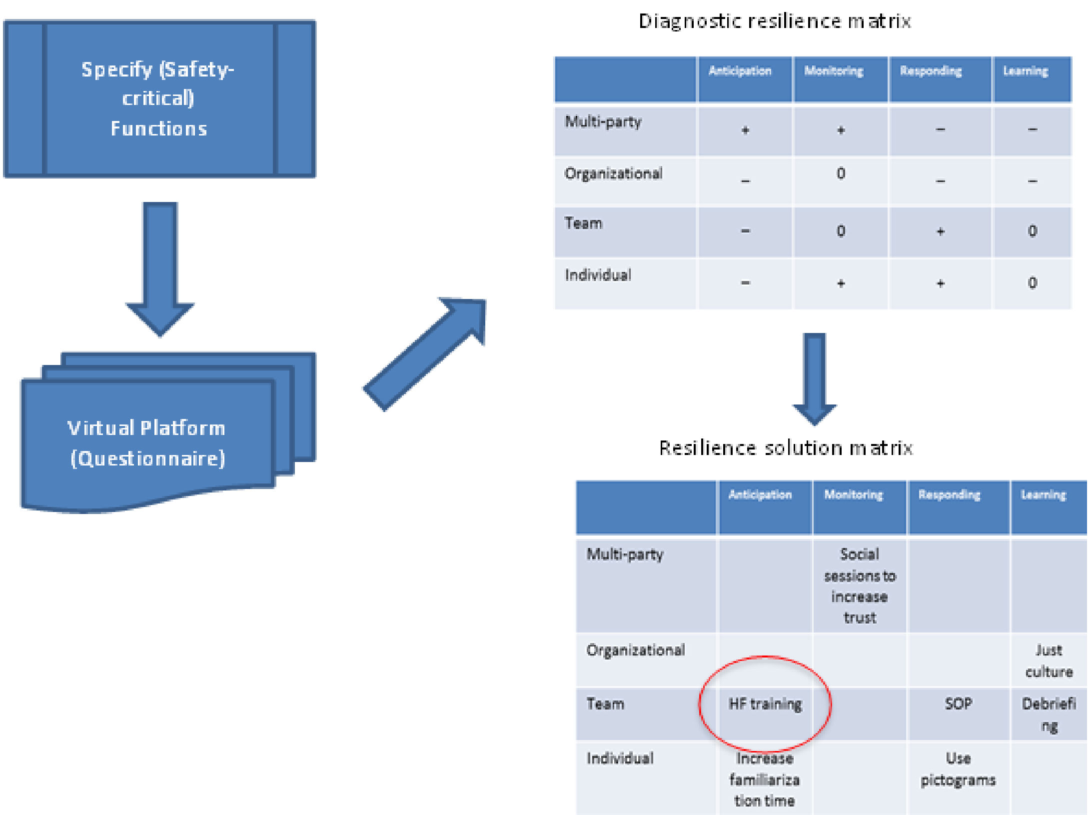


Figure 9-1 Main components of Resilience Assessment Tool (RAT), (SEAHORSE, 2016)

Maritime organisations need to design and sustain a robust resilience structure in order to be able to maintain good system performance has the capability to coop with changing condition. The main advantages of RAT are summarised in the below points:

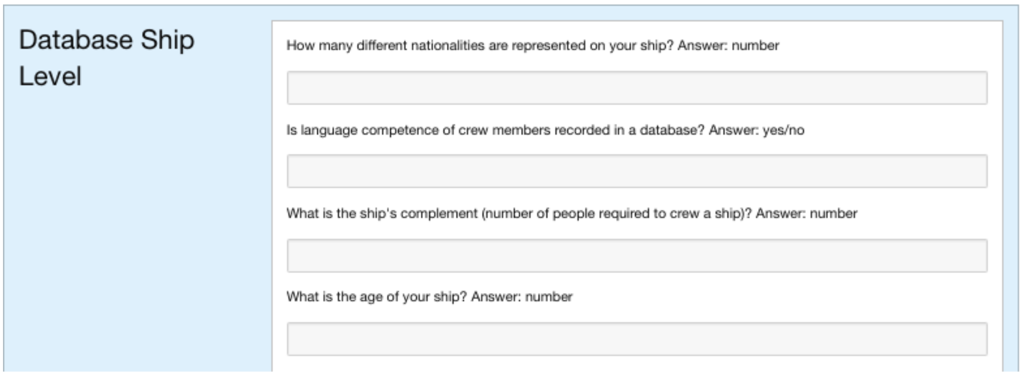
- Provide resilience assessment and grading method
- Identify gaps in the resilience structure of an organisation
- Detect weaknesses and non-compliances that may cause errors and accidents
- Notify the maritime organisation to prepare the resilience resources and solutions in order to address the identified gaps

9.6. Questionnaire

RAT questionnaire is constructed on widest concept of resilience include a set of questions for each ability and resilience level. The questionnaire evaluates the quality of the existing resources and schemes in order to attain the needed outcomes of the operational demands. This tool allows assess the four resilience abilities (anticipate, monitor, learn and response) of each level in the shipping organisation (Multi-Party Level, Organization Level, Team Level and Individual Level). Therefore, the answers of the questionnaire questions are divided to three types, which are

1- "Yes" or "No" related to if the level has certain element
2- The number of specific assets or factors such as the number of accidents
3- The evaluation of certain resilient element which is expressed with a number between 1 (worst state) and 5 (best condition).

The RAT aims to gather objective data from shore and ship. The Resilience Assessment Questionnaire contains selected set of questions organised to cover the four resilient abilities to each level. The questionnaire is scientifically validated, not a biased, subjective approach. It should be applied to specific function in the shipping company. The information could be obtained from current databases or by safety managers and ship's officers. Figure 9-2 presents part of the Ship database, and Figure 9-3 shows part of assessment of the multiparty level ability for anticipation. The questionnaire follows by questions of the others three abilities (learn, respond, monitor) for the same level. This structure is then repeated for the other three levels (organisation, team and individual). (See appendix D for the remaining questionnaire forms).


Database Ship Level

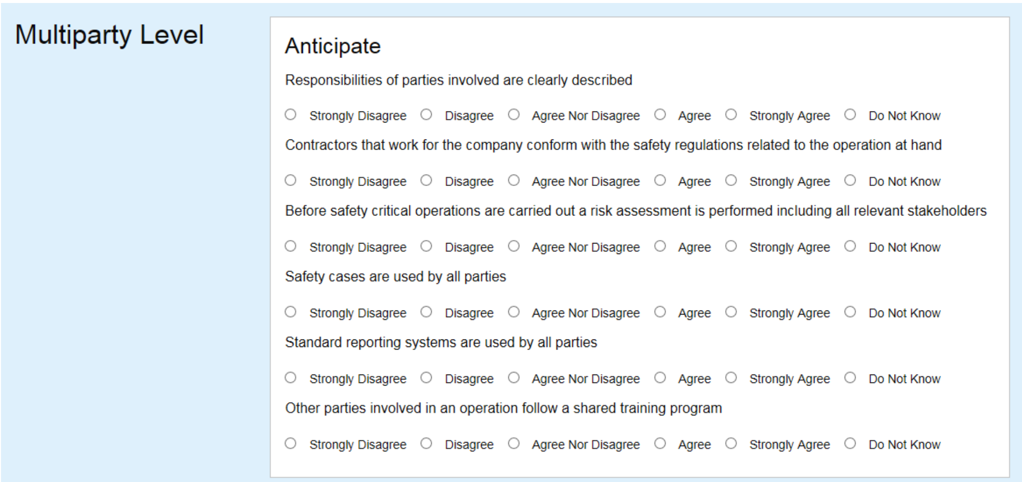
How many different nationalities are represented on your ship? Answer: number

Is language competence of crew members recorded in a database? Answer: yes/no

What is the ship's complement (number of people required to crew a ship)? Answer: number

What is the age of your ship? Answer: number

Figure 9-2 : The RAT database


Multiparty Level

Anticipate

Responsibilities of parties involved are clearly described

Strongly Disagree Disagree Agree Nor Disagree Agree Strongly Agree Do Not Know

Contractors that work for the company conform with the safety regulations related to the operation at hand

Strongly Disagree Disagree Agree Nor Disagree Agree Strongly Agree Do Not Know

Before safety critical operations are carried out a risk assessment is performed including all relevant stakeholders

Strongly Disagree Disagree Agree Nor Disagree Agree Strongly Agree Do Not Know

Safety cases are used by all parties

Strongly Disagree Disagree Agree Nor Disagree Agree Strongly Agree Do Not Know

Standard reporting systems are used by all parties

Strongly Disagree Disagree Agree Nor Disagree Agree Strongly Agree Do Not Know

Other parties involved in an operation follow a shared training program

Strongly Disagree Disagree Agree Nor Disagree Agree Strongly Agree Do Not Know

Figure 9-3: The RAT Questionnaire

9.7. Items of the questions

Inside every level resource are several items which are defined to be assessed within the questionnaire. The items selected based on accident reports, qualitative review of scientific records and brainstorm sessions with partners in the SEAHORSE project. Table 9-1 presents an example of the assessed items in the questionnaire including the addressed levels and abilities, (See appendix D for the remaining assessment items).

Table 9-1 presents an example of the assessed items in the questionnaire including the addressed levels and abilities

Topic	Level	Ability
Clear description of responsibilities	Multiparty Team	Anticipate
Ability (other party, team, individual, assets) to deal with unforeseen operational demands	Multiparty Team Individual Technical assets	Anticipate
Shared safety culture with other party	Multiparty	Monitor
Communication (with other party, between team members)	Multiparty Team	Monitor Respond

9.8. The Resilience Assessment Results

When the questionnaire is completed through face to face interview, the results are analysed. The results can show the condition of the resilience of the selected function. The tool has the ability to present the scores of the four resilience abilities for each level in qualitative form. The spider-chart (Figure 9-4) provides overview on the resilience performance in the way that allows the handler to identify the areas of weakness and strengths. The levels (multi-party, organisation, team and individual) is presented in a certain colour and the resilience abilities (anticipate, monitor, learn and react) scores are also demonstrated in the same figure. The scores are between 1 and 5, whereas 1 demonstrates poor resilience performance and 5 is an excellent. The score of 3 is the threshold of performance quality of an organisation and below it represents resilience deficiency.

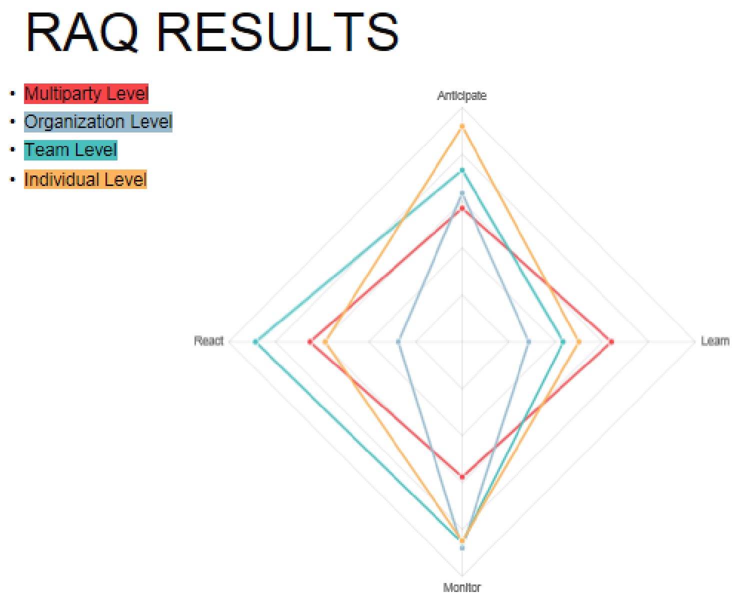


Figure 9-4: The graphical representation of the resilience structure

9.9. Discussion

The general results of the RAT (Figure 9-5) show that the resilient ability of the company organisation is above the threshold (3) of the risk level, which are between 3.8 and 4.8. However, after analysing the items details at each ability and level some warning signs of resilience shortage in certain areas were identified. Figure 9-6 presents the results of the multiparty level resilience assessment. The outcome shows that the scores of two critical areas are located on the risky zone but not yet develop to become a threat to the system. Table 9-2 presents the questionnaire questions that received low scores. The Anticipation ability could be affected because the responsibilities of external parties (e.g. stevedores, clients, agents, fleet management, subcontractors) involved are not clearly described. Also the monitoring ability is negatively influenced since the external parties do not share the same safety culture.

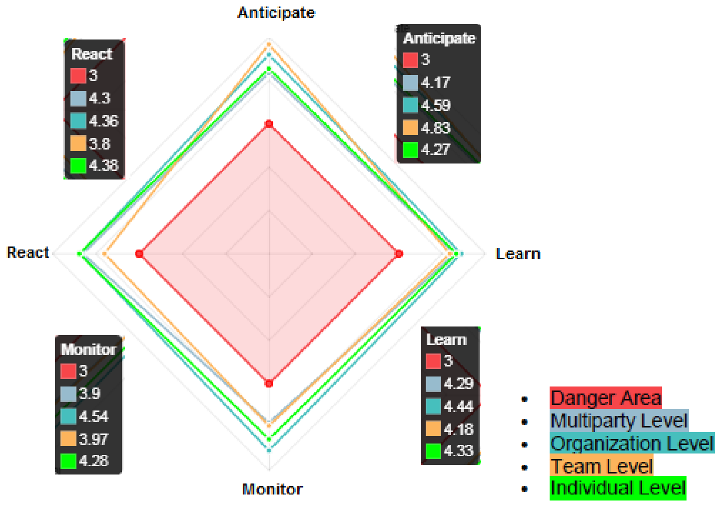


Figure 9-5 presents the general resilience assessment results of the company performance

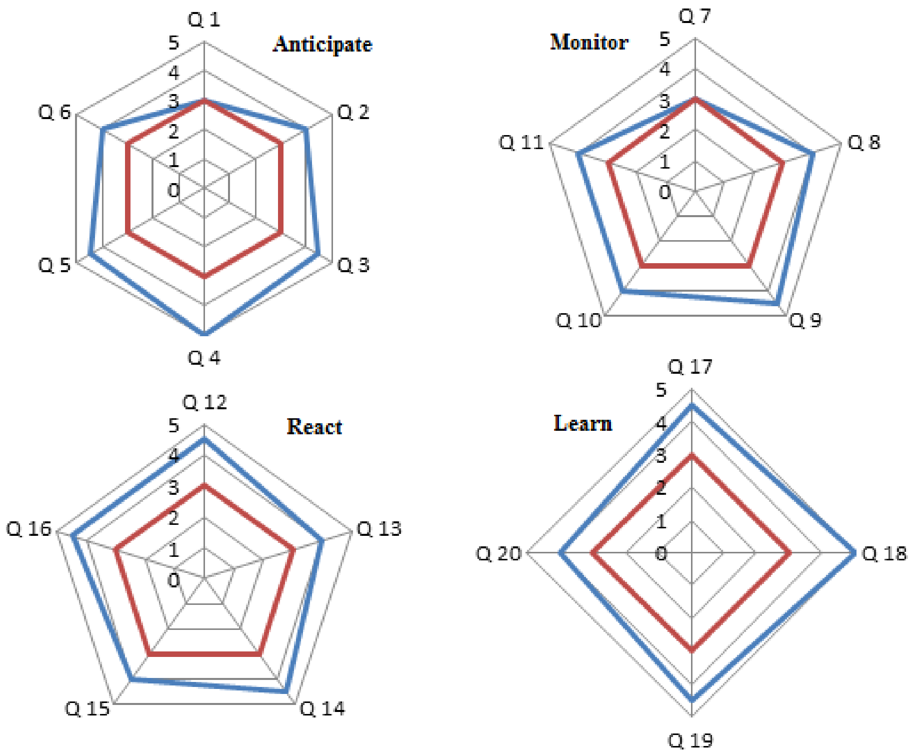


Figure 9-6 the resilience assessment results of the multiparty level

Table 9-2 low scores questions of the multiparty level

Questions received risky score
Q 1. Responsibilities of external parties (e.g. stevedores, clients, agents, fleet management, subcontractors) involved are clearly described
Q 7. External parties share the same safety culture

Figure 9-7 presents the results of resilience assessment at the organisational level. The outcome illustrates one critical area in this level could be considered risky scale but so far has not developed to become a threat to the operation system. Table 9-3 presents the questionnaire question that received low score. The Anticipation ability might be affected because the organisation not pre-planned some operation activities by using simulation. It is understood that it is hard to simulate each type of activity since it coast time and money. For that the critical type of operation usually is covered by simulation training.

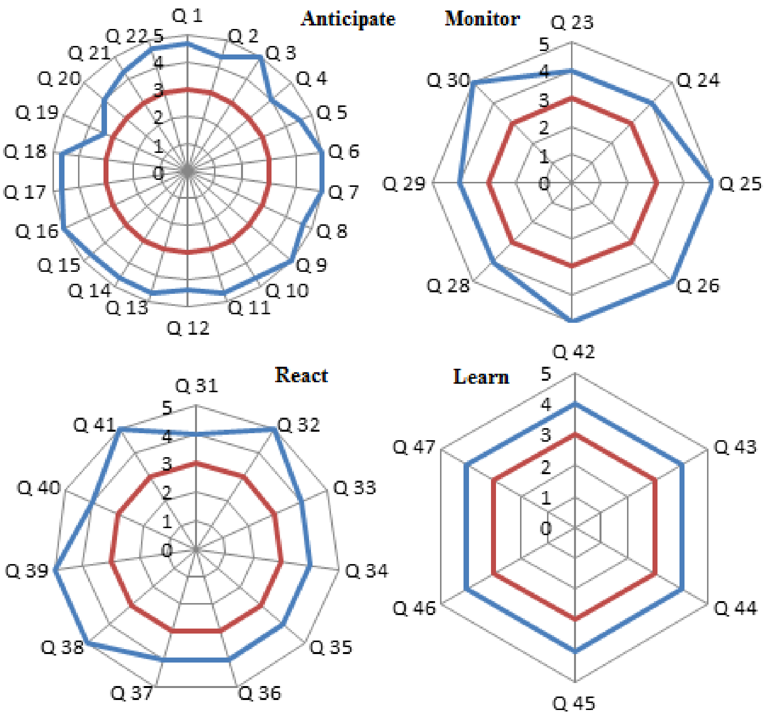


Figure 9-7 the resilience assessment results of the organization level

Table 9-3 low scores questions of the organization level

Questions received risky score
Q 19. The operation is pre-planned by using simulation

Figure 9-8 shows the results of the team level resilience assessment. The outcome demonstrates 3 critical areas in this level that might be considered in risky scale as the score located exactly on the hazard threshold zone. But to this point the resilience shortage do not grow to turn into a threat to the organisation system. Table 9-4 presents the questionnaire questions that received low scores. The Monitoring ability could be influenced during complex or time critical situations that the members in the crew could not speak out openly when they think differently about the solution. The reaction ability may reduce or diminish because during complex or time critical situations the crew cannot adheres to established work orders/ procedures, or tasks are shed by not doing, postponing, doing less frequently, or moving tasks to other crew members. The Learning ability could be affected for the reason that instructional duties are not shared around within the crew as it should be.

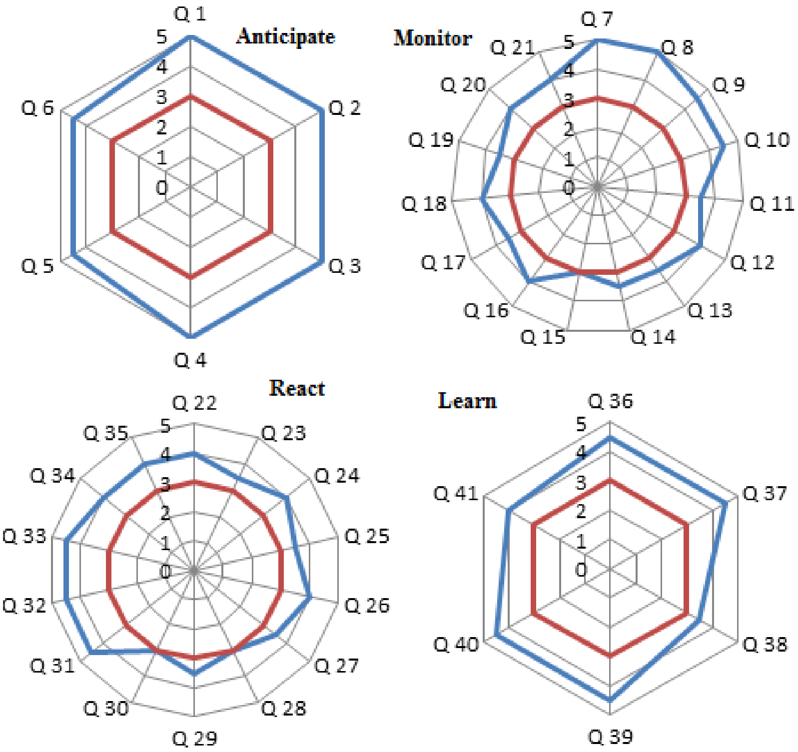


Figure 9-8 the resilience assessment results of the team level

Table 9-4 low scores questions of the team level

Questions received risky score
Q 15. During complex or time critical situations the members in the crew speak out openly when they think differently about the solution
Q 28. During complex or time critical situations the crew adheres to established work orders/ procedures
Q 30. During complex or time critical situations tasks are shed by not doing, postponing, doing less frequently, or moving tasks to other crew members

Figure 9-9 shows the outcome of the individual level resilience assessment. The results determined five key areas in this level could be considered as risky score since the scale located near the threshold scale. Table 9-5 presents the questionnaire questions that received low scores. But so far the condition do not develop to grow to be a threat to the operation system. The Anticipate ability of the individual level might be influenced as a result of there is not enough crew members who are made available to meet unforeseen demands. The Monitor capability could impact when in periods with high activity or a high number of simultaneous operations, crew members could not perform additional risk assessments to control for potential negative side effects. Also in periods with same condition crew members cannot monitor (potential) unexpected interactions between operations and/ or activities. The React aptitude might influence because crew members could not establish ' who does what ' during unforeseen operational demands. Also it might the case that there are not enough crew members available to respond appropriately to unforeseen operational demands.

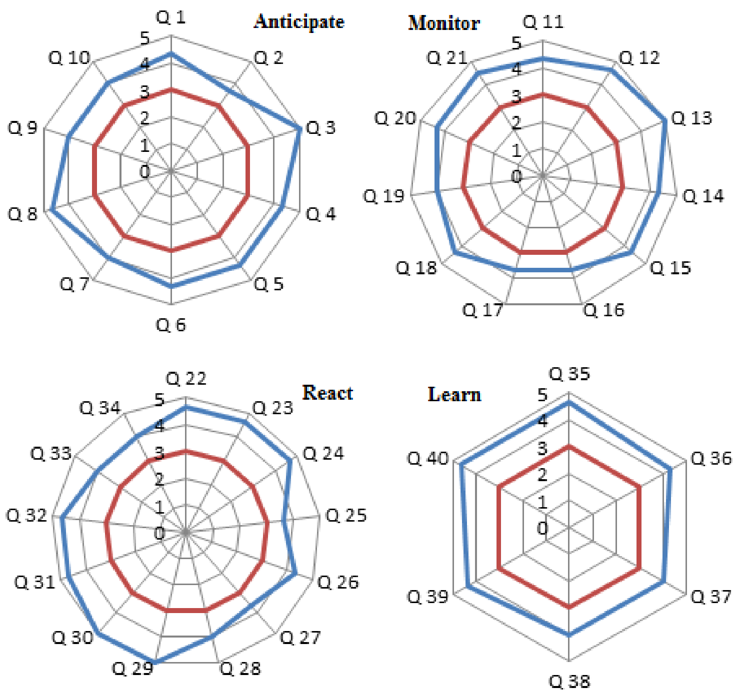


Figure 9-9 the resilience assessment results of the individual level

Table 9-5 low scores questions of the individual level

Questions received risky score
Q 2. Enough crew members are made available to meet unforeseen demands
Q 16. In periods with high activity or a high number of simultaneous operations, crew members perform additional risk assessments to control for potential negative side effects
Q 17. In periods with high activity or a high number of simultaneous operations, crew members monitor (potential) unexpected interactions between operations and/ or activities
Q 25. Crew members have established ' who does what ' during unforeseen operational demands
Q 27. Enough crew members are available to respond appropriately to unforeseen operational demands

9.10. Summary

To summarise, the goal of the resilience assessment tool is to provide shipping firms a wide-ranging support in their way towards safety and resilience. The application demonstrates several advantages that present resilience assessment and grading tool provide, including organisation's strengths, identifying the resilience gaps in the system, detect the weaknesses and/or non-compliances that might cause errors and mishaps, and offer quantitative results for the area that need improvement. The outcome of the case study could be used as a benchmark with other companies that give trends over time. The organisation is one of the leading establishment in the shipping and logistic business. For that, it was not surprised that the result of the RAT was good to excellent, because they are applying very high safety standard of safety procedure. However, after analysing the resilient items for each level it was discovered some critical areas which do not have the expected high resilience level (above the threshold). The resilience shortage of the detected elements have not yet reached the risky scale but with other deficiencies they might develop to critical condition. The drawbacks of this application are the answers of the participants may be influenced by the subjectivity of the participants or the small number of the sample. However, for future application, it could be useful if the RAT is used to assess the resilience of two or more shipping organisation have different safety performance to establish comparison study, and to demonstrate the benefit of the tool.

Chapter 10. Conclusion and Further Work

After analysing the accident reports of the Marine Accident Investigation Branch (MAIB), it was discovered that 127 accidents involving commercial ships occurred between 2010 and 2015, 56 of which were caused by navigation failures on the bridge. This fact motivates the author of this thesis to work for a solution that could prevent or reduce the consequences of such mishaps in the future. The concept of barrier management is a common tool in the market that helps to improve the safety of workplaces. The framework of this method was developed and modified by integrating resilience abilities into its functionality. The model is initiated by describing the operation of the navigation bridge, which relies on humans, technology and procedures. The shipping industry is a very old business that depends on people skills for designing, building, maintaining, regulating and operating the ships. The birth of the international convention for the safety of life at sea (SOLAS) in 1914 was the beginning of a new era of managing ships under effective regulation. The International Safety Management (ISM) Code is the international regulation for safe vessel operation and it has led to definite improvements to the navigation bridge. The training and certification of the crew members is regulated by the International Convention of Standards of Training Certification and Watchkeeping for Seafarers (STCW). Navigation technology has developed from classic ships relying on wind to a single-handed bridge. All three factors (human, technology and regulation) were analysed for the model application.

The model examined the MAIB accident reports for commercial vessels that were involved in accidents as a result of navigation deficiencies. The research found that eight main tasks were poorly performed by the bridge team. These miscarried tasks are misjudgement, inadequate emergency response, inadequate situational awareness, poor lookout, poor alarm management, poor leadership, ineffective passage planning and poor learning. This research identified 20 sub-factors that preceded the failure of the tasks. The factors could take different forms, such as procedure violation, poor bridge team competency, excessive workload and manning shortages. Poor task performance leads to navigation risk, which could be mitigated if the correct action was applied. The examination of the events found several mitigation elements to prevent or reduce the impact after the navigation risk had occurred. The impacts of the risks take four forms, which are: vessel damage, injury or fatality, pollution and the ship sinking. The correct actions to prevent the failures and the authorities' recommendation to the ship's owners, including the lessons learned, were documented to provide beneficial material and resources for the developed approach.

The findings of the risk analysis and the solutions were linked together in a bow-tie system to visualise the problems and the correct action. The navigation risk of the failures is located in the middle of the tool, between the top event of the fault tree analysis (FTA) and the initiated event of the event tree analysis (ETA). The FTA process defines the scenario of the causes of task deficiencies. The ETA presents the sequence for the development of events after the task fails and ends with the impacts. The eight tasks including the 20 sub-factors were analysed using this approach.

After describing the navigation system and defining the deficiencies of the operation, the solutions were developed to improve the safety of the performance and enhance the resilience capability. The approach is divided into two integrated schemes to construct an efficient barrier management system. The first part is the safety performance of each barrier. It includes function types such as preventative or mitigating. The barrier function should prevent capacity error, performance error, lack of communication, and unsafe acts. The mitigating kind should mitigate unsafe acts, unnoticed risky cause, event acceleration and confusion after an event took place. Each function requires various elements in different forms, such as technology, human and regulation. The second developed part is the resilience enhancement, which is integrated into the safety performance. It contains resilience ability, resources and control. The model provides four resilient abilities for the preventative functions, which are anticipation, monitoring, learning and responding. It also facilitates the preventative function with another four resilient abilities, which are plan/prepare, absorb, recover and adapt. The abilities are supported by resources and a control method. All these elements were developed and combined in eight bow-tie systems, each of which provides prevention and the mitigation from the navigation hazards that could be caused by the risk of the task failure. The relationships among the critical functions of the safety barrier were defined by the application of the Functional Resonance Accident Model (FRAM). The final results of the model application are guidelines and recommendations to improve the safety and the resilience of the navigation bridge standard operating procedure (SOP).

To test the model, a case study was prepared. Two groups were formed, each containing an OOW, a lookout and a helmsman. The first group (A) applied the typical bridge operation procedure and the second group (B) used the developed approach. The developed procedures and checklists were smaller and included short and clear sentences. They focused on the safety elements that are essential for each manoeuvring condition in a way that improves the performance and does not affect the safety. Several safety elements were added or enhanced in the bridge checklists that came from the model. Closed loop communication (plan, execute and verify) was enforced in the checklists, including blocking signs to prevent the operator from neglecting a critical element. The experiment contained five scenarios: normal navigation, passing agreement, restricted visibility, shallow water effect and pilot on board. The resilience abilities (anticipation, monitoring, learning and responding) of the two teams were evaluated according to the following indicators: 1) judgement ability, 2) emergency preparation, 3) situational awareness, 4) lookout quality, 5) alarm management, 6) leadership, 7) passage planning and 8) learning. The results of the appraisal indicated a promising outcome for the developed procedure. In the first scenario, the performance of group B was 124% higher than that of group A. In the second scenario, group B’s performance was 108% higher than that of group A. For the third scenario, group B’s performance was 28% higher than that of group A. In the fourth scenario, group B’s performance was 67% higher than that of group A. For the fifth scenario, group B’s performance was 93% higher than that of group A.

The resilience assessment tool (RAT) was developed and validated by experts team of SEAHORSE project. It provides shipping organisations wide-ranging support in their way towards safety and resilience. The method was applied first time to assess the resilience of one of the well-known maritime organisation. The implementation of the tool demonstrates several benefits include resilience assessment and grading scheme, detect the resilience gaps in a system, discover the weak areas which may cause errors, and offer quantitative outcomes. The result of the case study could be used as a benchmark with other companies. The results of the RAT were good to excellent as the organisation has high safety standard procedure. Though, after examining the resilient elements for each level, it was discovered some critical areas do not have the expected sufficient resilience standard. The shortages are not yet reach the risky scale but with other error may advance to serious situation. The downsides of the application are the responses of the questioner might be affected by the subjectivity of the participants or the small number of the sample.

10.1. Conclusion

Integrating the abilities of resilience engineering with barrier management is a novel approach for navigation bridge operation. The target is to improve the safety and reliability of the ship in the face of changing conditions. The application of the model demonstrated Promising enhancement. The common barrier management system has passive functions and elements for prevention or mitigation risks. The resilience abilities and resources contained proactive features to enhance the operation quality. The anticipation, monitoring, learning and reaction become part of the scheme, and they play significant roles within the safety system.

- The study, based on the accident analyses, concluded that, if bridge operation not performed properly by the bridge team, the following factors are the major deficiencies which lead to accidents: misjudgement, inadequate emergency response, inadequate situational awareness, poor lookout, poor alarm management, poor leadership, ineffective passage planning and poor learning.
- The tasks were influenced by 20 sub-factors which could take different forms, such as procedure violation, poor bridge team competency, excessive workload and manning shortages.
- The study concluded that accident reports are a rich source for identifying underlying reasons for accidents, and designing resilience based procedures to enhance the navigational safety.

- Navigational safety can be enhanced by adopting resilience based procedure through integration of barrier management and resilience abilities.
- Comparative assessment of resilience based procedures against the classical procedures concluded that the safety performance of a bridge team can be significantly enhanced, leading to a reduction of safety critical conditions, such as collision, grounding and contact. Simulator experiments clearly shown that group B, which followed the resilience based procedures, enhanced its performance by between 26% and 124% against group A, which followed the classical procedures. The performance enhancement varied depending on the scenarios tested.
- Full-mission simulator environment, which is an excellent platform to design, assess and validate new procedures, should be recognised by maritime authorities as a training and skill enhancement approach.
- The Resilience Assessment Tool (RAT) has demonstrated that it can capture strengths and weaknesses of the organisations and should be implemented to enhance the resilience abilities of the organisations, multi-party, different teams and individuals.

10.2. Limitation

The difficulty of this model is that one has to deal with the massive quantities of data that are received during the process. The implementer should be an expert in the maritime field and be able to select the relevant information. Furthermore, not all the events have a similar line of expansion, potentially driving the implementer to be selective and place the relevant facts in line to be manageable and applicable.

The application takes time and effort, which requires the implementers to be specific when choosing the critical function for the application. All these obstacles can be minimised by continuous application of the model and better sub-grouping of the questions to identify systematically underlying issues.

The advantages of this approach are that it reduces errors by the navigator by enhancing the operation responses, improves the monitoring task and the efficiency of the planning, increases the system reliability via the learning from the past mistakes and maintains a strong and flexible system during changing conditions because of the anticipation ability.

10.3. Future Work

In future work, the risk analysis should be reviewed to develop a system that is able to deal with the nonlinear causes and factors of the events. The control and management of the safety elements and the resilience resources require improvement and unity. Future applications must consider the navigation bridge demands for humans, technology and procedure for different ship types and various operation conditions. To improve the model validation adapting a quantitative assessment approach will advance the framework outcomes. Finally, it could be useful to develop computer software for the model process that is able to provide an effective system and faster solutions to the shipping organisation during changing conditions.

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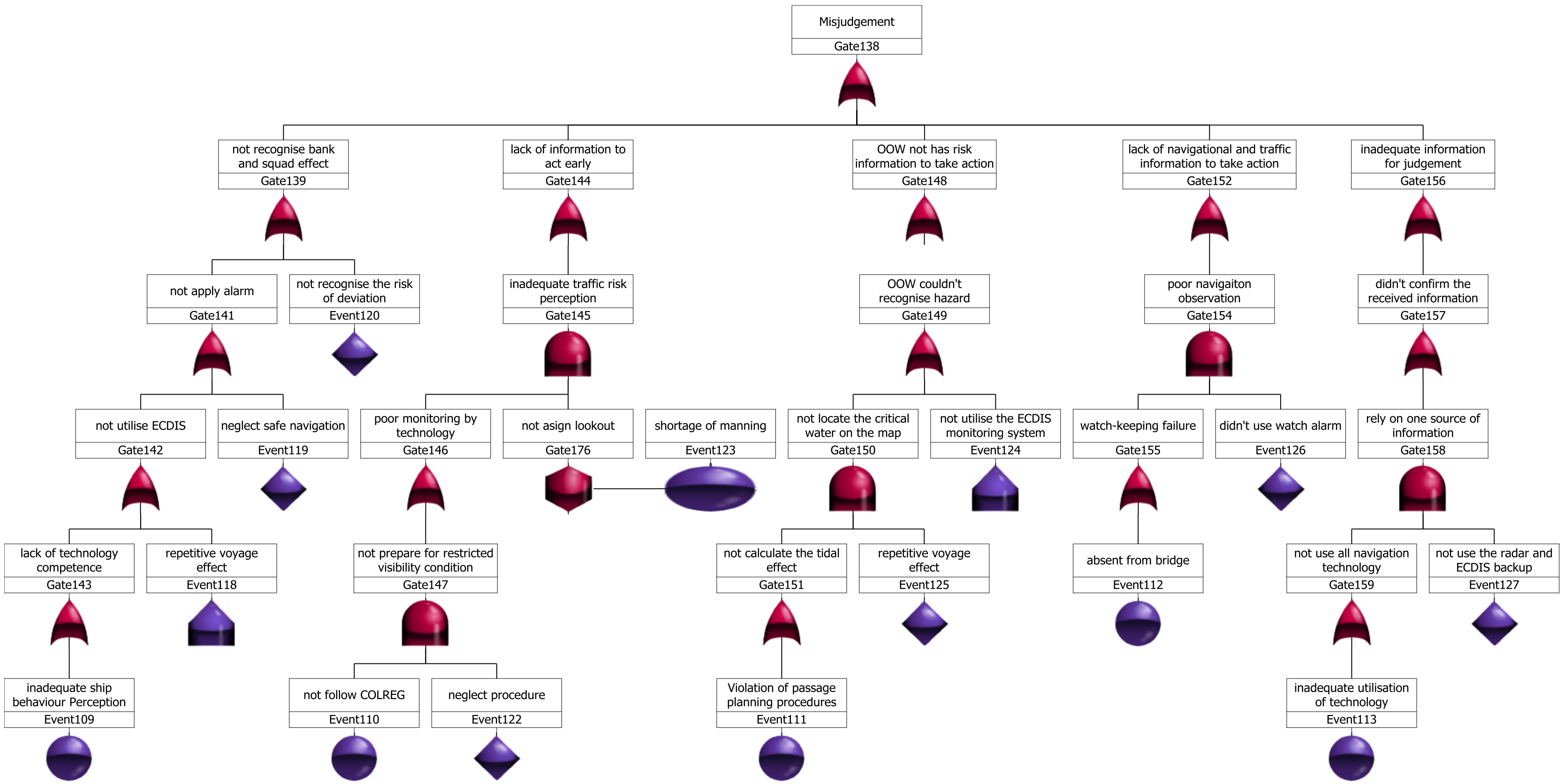
Chapter 11. APPENDIX

11.1. APPENDIX A

11.1.1 Process of Planning the Resilient Safety system to Prevent Misjudgement



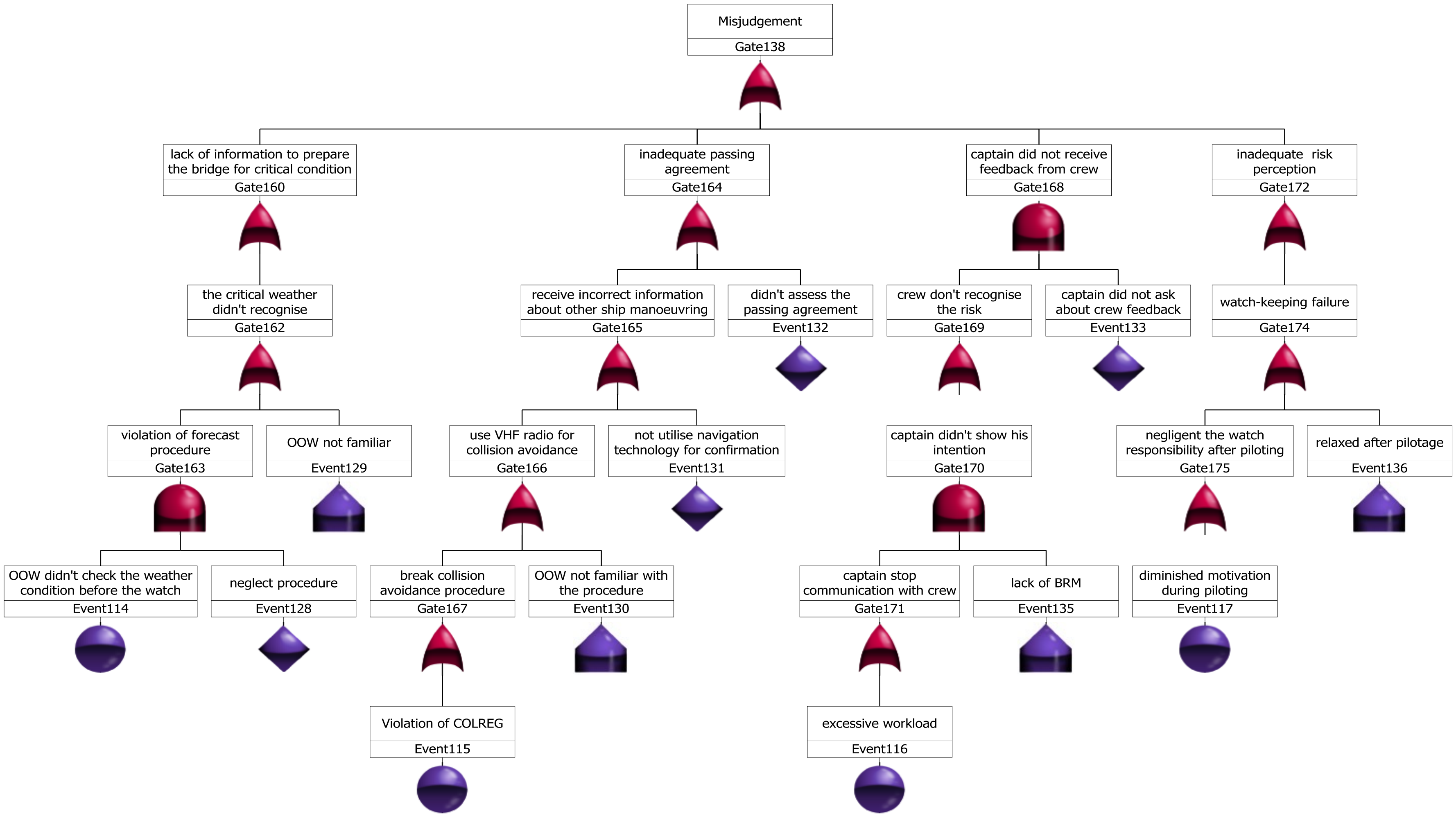


Figure 11-1 Misjudgement FTA

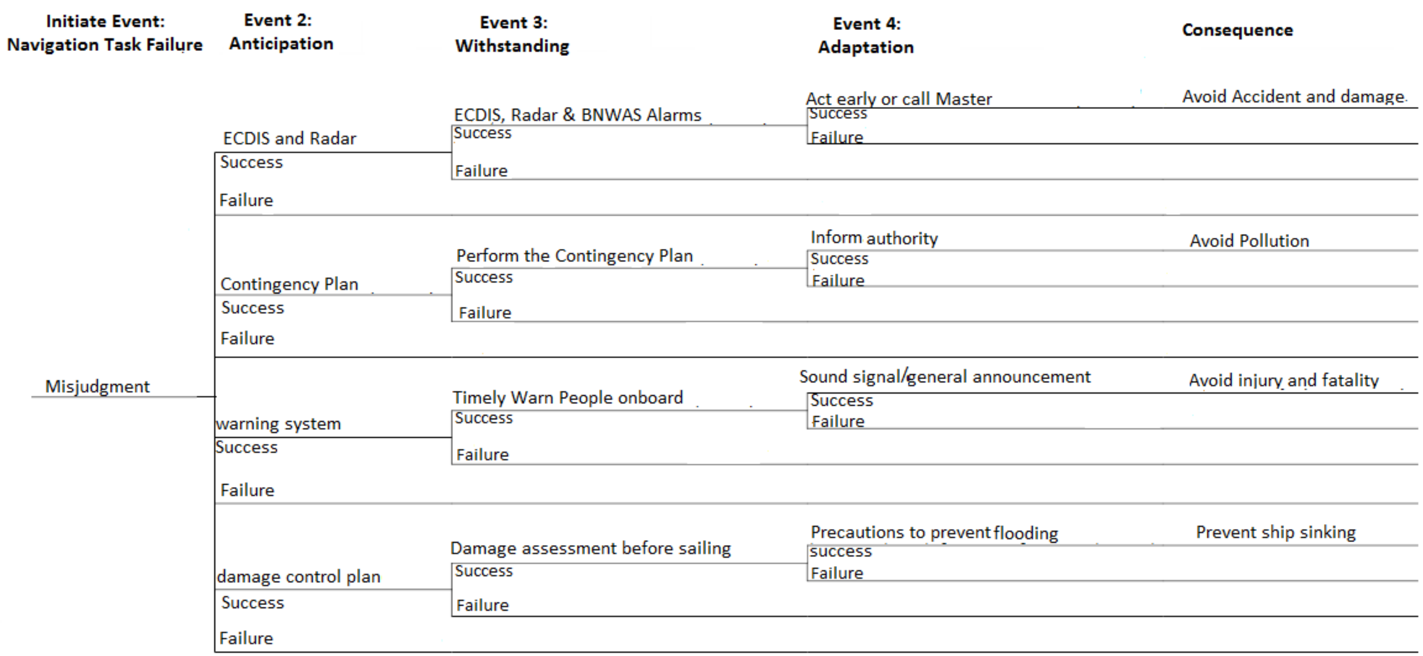


Figure 11-2 Misjudgement ETA

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Misjudgement) **Prevent inadequate ship behaviour Perception (bank and squad effect)**	Prevent capacity error	OOW must utilise ECDIS	Anticipation (Knowing what to expect)	-OOW familiar with ECDIS - ECDIS is operating all time and Check performance and setting	procedure: organisation validate OOW's knowledge procedure: watch checklist
	Prevent performance error	Observing ship position	Monitoring (Knowing what to look for)	Using ECDIS alarms Ensure ECDIS alarms and sound are on	procedure: watch checklist
	Prevent lack of communication	Receive information to recognise bank and squat effect	Learning (Knowing what has happened)	Captain perform briefing before shallow water	Method: Add comment on the chart about shallow water
	Prevent unsafe act	Early action or call master	Responding (knowing what to do)	OOW able to assess the speed risk and manoeuvre limitation	Training: Simulator

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Misjudgement) **Prevent inadequate traffic risk perception (restricted visibility condition)**	Prevent capacity error	Follow COLREG (restricted visibility)	Anticipation	OOW familiar with COLREG procedure (restricted visibility)	Procedure: organisation validate OOW knowledge
	Prevent performance error	Monitor ships traffic	Monitoring	Utilize Radar and AIS and use their alarms	Procedure: (watch check List)
	Prevent lack of communication	Find information of ships traffic condition and assess the risk	Learning	- Utilise navigation technology -Extra lookout -Call master for advise	Training: BRM
	Prevent unsafe act	Act early to avoid accident	Responding	-OOW familiar with collision avoidance and risk assessment - CPA safe distance	Procedure: Master's standing orders (minimum safe passing)

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Misjudgement) **Prevent Violation of passage planning (PP) procedures (calculating the tidal affect)**	Prevent capacity error	follow passage planning procedure	Anticipation	voyage plan briefing	Procedure: passage planning checklist
	Prevent performance error	recognise hazard during the watch	Monitoring	beginning of the watch assess for future risk (tidal, or route hazards)	Procedure: (watch checklist)
	Prevent lack of communication	critical areas should be defined clearly	Learning	Add notes on the chart	Procedure: passage planning checklist
	Prevent unsafe act	act early for avoidance	Responding	contingency procedure for encounters unprepared hazard	Training : simulator

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Misjudgement) **Prevent Abandoned bridge**	Prevent capacity error	OOW must remain on bridge during the watch	Anticipation	OOW should not leave bridge without a replacement	Procedure: personnel number
	Prevent performance error	Perform watch keeping (avoid sleep)	Monitoring	Use the BNAWS	Procedure: watch checklist
	Prevent lack of communication	OOW must be able to realise navigation operation and traffic condition (E.g. not fatigue)	Learning	Develop a threshold scale show the safety of a watch that display OOW ability vs sailing condition	Procedure: bridge procedure
	Prevent unsafe act	OOW must call master if he requires to leave bridge or he couldn't able to perform the watch	Responding	develop procedure and manning if OOW couldn't able to perform the watch	Procedure: personnel number

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Misjudgement) **Prevent Inadequate utilisation of technology**	Prevent capacity error	OOW must utilise all bridge technology (avoid neglect)	Anticipation	Ensure OOW is familiar with bridge technology	<u>Procedure:</u> organisation validate OOW knowledge <u>Method:</u> technology guideline
	Prevent performance error	Keep backup navigation equipment running	Monitoring	OOW must recognise using backup navigation equipment	<u>Method</u>: Write note on equipment
	Prevent lack of communication	validate information with different equipment	Learning	aware about technology capabilities and limitations	<u>Method</u>: technology guideline
	Prevent unsafe act	Always check technology performance and setting	Responding	contingency procedure for bridge technology deficiencies	<u>Procedure:</u> watch checklist refer to contingency procedure

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Misjudgement) **Prevent violation of forecast procedure**	Prevent capacity error	perform weather forecast and use its technology	Anticipation	OOW must be familiar with weather forecast process and technology	<u>Procedure:</u> organisation validate OOW knowledge <u>Method:</u> technology guideline
	Prevent performance error	Check weather forecast during a watch	Monitoring	Ensure OOW perform the forecast before or within a watch	<u>Procedure</u>: (watch checklist)
	Prevent lack of communication	Ensure Perceiving correct weather information	Learning	Check different resources of weather warning technology	<u>Procedure</u>: (watch checklist)
	Prevent unsafe act	bridge operation is prepared for weather condition	Responding	Develop Windage assessments scale considering manoeuvring limitation in different weather condition	<u>Method:</u> Windage assessments scale

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Misjudgement) **Violation of COLREG (Avoid VHF radio for collision avoidance)**	Prevent capacity error	Follow collision avoidance procedure	Anticipation	Ensure OOW aware about the collision avoidance procedure	Method: provide COLREG training software onboard
	Prevent performance error	Perceive traffic intention (Avoid using VHF radio)	Monitoring	risk assessment of ships traffic without using VHF	Method: add warning note on the VHF
	Prevent lack of communication	Perceive other ship intention and passing agreement	Learning	traffic Risk assessment by all resources (technology, lookout)	Training: BRM
	Prevent unsafe act	OOW must recognise minimum safe passage	Responding	Define minimum safe passage	Procedure: Master's standing orders

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Misjudgement) **Prevent Excessive workload (captain not communicate with crew)**	Prevent capacity error	bridge team must Communicate together	Anticipation	Master and OOW must by familiar with the bridge resource management	Training: BRM
	Prevent performance error	crew report to OOW	Monitoring	brief crew about manoeuvring	Procedure: departure and arrival checklists
	Prevent lack of communication	OOW ensure receive feedback from crew	Learning	Ensure two ways communication	Procedure: departure and arrival checklists
	Prevent unsafe act	OOW intention is clear to crew	Responding	Out loud thinking	Procedure: departure and arrival checklists

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Misjudgement) **Prevent diminished motivation (being negligent for the watch responsibility after piloting)**	Prevent capacity error	OOW must back to normal performance after piloting	Anticipation	OOW must be aware about Potential for low arousal after pilotage	Procedure: pilot checklist
	Prevent performance error	examine all technology functions and ship position	Monitoring	Master not leave bridge before OOW is ready for the watch	Procedure: pilot checklist
	Prevent lack of communication	Adequate perception of traffic	Learning	Suitable perception of traffic during piloting helps after pilot leaves	Procedure: pilot checklist
	Prevent unsafe act	Keep communicating with pilot	Responding	Master and OOW understand that pilot is part of bridge team (communicate with him and challenge his decisions)	Procedure: pilot checklist

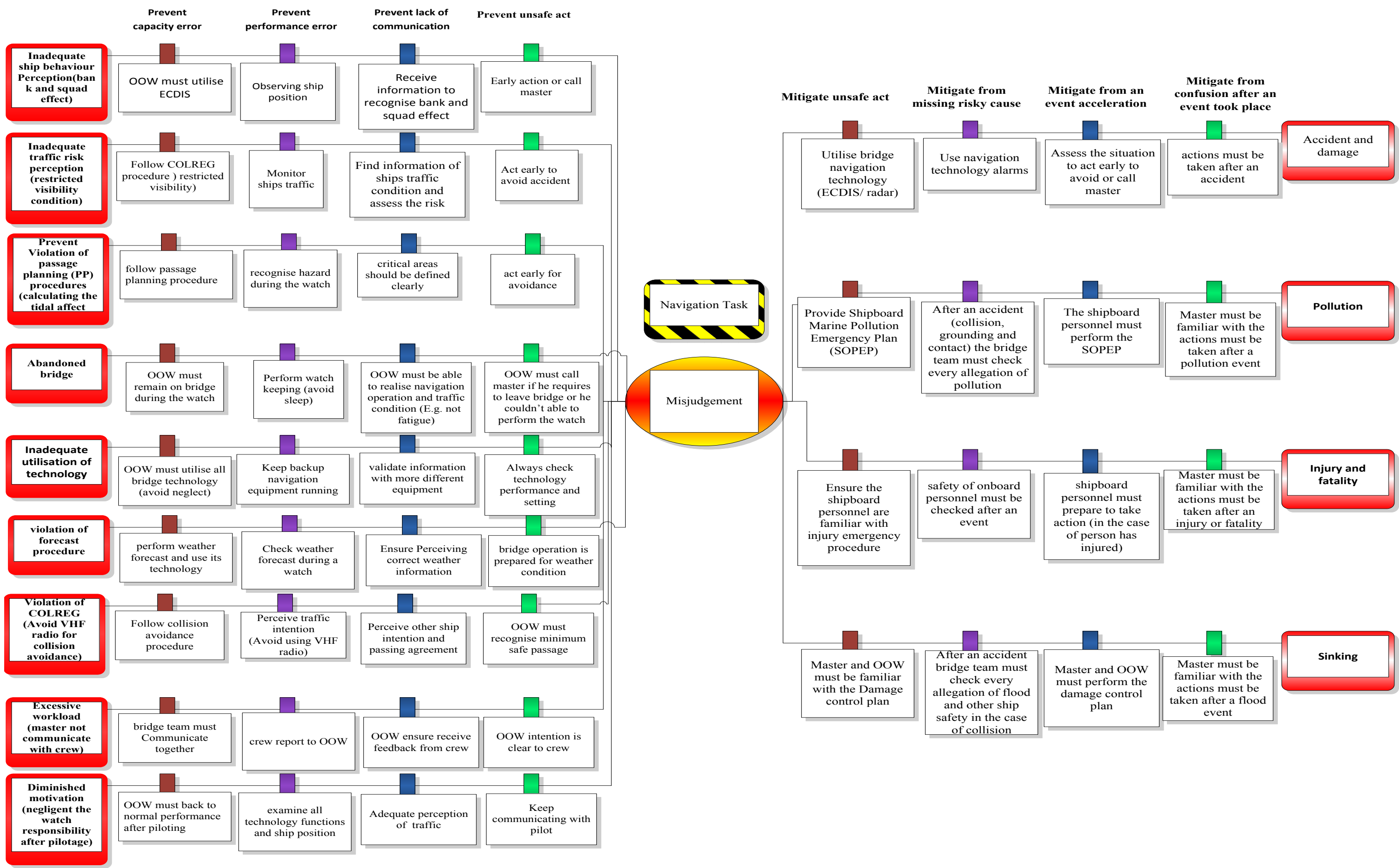
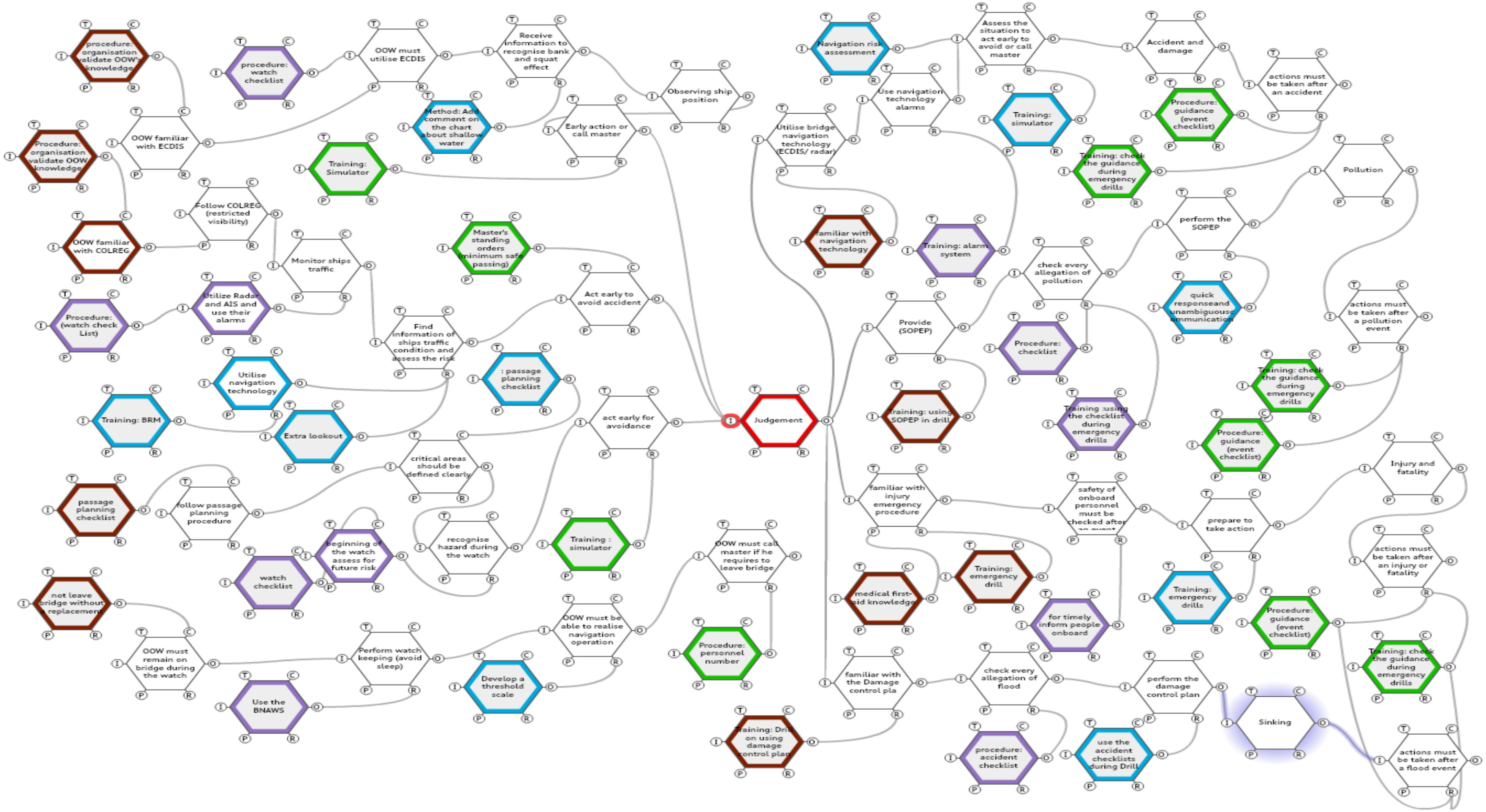
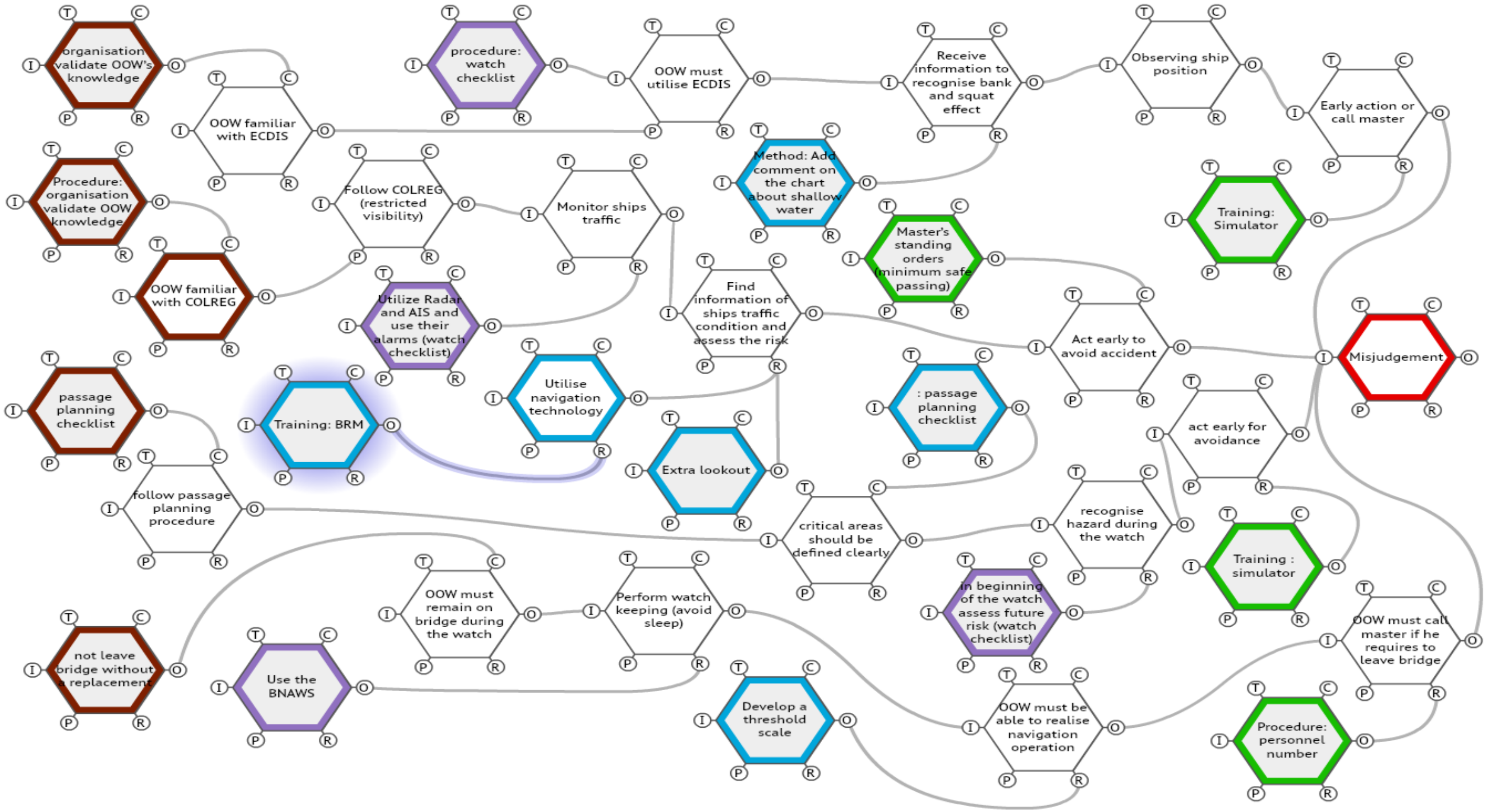


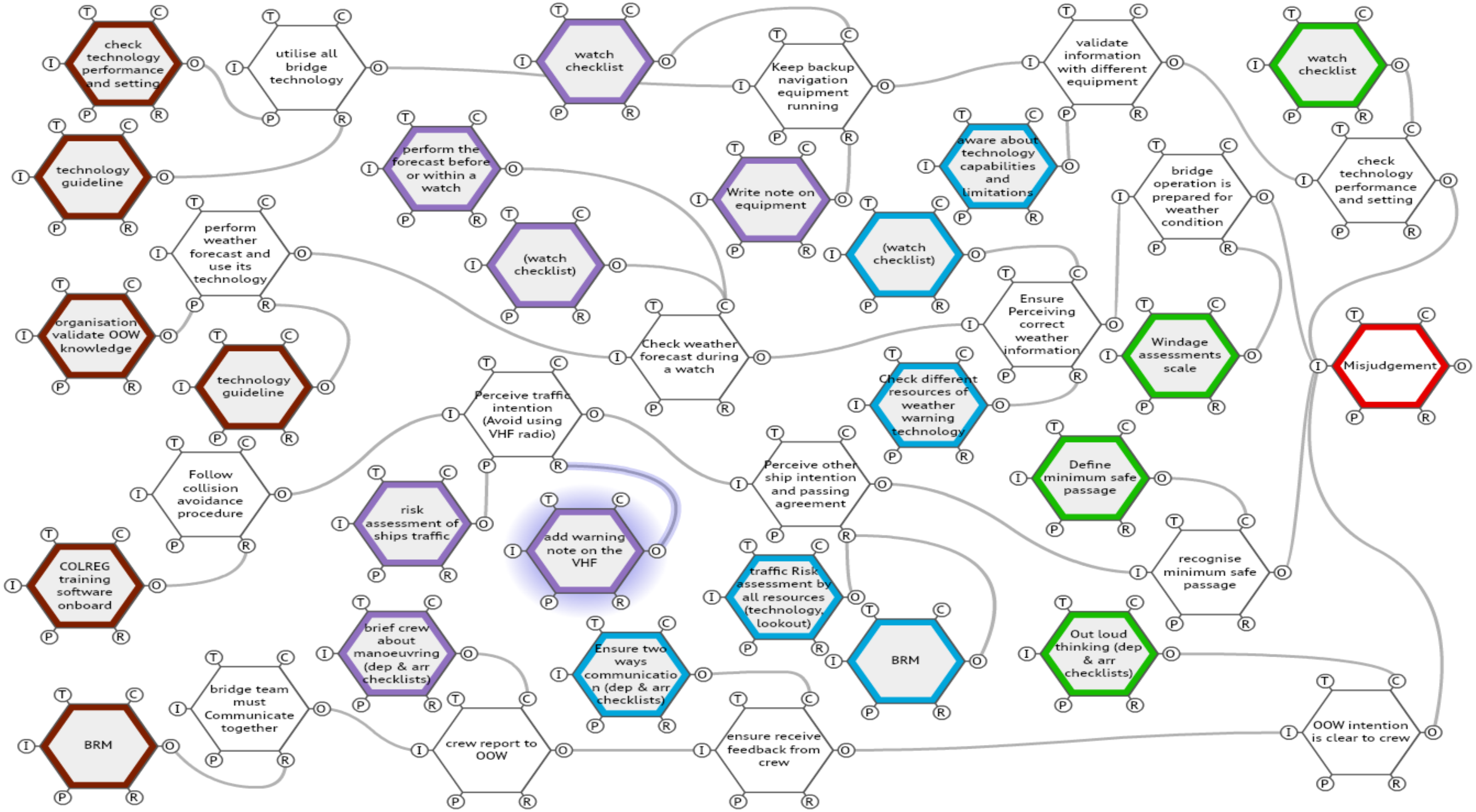
Figure 11-3 Misjudgement Bow-tie



procedure: organisation validate OOW's knowledge
procedure: watch checklist
OOW must utilise ECDIS
Receive information to recognise bank and squat effect
Observing ship position
Navigation risk assessment
Assess the situation to act early to avoid or call master
Accident and damage
actions must be taken after an accident
Procedure: organisation validate OOW knowledge
OOW familiar with ECDIS
Method: Add comment on the chart about shallow water
Early action or call master
Use navigation technology alarms
Utilise bridge navigation technology (ECDIS/ radar)
Training: simulator
Procedure: guidance (event checklist)
Training: Simulator
Follow COLREG (restricted visibility)
Training: check the guidance during emergency drills
Pollution
OOW familiar with COLREG
Monitor ships traffic
Master's standing orders (minimum safe passing)
familiar with navigation technology
Training: alarm system
check every allegation of pollution
perform the SOPEP
Act early to avoid accident
Procedure: (watch check List)
Utilize Radar and AIS and use their alarms
Find information of ships traffic condition and assess the risk
Provide (SOPEP)
quick responseand unambiguous communication
actions must be taken after a pollution event
Procedure: checklist
Utilise navigation technology
: passage planning checklist
Training: check the guidance during emergency drills
Training: BRM
Extra lookout
act early for avoidance
Judgement
Training: using SOPEP in drill
Training :using the checklist during emergency drills
Procedure: guidance (event checklist)
critical areas should be defined clearly
familiar with injury emergency procedure
safety of onboard personnel must be checked after an event
Injury and fatality
passage planning checklist
follow passage planning procedure
prepare to take action
beginning of the watch assess for future risk
recognise hazard during the watch
Training : simulator
OOW must call master if he requires to leave bridge
Training: emergency drill
actions must be taken after an injury or fatality
watch checklist
medical first-aid knowledge
Training: emergency drills
not leave bridge without replacement
OOW must be able to realise navigation operation
for timely inform people onboard
Procedure: guidance (event checklist)
OOW must remain on bridge during the watch
Perform watch keeping (avoid sleep)
Procedure: personnel number
Training: check the guidance during emergency drills
familiar with the Damage control pla
check every allegation of flood
perform the damage control plan
Use the BNAWS
Develop a threshold scale
Sinking
Training: Drill on using damage control plan
procedure: accident checklist
use the accident checklists during Drill
actions must be taken after a flood event



Misjudgement FRAM



Misjudgement FRAM

11.1.2 Process of Planning the Resilient Safety system to Prevent Inadequate Emergency Response

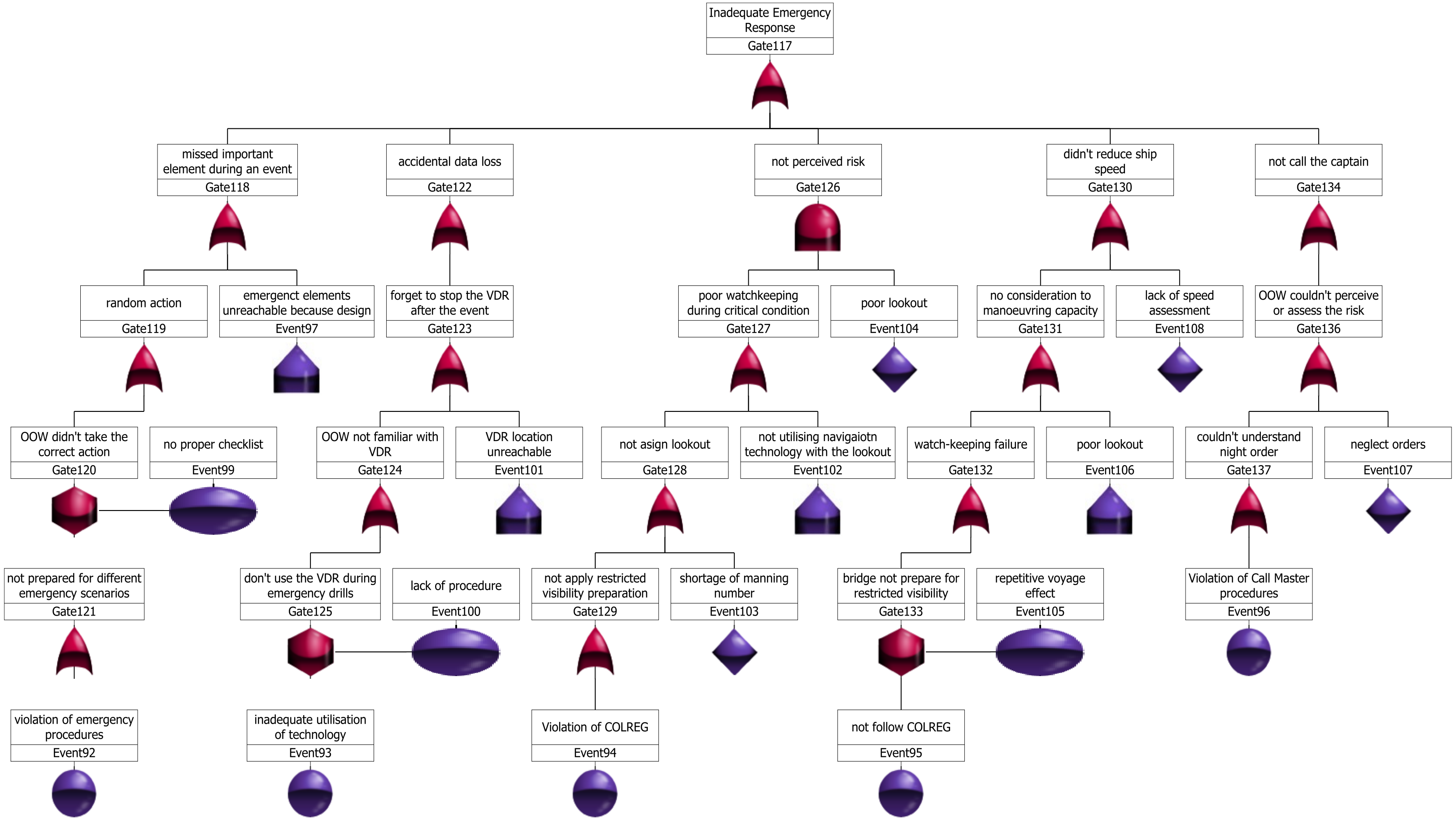


Figure 11-4 Inadequate Emergency Response FTA

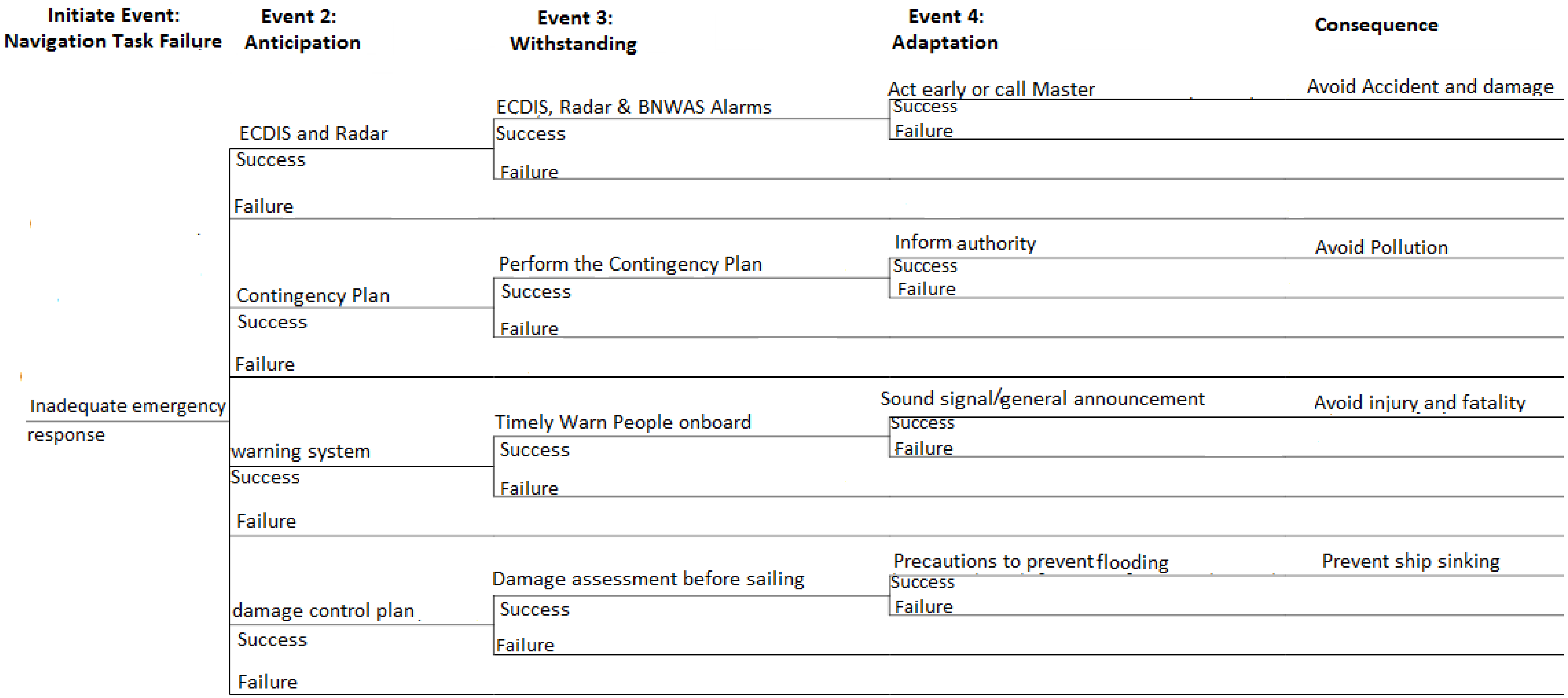


Figure 11-5 Inadequate emergency response ETA

Safety Performance			Resilience Enhancement		
Purpose	**Barrier function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Inadequate Emergency Response) **Prevent Violation of emergency procedures (miss important element during an event)**	Prevent capacity error	OOW must follow the emergency procedure	Anticipation	OOW must be familiar with the emergency procedure	Procedure: organisation validate OOW knowledge
	Prevent performance error	Emergency procedures must be located in feasible location	Monitoring	provide checklists for different emergency events	Training: use emergency checklists during emergency drill
	Prevent lack of communication	Good observation and feedback during an event	Learning	Ensure manning number can cover different events	Procedure: Review manning number comparing to the needs for different events
	Prevent unsafe act	Recognise emergency elements (E.g. sound signal, Checklist)	Responding	Ability to deal with different scenarios	Training: Drill in different scenarios (even minor or rare once)

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Inadequate Emergency Response) **Prevent Inadequate utilisation of technology (Miss using VDR after an event)**	Prevent capacity error	Follow emergency procedure (VDR)	Anticipation	OOW must be familiar with the emergency procedure (VDR)	Procedure: organisation validate OOW knowledge
	Prevent performance error	Ensure stopping the VDR after an accident to prevent overwriting	Monitoring	Knowing the risk of not stop the VDR after an event	Training: use VDR during drill
	Prevent lack of communication	Ensure bridge team keep organised after an accident	Learning	- Ensure manning number -Ensure BRM	Training: BRM
	Prevent unsafe act	The VDR button should in clear location	Responding	Ensure designing the VDR button could be reached easily after an accident	Procedure: organisation

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Inadequate Emergency Response) **Prevent Violation of COLREG (not apply Restricted visibility preparation)**	Prevent capacity error	Follow COLREG (Restricted visibility)	Anticipation	OOW must be familiar with Restricted visibility preparation	Procedure: organisation validate OOW knowledge
	Prevent performance error	OOW must be able to provide good lookout or ask for lookout	Monitoring	the capability of OOW must be consider	Procedure: Review manning number comparing to the needs for different events
	Prevent lack of communication	Ensure effective communication on bridge	Learning	Provide two ways communication between OOW and the lookout	Procedure: (restricted visibility checklist)
	Prevent unsafe act	Ensure take correct action by verifying information	Responding	Out laud thinking	Procedure: (restricted visibility checklist)

Safety Performance			Resilience Enhancement		
Purpose	**Barriers Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Inadequate Emergency Response) **Prevent Violation of COLREG (lack of Speed assessment)**	Prevent capacity error	consider ship ability and limitation	Anticipation	Ensure OOW has experience and knowledge for manoeuvring	Training: simulator
	Prevent performance error	Speed assessment	Monitoring	Ensure OOW perform speed risk assessment	Procedure: (departure and arrival checklist checklist)
	Prevent lack of communication	Manoeuvring Validation by receiving crew feedback	Learning	Manoeuvring Briefing for crew	Procedure: (departure and arrival checklist checklist)
	Prevent unsafe act	Emergency action must be in place to prevent speed risk	Responding	Ensure the bridge team has emergency procedure to prevent or reduce speed risk (E.g. drop anchor)	Procedure: (departure and arrival checklist checklist)

Safety Performance			Resilience Enhancement		
Purpose	**Barriers Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Inadequate Emergency Response) **Prevent violation of call master procedures**	Prevent capacity error	Follow master standing orders	Anticipation	OOW must understand master standing orders	Procedure: captain confirm understanding
	Prevent performance error	OOW and bridge team must observe with all possible method	Monitoring	Good ability to observe and assess risk	Procedure: captain confirm the ability
	Prevent lack of communication	perceive critical condition that required expert support	Learning	Include default calling master	Procedure: Master standing order
	Prevent unsafe act	Call master	Responding	master ensure OOW will not hesitate to call him	Method: friendly encouraging environment for communication

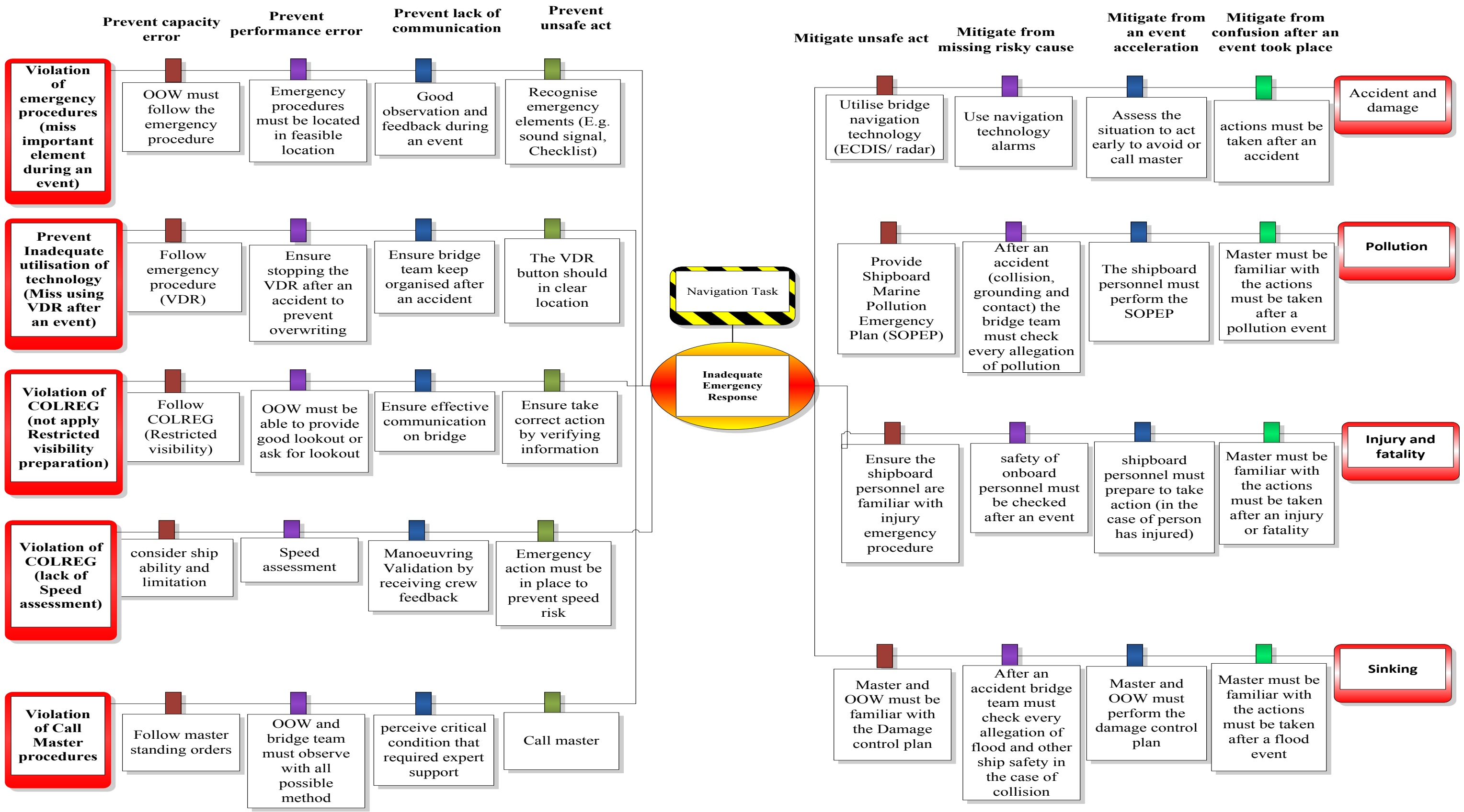
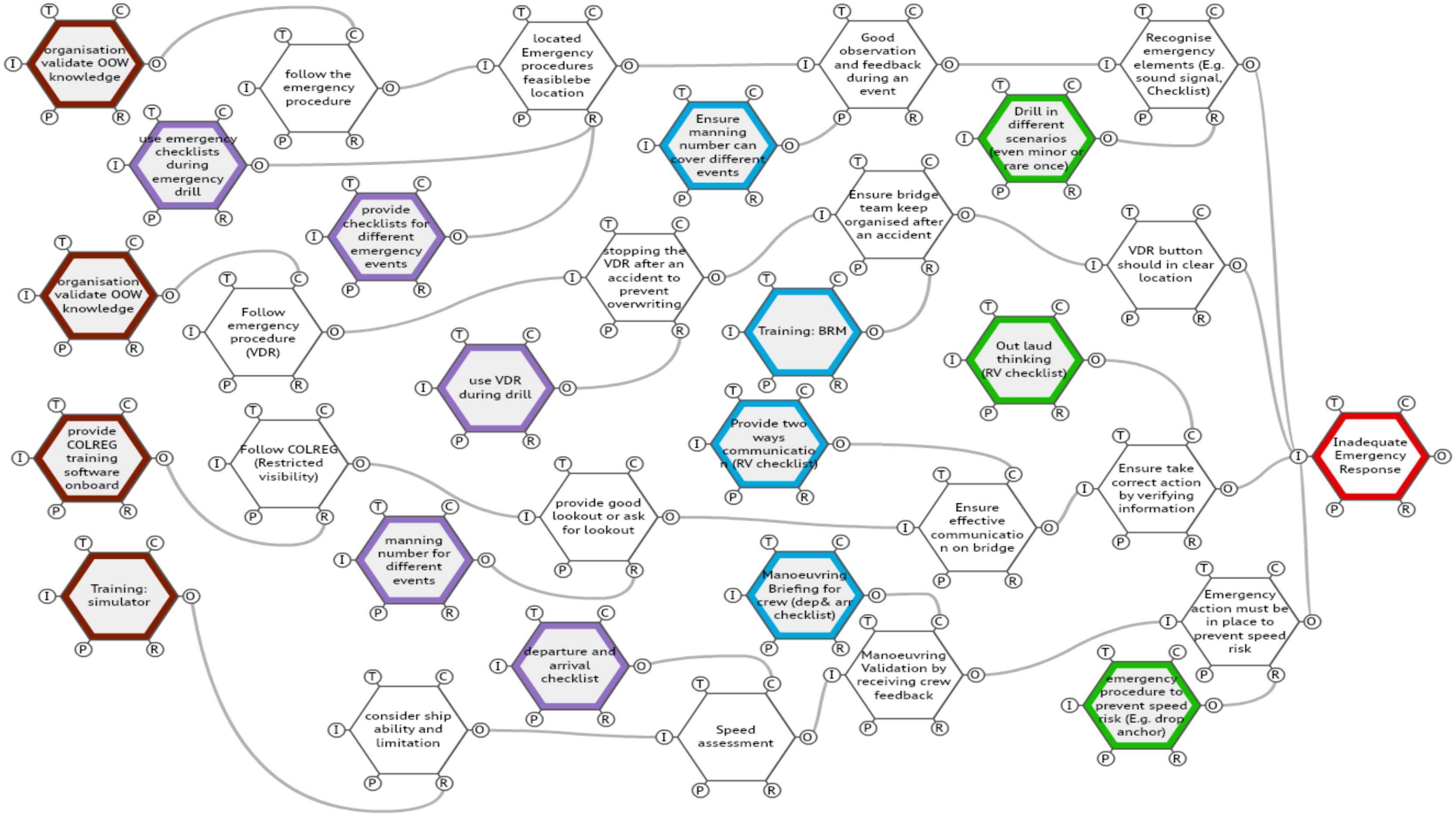
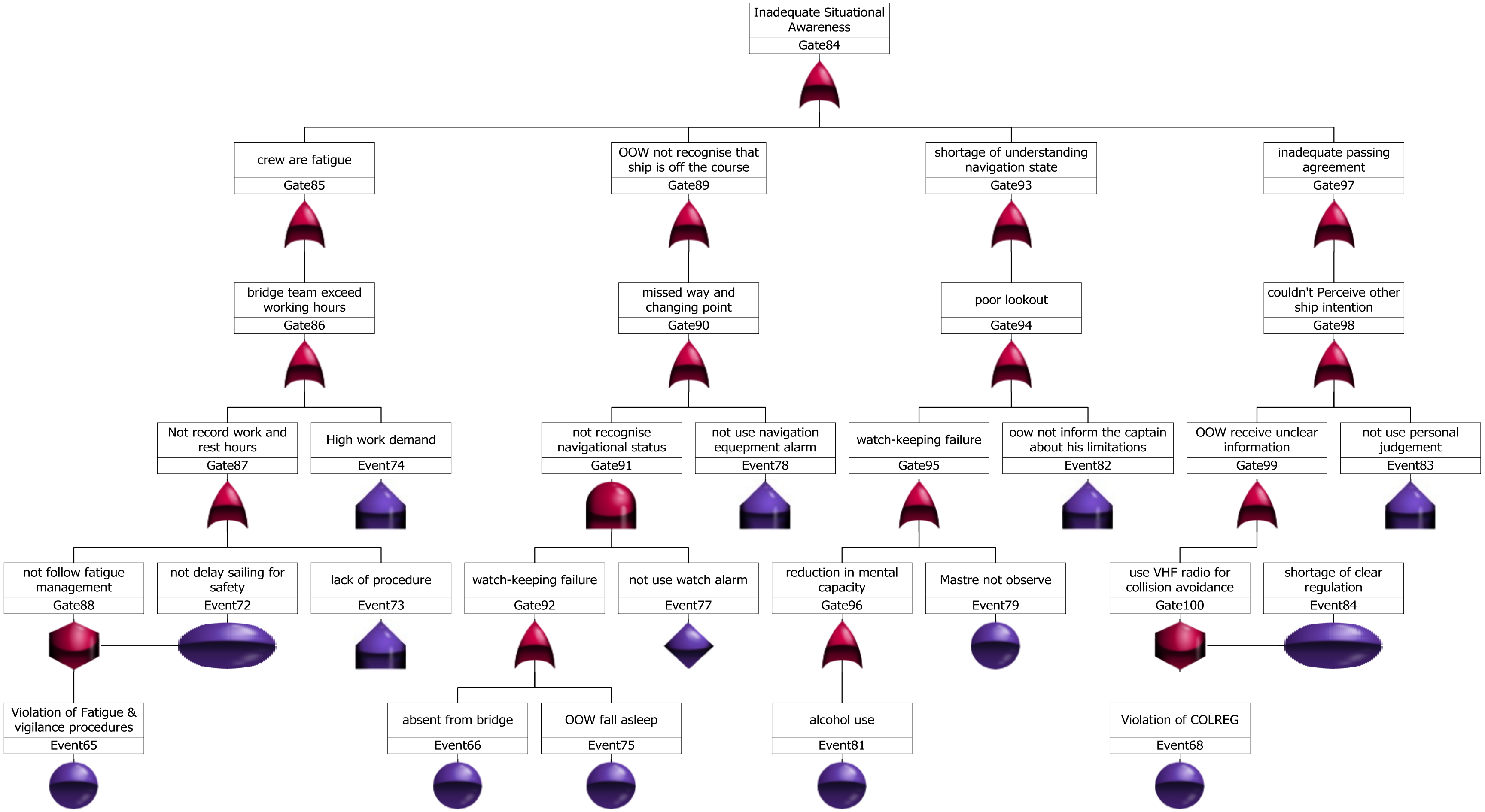


Figure 11-6 Inadequate emergency response Bow-tie



Inadequate emergency response FRAM

11.1.3 Process of Planning the Resilient Safety system to Prevent Inadequate Situational Awareness



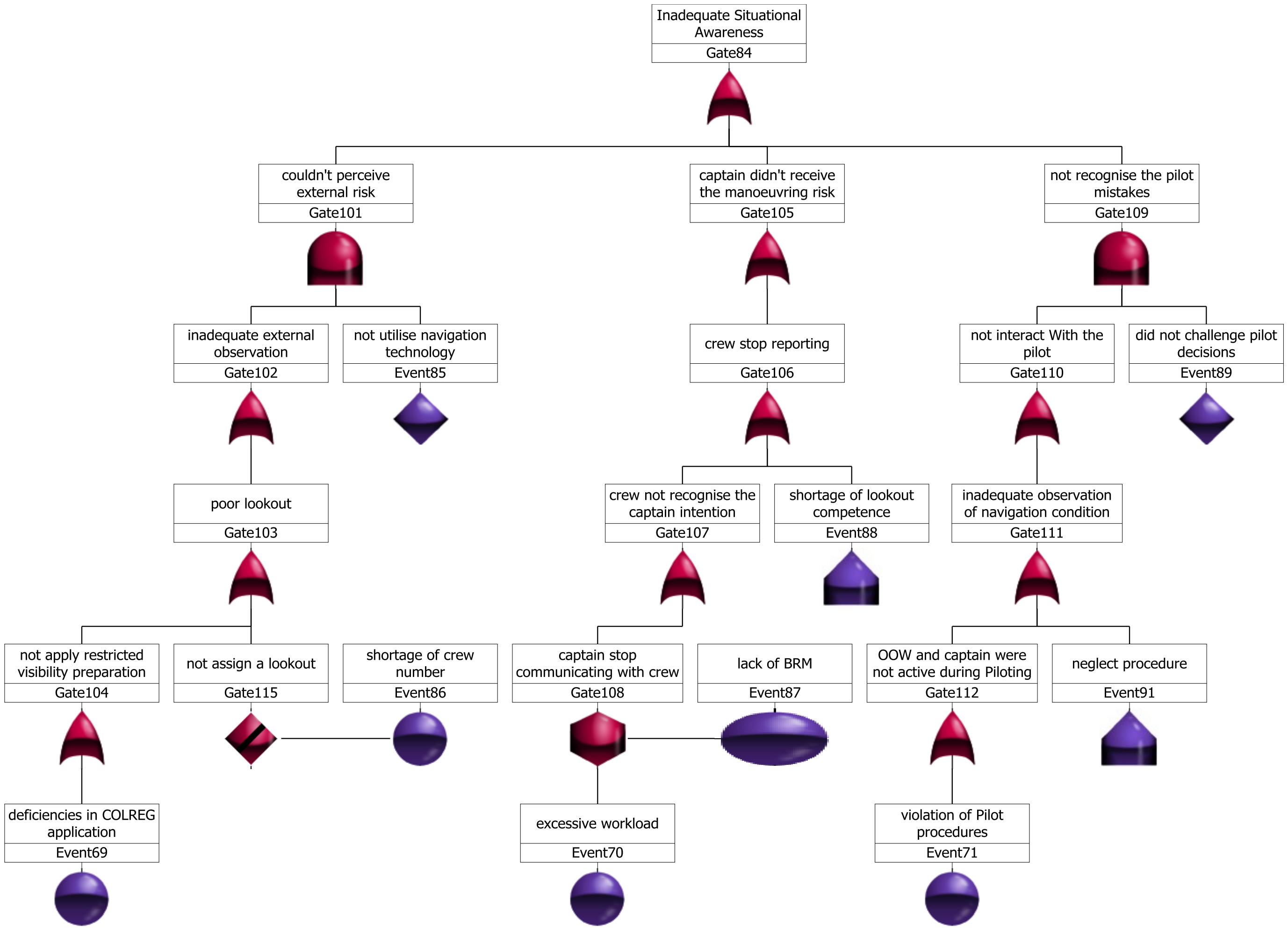


Figure 11-7 Inadequate Situational Awareness FTA

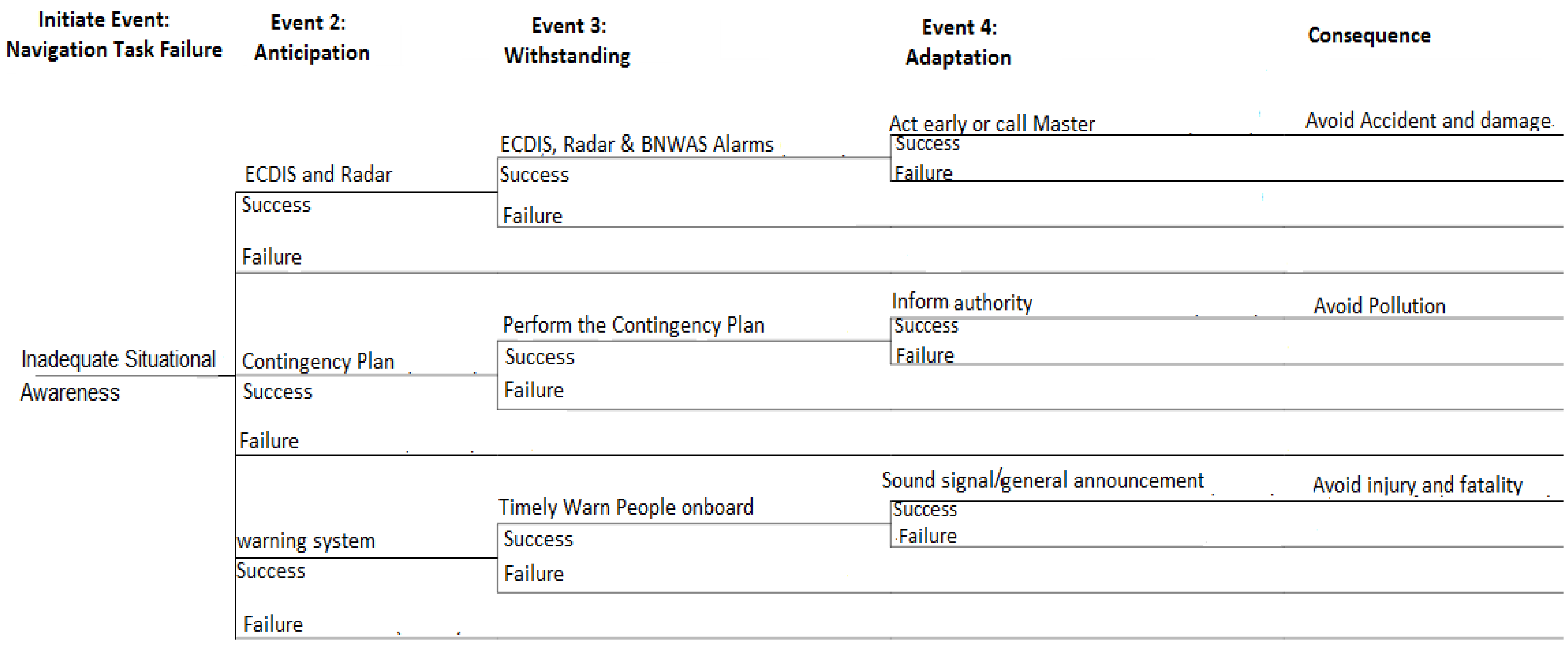


Figure 11-8 Inadequate situational awareness ETA

Safety Performance				Resilience Enhancement	
Purpose	**Barrier function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Inadequate Situational Awareness) **Prevent violation of fatigue & vigilance procedures**	Prevent capacity error	Follow fatigue management guidance in SMS	Anticipation	Provide fatigue procedure familiar about fatigue risk	<u>Procedure</u>: fatigue procedure
	Prevent performance error	Bridge team shouldn't exceed the working hours that defined by the ILO	Monitoring	Ensure bridge team manage between operation demanding and rest	<u>Method</u>: record working and rest hours
	Prevent lack of communication	Bridge team shouldn't reach the level of mental ability reduction	Learning	Crew changes to minimise the workload impact on master and OOW (Review vessel manning)	<u>Procedure</u>: Review manning number comparing to the needs for different operation
	Prevent unsafe act	master must ensure the bridge team is able to navigate safely	Responding	The organisation Support masters' decision to delay the ship sailing for safety	<u>Procedure:</u> organisation

Safety Performance				Resilience Enhancement	
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Inadequate Situational Awareness) **Prevent Abandoned bridge**	Prevent capacity error	OOW must remain on bridge during watch	Anticipation	OOW should not leave bridge without a replacement	<u>Procedure:</u> master standing order
	Prevent performance error	Perform watch keeping (avoid sleep)	Monitoring	Ensure the BNWAS is part from the watch process	<u>Procedure</u>: watch checklist
	Prevent lack of communication	OOW must be able to realise navigation operation and traffic condition	Learning	Stay active and utilise navigation technology	<u>Training</u>: BRM
	Prevent unsafe act	OOW must call master if requires to leave bridge or couldn't able to perform	Responding	develop procedure and manning if OOW couldn't able to perform the watch	<u>Procedure:</u> for replacement OOW

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Inadequate Situational Awareness) **Prevent alcohol use**	Prevent capacity error	Bridge team must not operate the bridge while impaired by drugs or alcohol	Anticipation	That organisation must provide a clearly written policy on drug and alcohol abuse	Procedure: drug and alcohol abuse
	Prevent performance error	Master must observe alcohol consumption on board	Monitoring	Master must provide random alcohol test to the bridge team	Procedure: random alcohol test
	Prevent lack of communication	OOW must has the mental capacity (not losing traffic perception)	Learning	Bridge team must be familiar with the maximum permissible blood alcohol content (BAC) and abstinence periods	Procedure: BAC guidance
	Prevent unsafe act	When crew member violates alcohol regulation must receive a punishment	Responding	Warn crew about the punishment (custodial Sentence)	Procedure: punishment

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Inadequate Situational Awareness) **Violation of COLREG (Avoid VHF radio for collision avoidance)**	Prevent capacity error	Follow collision avoidance procedure	Anticipation	Ensure OOW aware about the collision avoidance procedure	Training: COLREG software onboard
	Prevent performance error	Perceive traffic intention without VHF	Monitoring	Ensure OOW is able to establish a risk assessment of ships traffic	Method: add warning note on the VHF
	Prevent lack of communication	Perceive other ship intention and passing agreement	Learning	perform traffic risk assessment with resources (technology and lookout)	Training: BRM
	Prevent unsafe act	OOW must recognise minimum safe passing	Responding	-Define minimum safe passing	Procedure: Master's standing orders

Safety Performance			Resilience Enhancement		
Purpose	**Barriers Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Inadequate Situational Awareness) **Prevent Violation of COLREG (not apply Restricted visibility preparation)**	Prevent capacity error	Follow COLREG (Restricted visibility)	Anticipation	OOW must be familiar with Restricted visibility preparation	Procedure: organisation validate OOW knowledge
	Prevent performance error	OOW must be able to provide good lookout or ask for lookout	Monitoring	Ensure there is enough people for lookout or the capability of OOW must be consider	Procedure: evaluate manning level
	Prevent lack of communication	Ensure effective communication on bridge	Learning	Provide two ways communication between OOW and the lookout	Procedure: Restricted visibility checklist
	Prevent unsafe act	Ensure the correct action by verifying the information on bridge	Responding	Out laud thinking	Procedure: Restricted visibility checklist

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Inadequate Situational Awareness) **Prevent Excessive workload (master not communicate with crew)**	Prevent capacity error	Master or OOW must Communicate with the bridge team	Anticipation	Master and OOW must by familiar with the bridge resources management	Training: BRM
	Prevent performance error	Master or OOW must ensure receive feedback from crew	Monitoring	- communication during manoeuvring - Develop briefing	Procedure: (departure and arrival checklists)
	Prevent lack of communication	Master or OOW should validate his perception with the lookout	Learning	Ensure the crew are active during manoeuvring - Ensure two ways communication	Procedure: (departure and arrival checklists)
	Prevent unsafe act	Ensure the master intention is clear to the team bridge	Responding	Out loud thinking	Procedure: (departure and arrival checklists)

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Inadequate Situational Awareness) **Prevent Violation of Pilotage procedures**	Prevent capacity error	Exchange Information between master and pilot	Anticipation	Master and bridge team should define what pilot must know about bridge condition and what they need	Method: (perform bridge team meeting)
	Prevent performance error	Adequate observation of traffic status during pilotage	Monitoring	OOW should perform normal watch and remain active during pilotage	Procedure: (pilot checklist)
	Prevent lack of communication	Interact With pilotage and challenge pilot decisions	Learning	Ensure master and OOW understand that the pilot is a part of bridge team	Procedure: (pilot checklist)
	Prevent unsafe act	If the pilot couldn't clarify his decisions captain should take the command	Responding	Ensure master has the ability to evaluate the pilot performance and take the command without hesitation	Procedure organisation validate Master's knowledge and ability

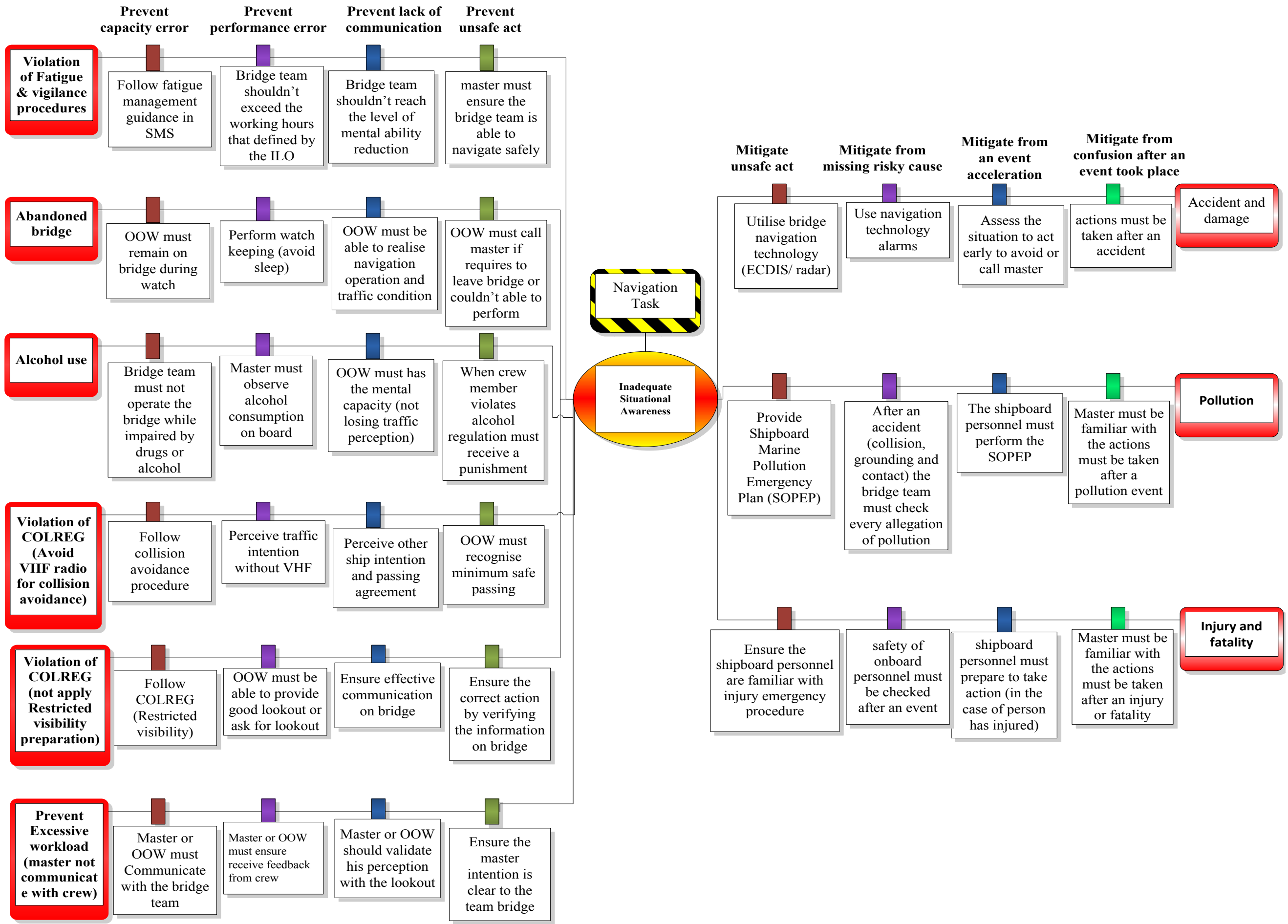
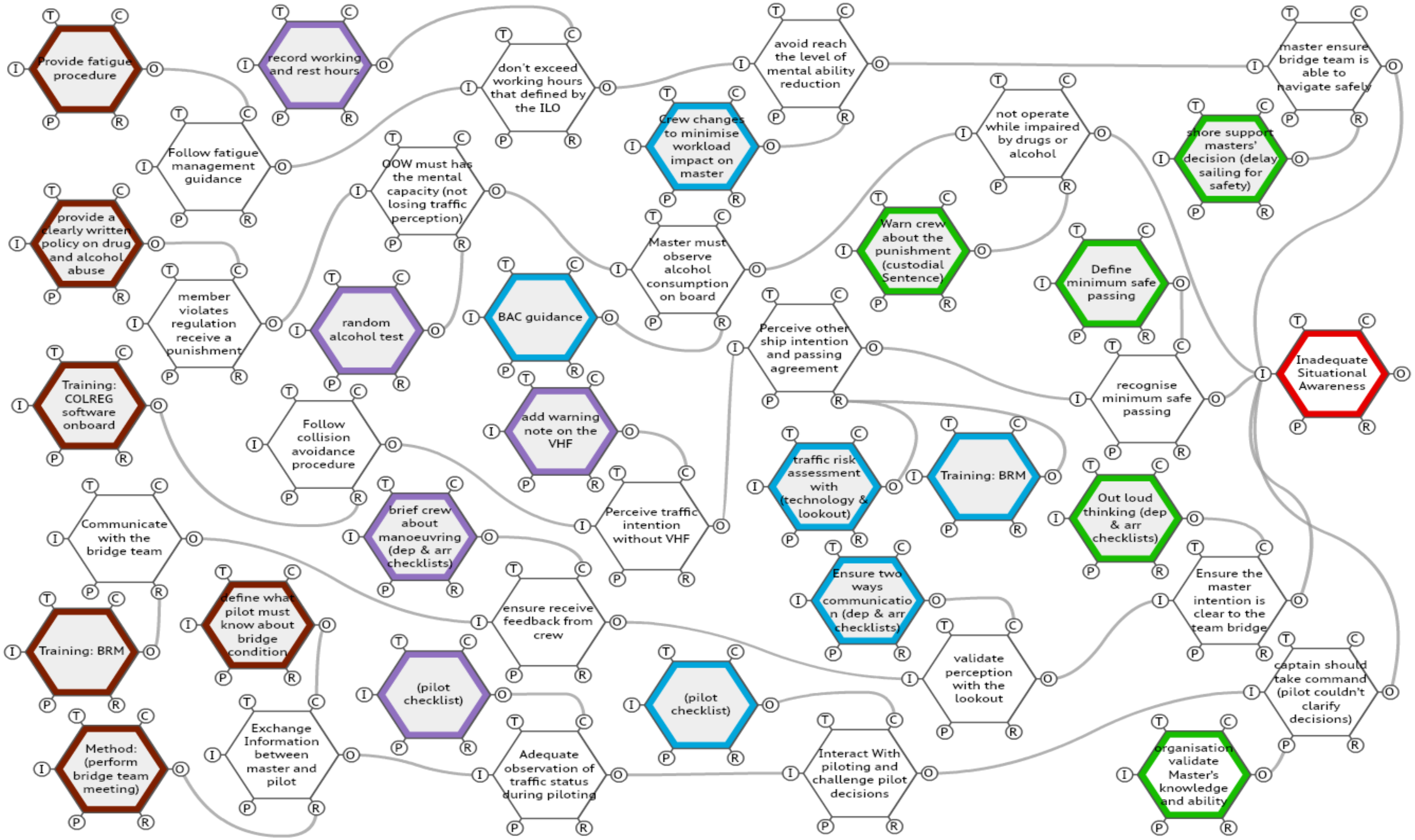


Figure 11-9 Inadequate Situational Awareness Bow-tie



Inadequate situational awareness FRAM

11.1.4 Process of Planning the Resilient Safety system to Prevent Poor Lookout

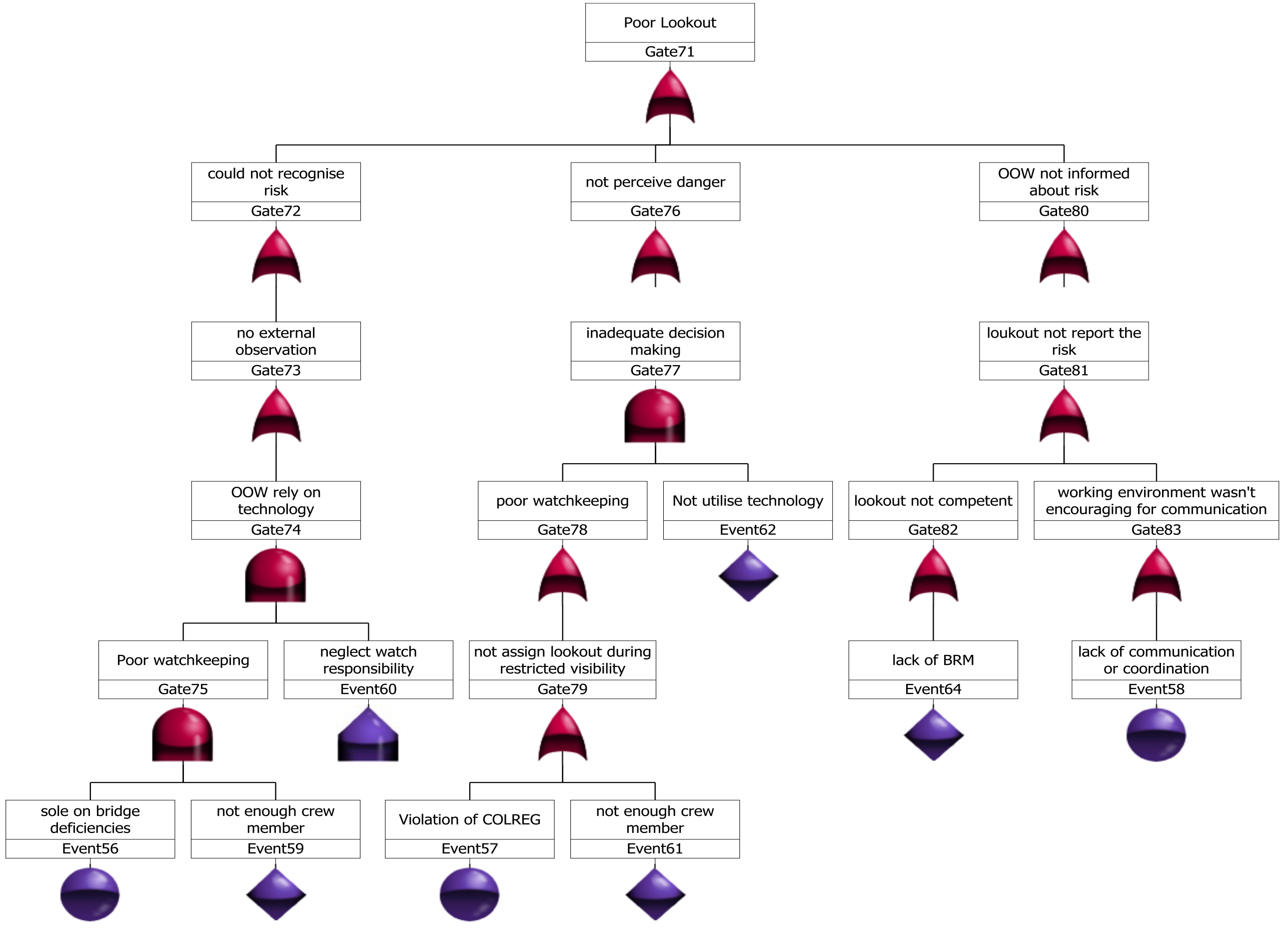


Figure 11-10 Poor lookout FTA

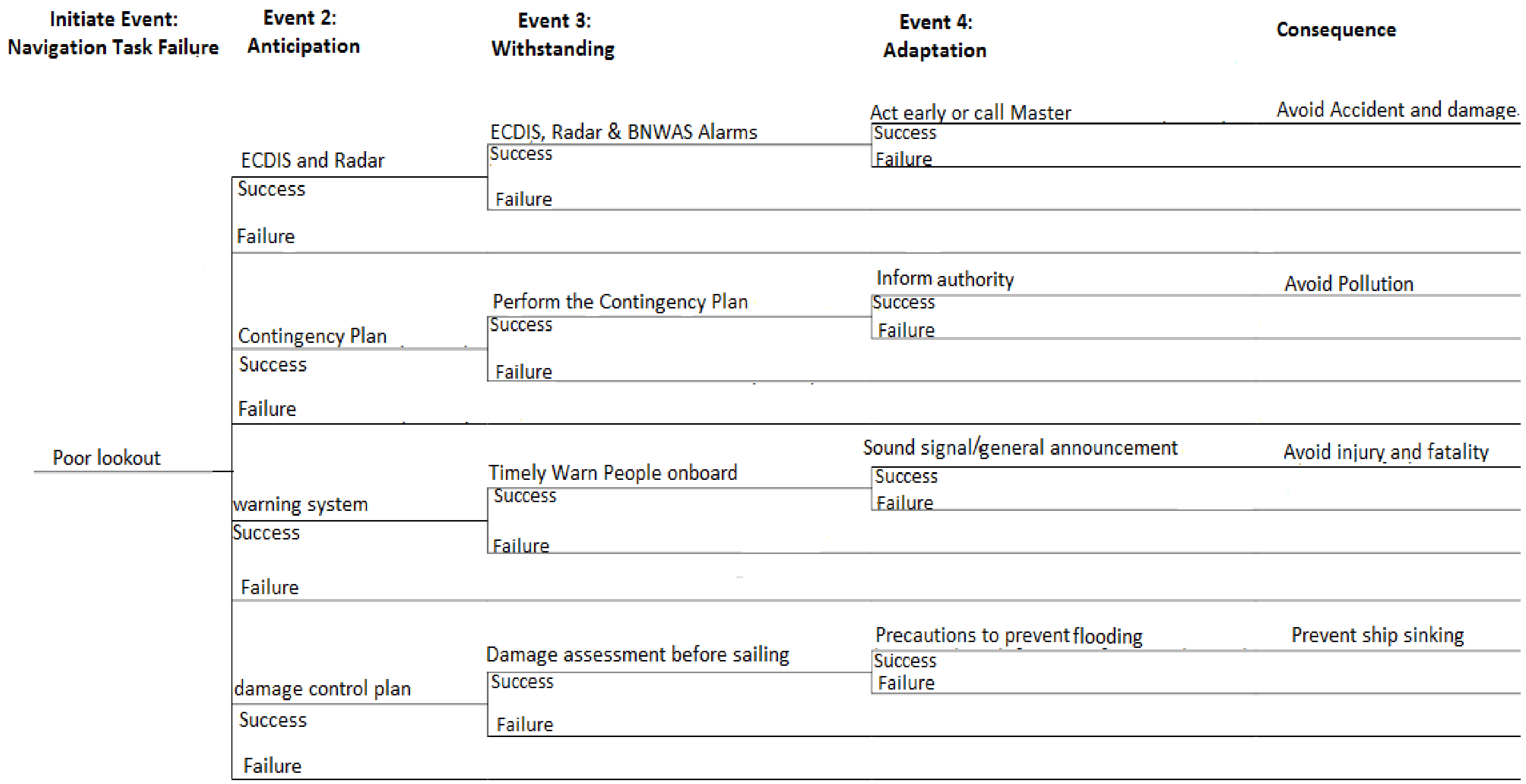


Figure 11-11 Poor lookout ETA

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Poor Lookout) **Prevent sole person on bridge deficiencies (poor lookout)**	Prevent capacity error	OOW must has the capacity to perform watchkeeping and lookout task	Anticipation	Captain should assess OOW ability	Procedure: captain check
	Prevent performance error	utilise navigation technology	Monitoring	OOW must be able to function navigation technology alarms	Procedure: (watch checklist)
	Prevent lack of communication	Maintaining a good lookout all time by technology and external observation	Learning	Ensure OOW is motivated to perform the watch (consider the low arousal effect)	Procedure: captain check
	Prevent unsafe act	Call master for lookout support	Responding	Ensure OOW can find lookout help when it require	Procedure: manning requirement

Safety Performance			Resilience Enhancement		
Purpose	**Barriers Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Poor Lookout) **Prevent Violation of COLREG (not assign lookout during restricted visibility)**	Prevent capacity error	Follow COLREG) (restricted visibility)	Anticipation	OOW familiar with COLREG procedure (restricted visibility)	Procedure: organisation validate OOW knowledge
	Prevent performance error	utilise navigation technology	Monitoring	OOW must be able to function navigation technology alarms	Procedure: (restricted visibility checklist)
	Prevent lack of communication	Maintaining a good lookout all time by technology and external observation	Learning	Ensure OOW is motivated to perform the watch (consider the low arousal effect)	Procedure: captain check
	Prevent unsafe act	Call master for lookout support	Responding	Ensure OOW can find lookout help when it require	Procedure: manning requirement

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Poor Lookout) **Prevent Lack of communication or coordination**	Prevent capacity error	lookout must be competent with his duty	Anticipation	lookout must be familiar with his responsibility	Procedure: organisation validate Lookout knowledge
	Prevent performance error	Ensure lookout understand the condition of the watch	Monitoring	provide a briefing to the lookout about what to expect	Procedure: (watch checklist)
	Prevent lack of communication	Ensure effective communication on bridge	Learning	Provide two ways communication between OOW and the lookout	Procedure: (watch checklist)
	Prevent unsafe act	Ensure correct action by verifying information with lookout	Responding	Out laud thinking	Procedure: (watch checklist)

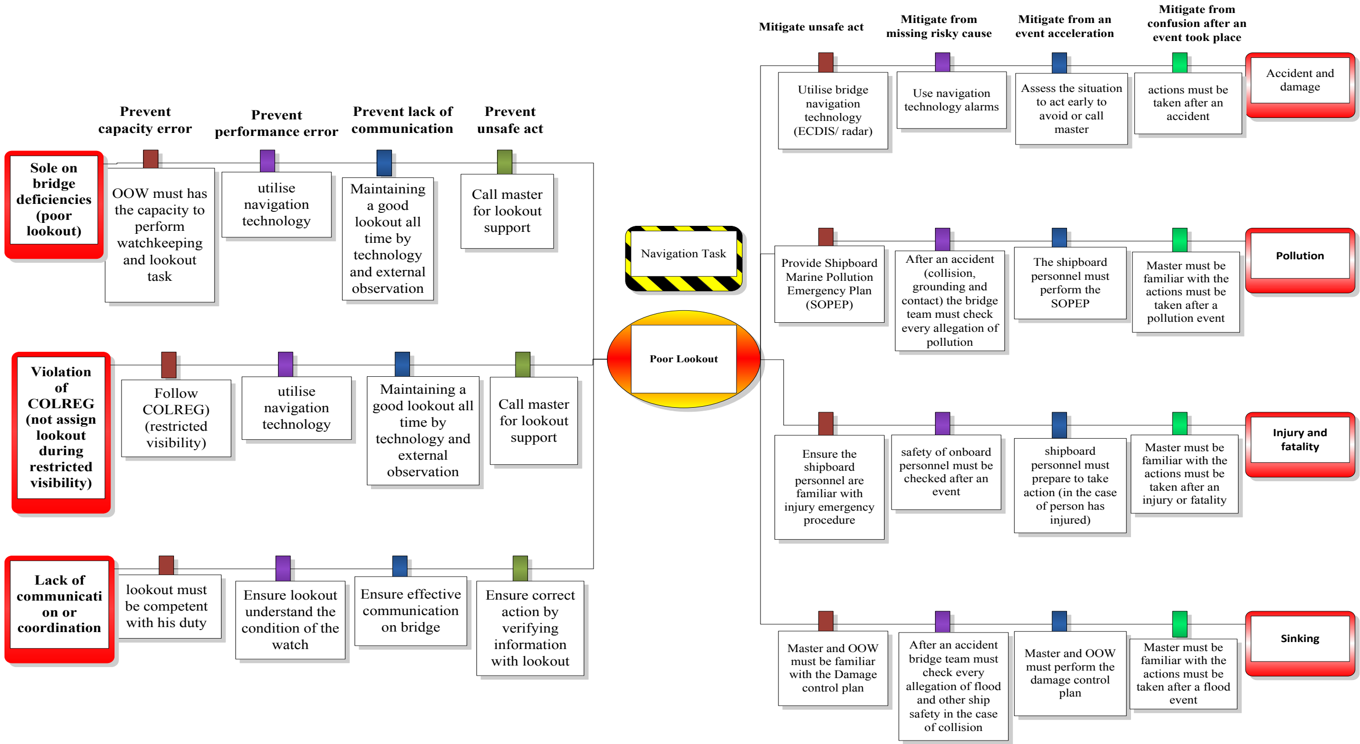
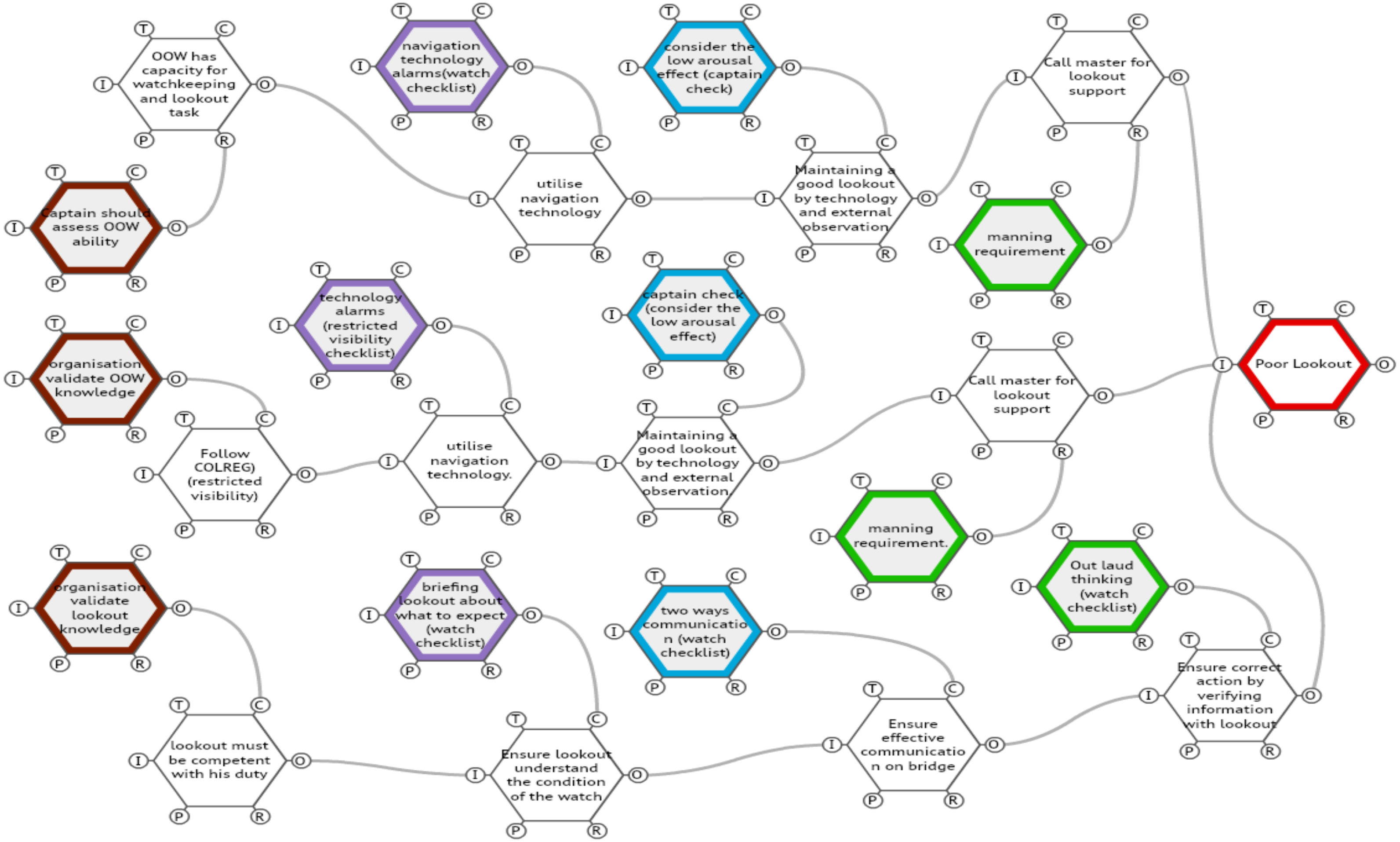


Figure 11-12 Poor lookout Bow-tie



Poor lookout FRAM

11.1.5 Process of Planning the Resilient Safety system to Prevent Inadequate Alarm Management

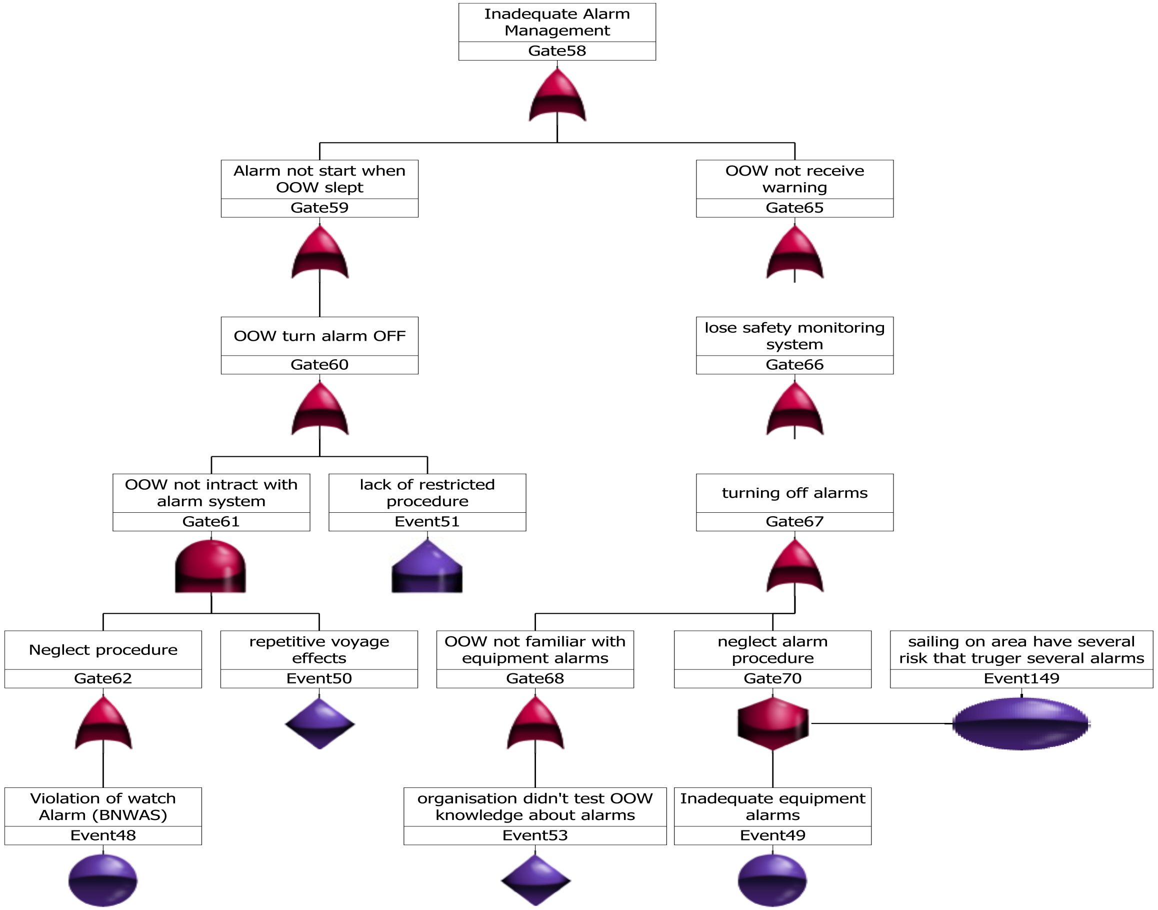


Figure 11-13 Poor alarm management FTA

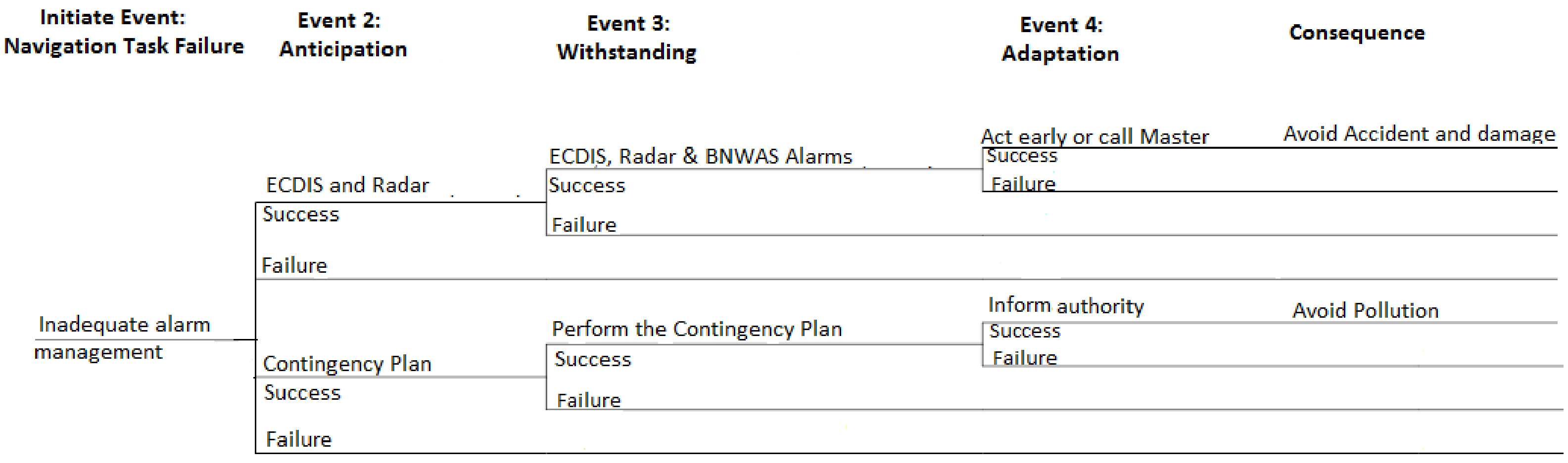


Figure 11-14 Inadequate alarm management ETA

Safety Performance			Resilience Enhancement		
Purpose	**Barrier type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
Prevent violation of watch alarm (bridge navigation watch alarm system – BNWAS)	Prevent capacity error	Follow night watch alarm procedure	Anticipation	OOW must be familiar with the night watch procedure	Procedure: organisation validate OOW knowledge
	Prevent performance error	Use BNWAS (especially in the sole lookout)	Monitoring	Ensure using the BNWAS in the night watch and become mandatory during the sole lookout watch	Procedure: watch checklist Method: Connect the BNWAS to autopilot with password
	Prevent lack of communication	Interact with the BNWAS alarms	Learning	Ensure the BNWAS is part from the watch process	Procedure: watch checklist
	Prevent unsafe act	OOW doesn't acknowledge an alarm unless he is fit for the watch	Responding	Ensure the OOW can find the assistant in the case of night and sole lookout watch	Master's standing orders

Safety Performance			Resilience Enhancement		
Purpose	**Barriers Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Poor alarm management) **Inadequate equipment alarms**	Prevent capacity error	OOW should utilise all navigation technology alarms	Anticipation	Ensure OOW are familiar with bridge technology alarms	Procedure: organisation validate OOW knowledge Method: Ensure all ships have similar alarms
	Prevent performance error	Set the navigation technology alarms on and their sound on	Monitoring	Ensure recognise all alarms	Procedure: watch checklist
	Prevent lack of communication	OOW must receive warning alarms and validate it before press acknowledge button	Learning	Ensure to develop alarms management procedure	Procedure: provide guideline for bridge alarms Training: alarms management
	Prevent unsafe act	OOW should know how to respond to the received alarm or call captain	Responding	captain ensure OOW will not hesitate to call him	Method: friendly encouraging environment for communication

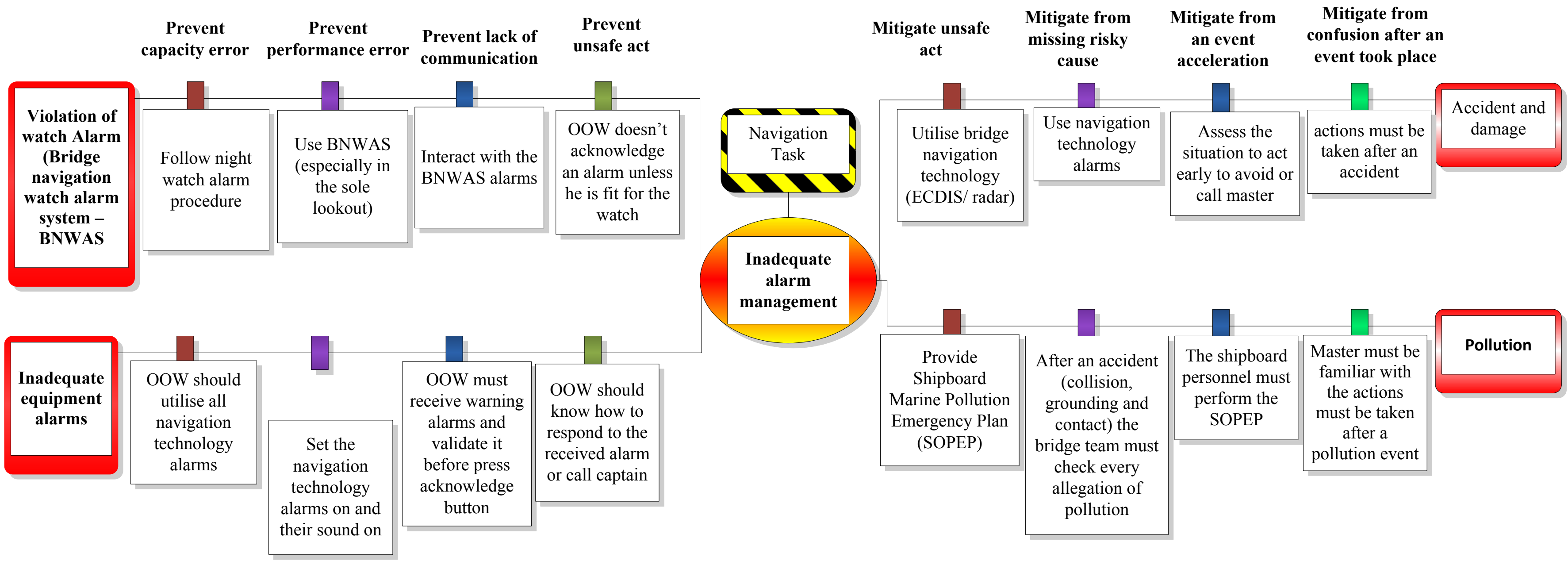
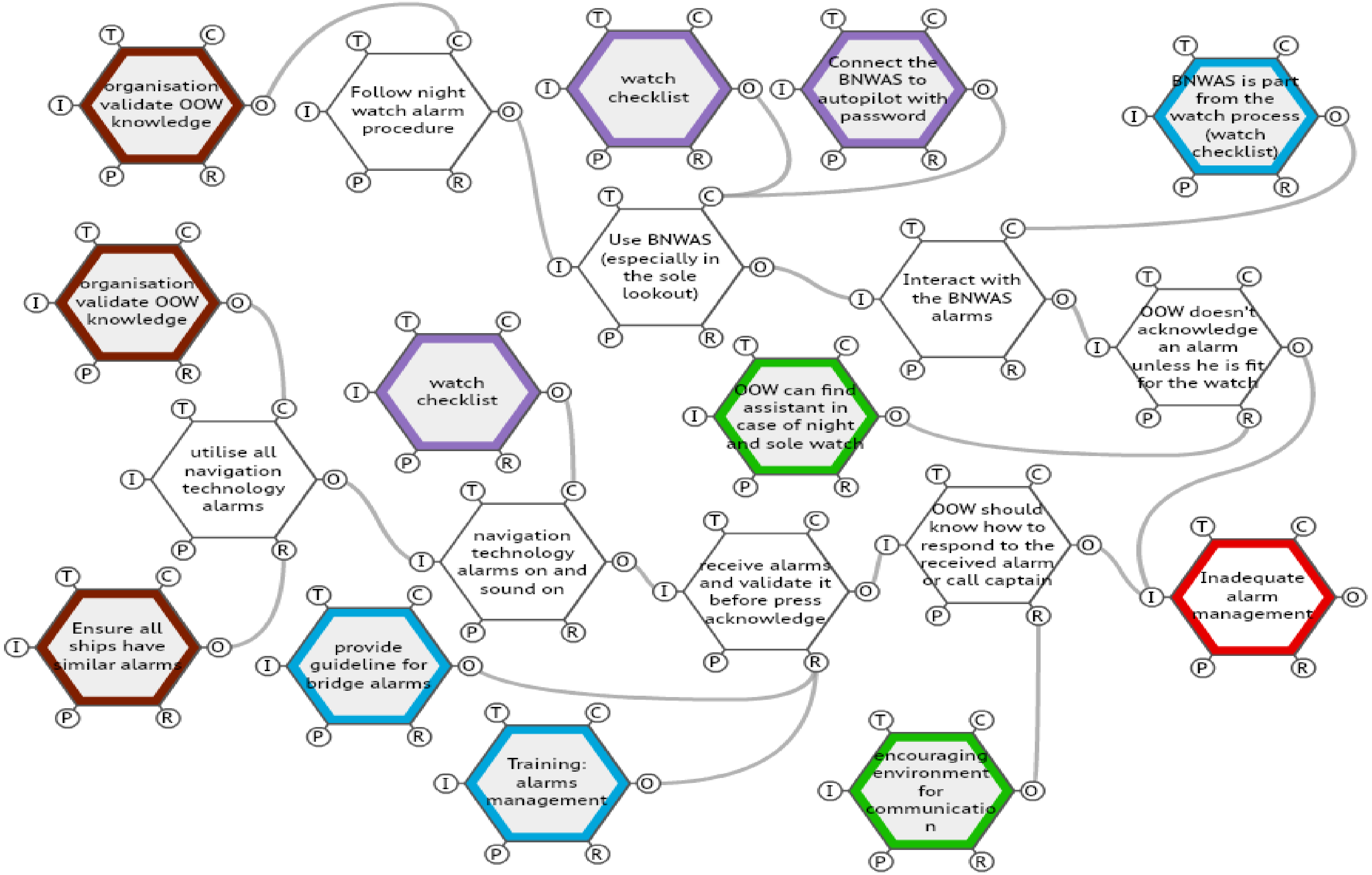


Figure 11-15 Inadequate alarm management Bow-tie



Inadequate alarm management FRAM

11.1.6 Process of Planning the Resilient Safety system to Prevent Poor Leadership

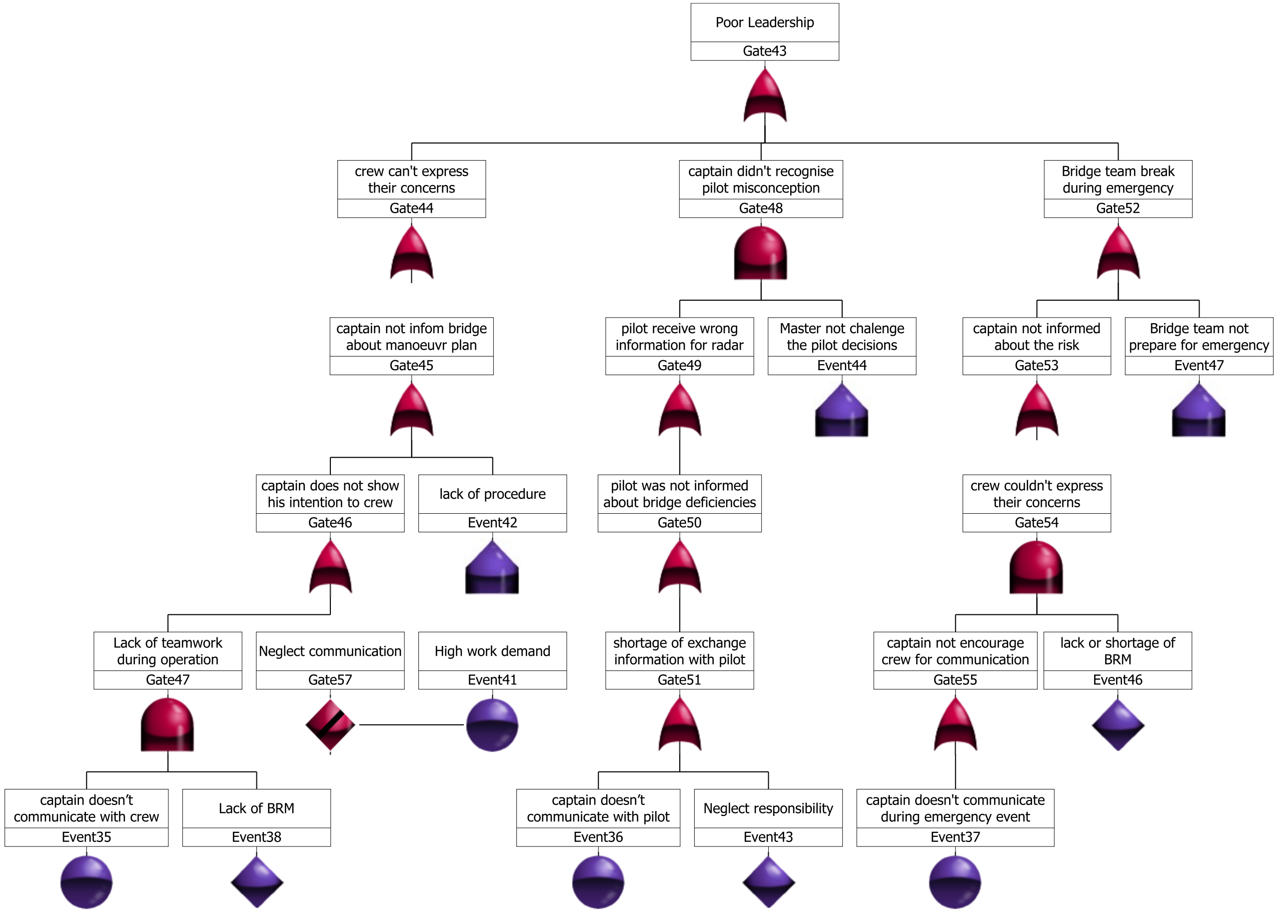


Figure 11-16 Poor Leadership FTA

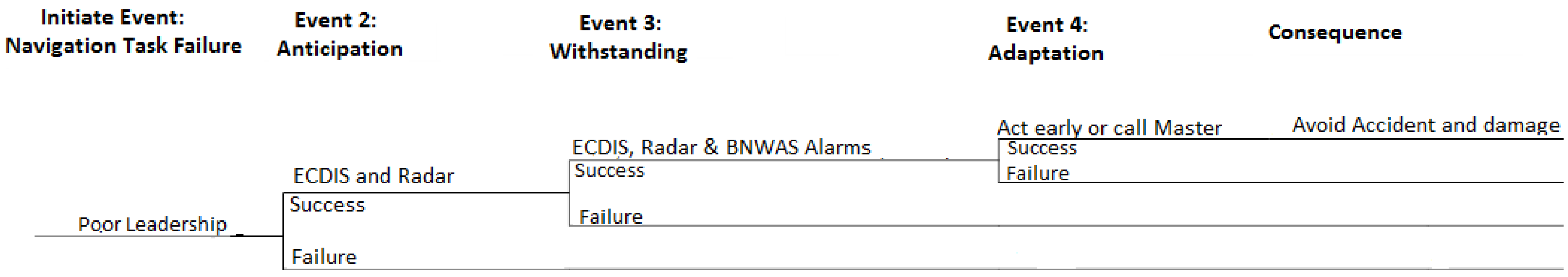


Figure 11-17 Poor Leadership ETA

Safety Performance			Resilience Enhancement		
Purpose	**Barriers type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Poor Leadership) **Lack of communication or coordination (Master doesn't communicate with crew)**	Prevent capacity error	master and bridge team must work as a team	Anticipation	Ensure master and bridge team are familiar with BRM	Training: BRM
	Prevent performance error	captain ensure bridge team know manoeuvring plan	Monitoring	Ensure captain brief the bridge team before manoeuvring start	Procedure: departure and arrival checklists
	Prevent lack of communication	captain should communicate his intention to crew	Learning	Out loud thinking	Procedure: departure and arrival checklists
	Prevent unsafe act	Bridge team should be able to ask the captain on his intention	Responding	communication friendly environment allow crew to express their concern	Procedure: departure and arrival checklists

Safety Performance			Resilience Enhancement		
Purpose	**Barrier type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Poor Leadership) **Lack of communication or coordination (Master doesn't communicate with pilot)**	Prevent capacity error	Exchange Information between master and pilot	Anticipation	Master and bridge team should define what pilot must know about bridge condition and what they need	Method: (perform bridge team meeting)
	Prevent performance error	Adequate observation of traffic status during pilotage	Monitoring	OOW should perform normal watch and remain active during pilotage	Procedure: (pilot checklist)
	Prevent lack of communication	Interact With piloting and challenge pilot decisions	Learning	Ensure master and OOW understand that the pilot is a part of bridge team	Procedure: (pilot checklist)
	Prevent unsafe act	If the pilot couldn't clarify his decisions captain should take the command	Responding	Ensure master has the ability to evaluate the pilot performance and take the command without hesitation	Procedure organisation validate Master's knowledge and ability

Safety Performance			Resilience Enhancement		
Purpose	**Barriers type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Poor Leadership) **Lack of communication or coordination (Master doesn't communicate during emergency event)**	Prevent capacity error	Master or OOW must Communicate with the bridge team	Anticipation	Master and OOW must by familiar with the bridge resources management	Training: BRM
	Prevent performance error	Master or OOW must ensure receive feedback from crew	Monitoring	- communication during manoeuvring - Develop briefing	Procedure: (departure and arrival checklists)
	Prevent lack of communication	Master or OOW should validate his perception with the lookout	Learning	- Ensure the crew are active during manoeuvring - Ensure two ways communication	Procedure: (departure and arrival checklists)
	Prevent unsafe act	Ensure the master intention is clear to the team bridge	Responding	Out loud thinking	Procedure: (departure and arrival checklists)

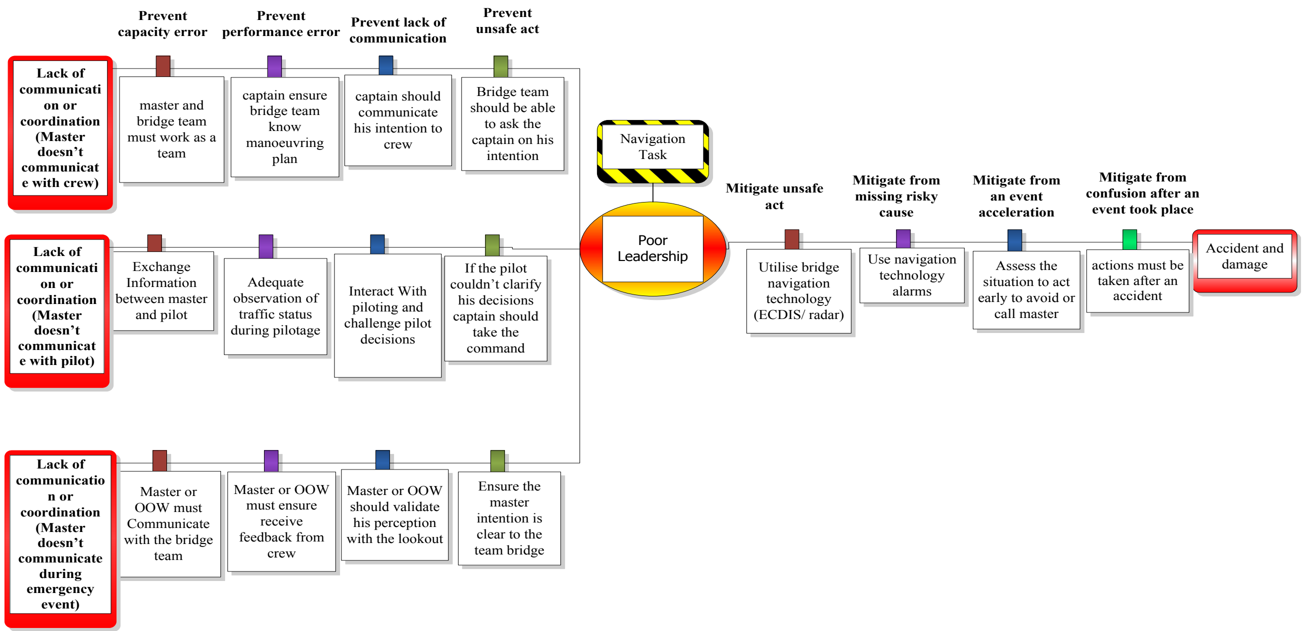
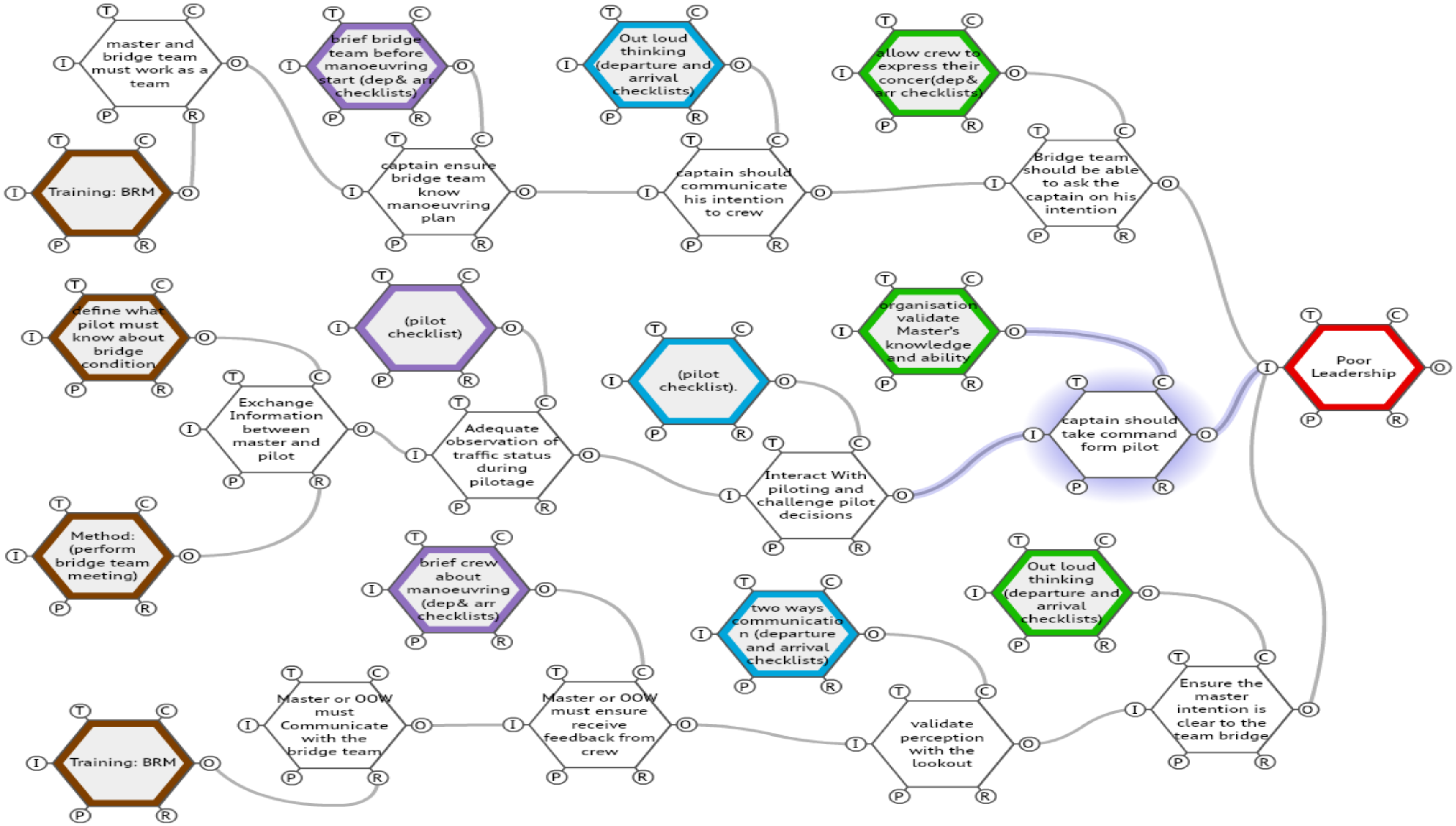


Figure 11-18 Poor leadership Bow-tie



Poor Leadership FRAM

11.1.7 Process of Planning the Resilient Safety system to Prevent Ineffective Passage Planning

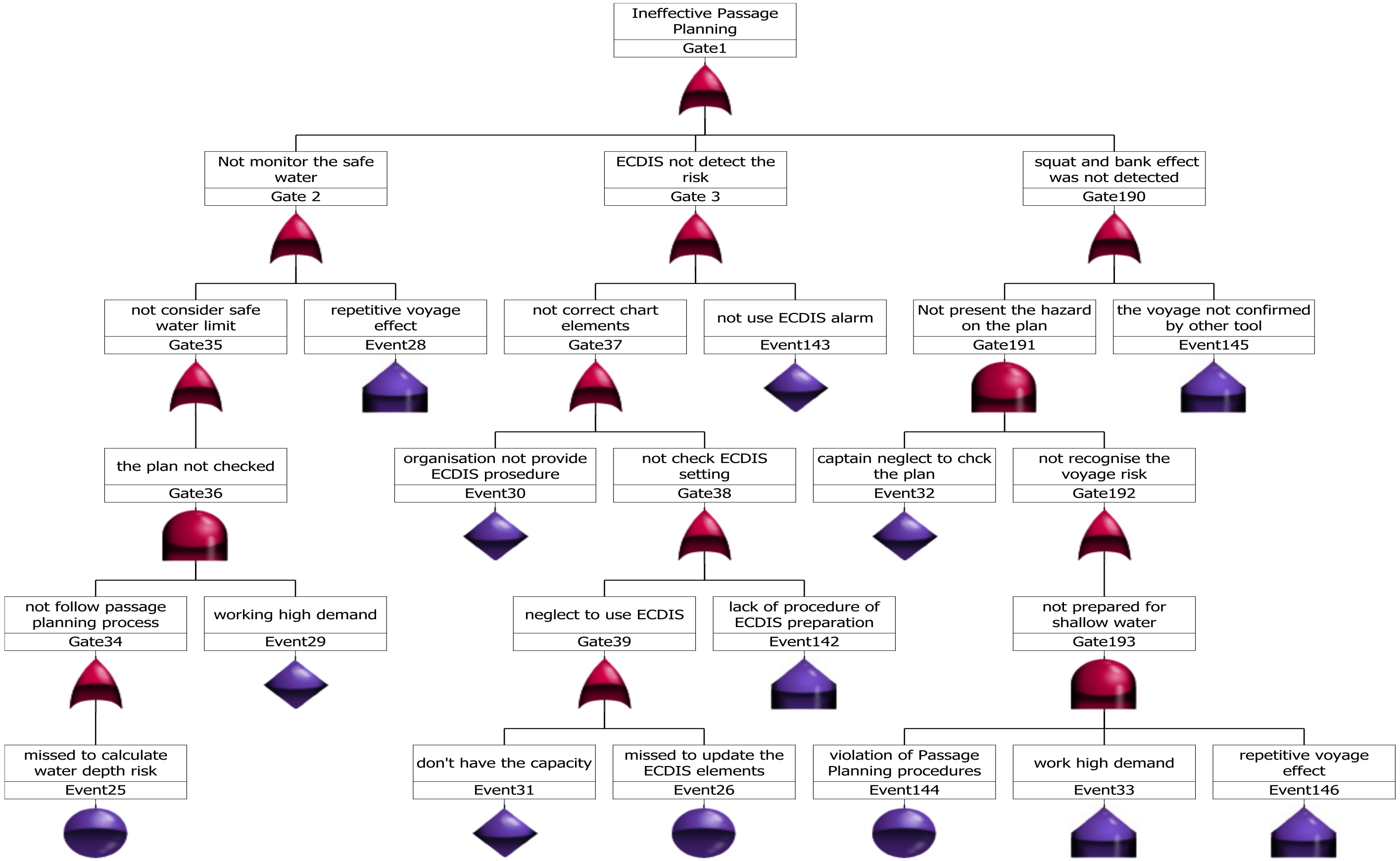


Figure 11-19 Ineffective passage plan FTA

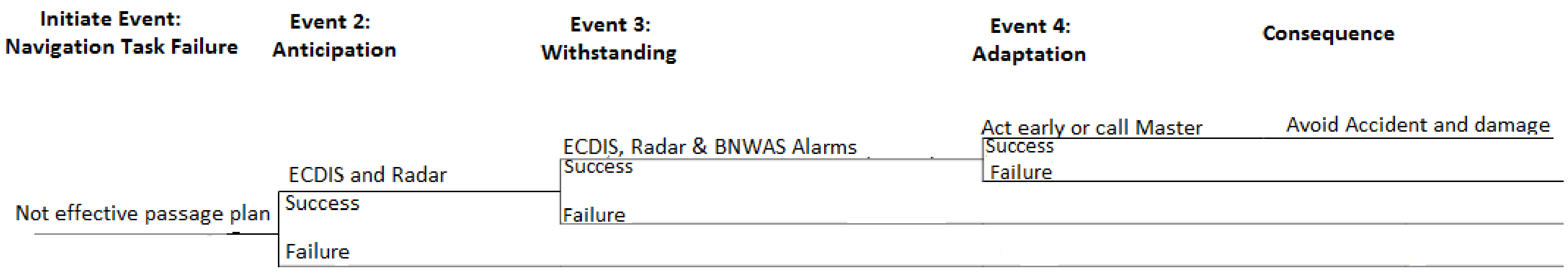


Figure 11-20 Ineffective passage plan ETA

Safety Performance			Resilience Enhancement		
Purpose	**Barriers Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Ineffective passage plan) **Violation of Passage Planning procedures (missed to calculate water depth risk)**	Prevent capacity error	follow passage planning process (Appraisal, Planning, Execution and Monitoring)	Anticipation	OOW must be familiar with the passage planning process	Procedure: organisation validate OOW's knowledge Procedure: PP checklist
	Prevent performance error	captain check passage planning preparation	Monitoring	captain ensure Navigation officer followed passage planning steps	Procedure: PP checklist
	Prevent lack of communication	calculate the safe water limit, tide and UKC	Learning	Show the hazards and risk rang on charts	Procedure: PP checklist
	Prevent unsafe act	If OOW sense suspicion, he must lead his ship to safety and inform captain	Responding	Ensure OOW check the ship's passage with all method and not hesitate to take a correct action or inform master	Procedure: watch checklist

Safety Performance			Resilience Enhancement		
Purpose	**Barriers Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Ineffective passage plan) **Violation of Passage Planning procedures (missed to update the ECDIS elements)**	Prevent capacity error	OOW must utilise ECDIS	Anticipation	OOW must be familiar with the ECDIS features	Procedure: organisation validate OOW's knowledge
	Prevent performance error	OOW should examine the ECDIS setting every watch	Monitoring	using ECDIS alarms	Procedure: watch checklist
	Prevent lack of communication	Before a watch check safety elements (route, depth ,cross track, safety contour and chart scale)	Learning	Ensure not missed any ECDIS futures that may cause a risk	Procedure: watch checklist
	Prevent unsafe act	If OOW felt any doubt he must confirm ECDIS information with other methods or call captain	Responding	Ensure OOW know what action to take if he doubt about ECDIS performance	Procedure: provide guidance

Safety Performance			Resilience Enhancement		
Purpose	**Barriers Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Ineffective passage plan) **Violation of Passage Planning procedures (not prepared for squat and bank effect)**	Prevent capacity error	follow passage planning process (bank and squat affect)	Anticipation	OOW must be familiar with the passage planning process	Procedure: organisation validate OOW's knowledge Procedure: PP checklist
	Prevent performance error	captain check passage planning preparation	Monitoring	captain ensure Navigation officer followed passage planning steps	Procedure: PP checklist
	Prevent lack of communication	Ensure navigation risk areas are clear to the bridge team	Learning	show the navigation risk areas on chart	Procedure: PP checklist
	Prevent unsafe act	OOW must verify the course with different methods and call the captain in doubt	Responding	provide communication friendly environment allow crew to express their concern	Procedure: watch checklist

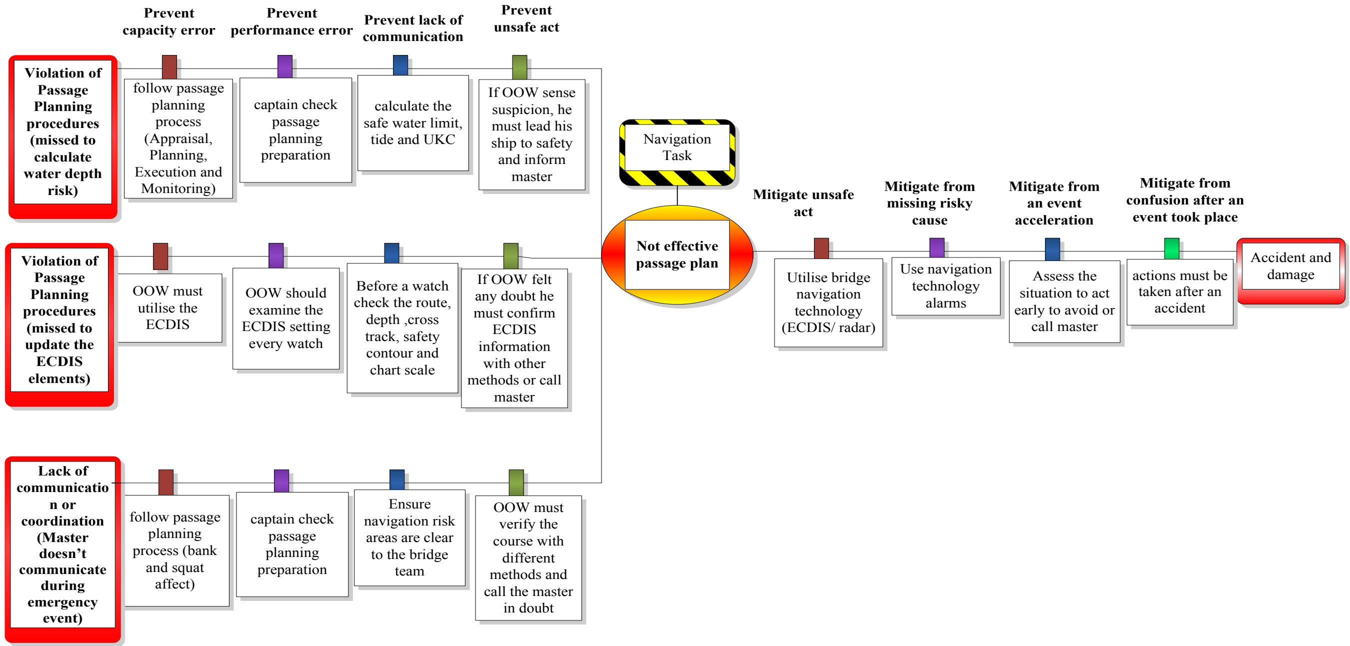
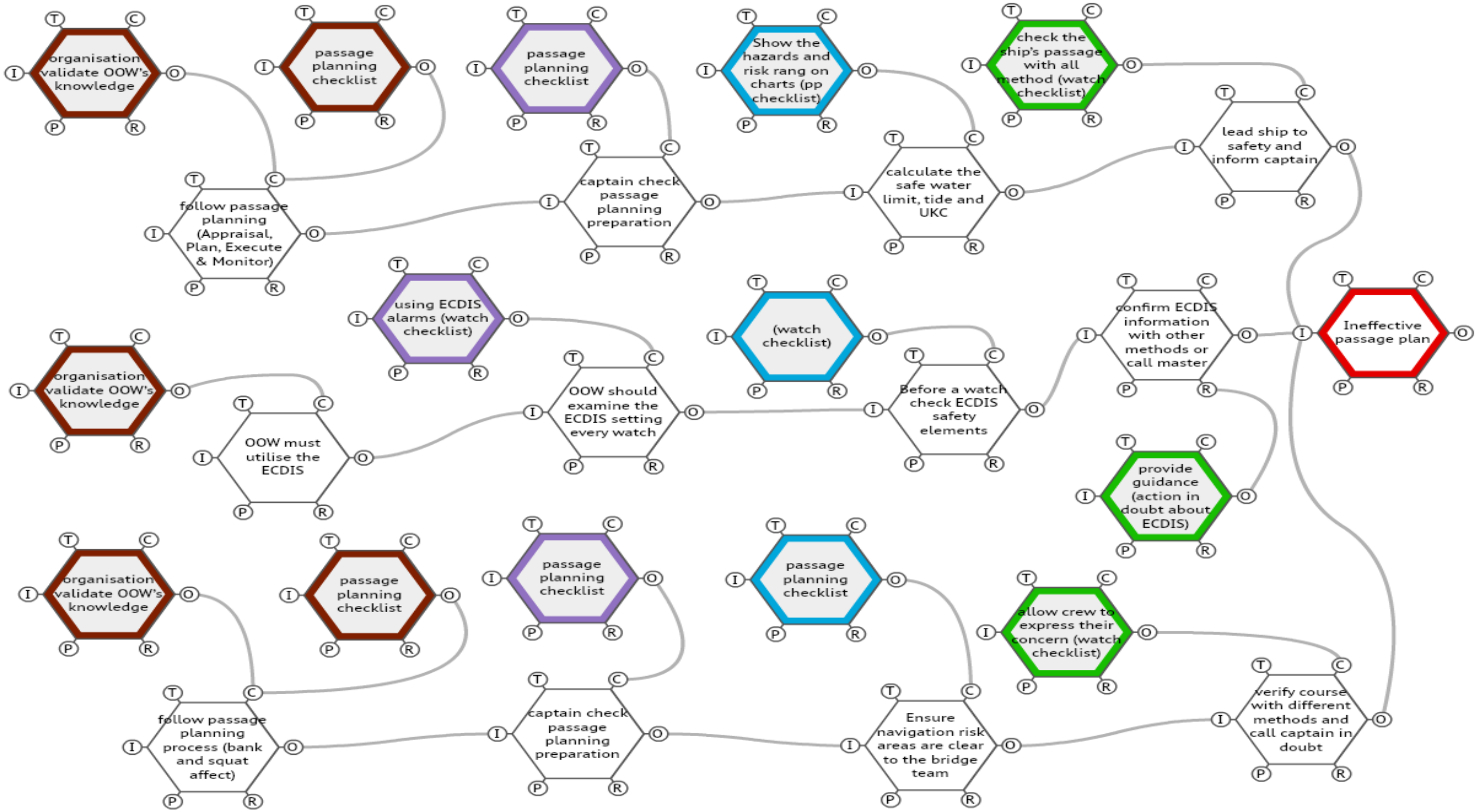


Figure 11-21 Ineffective passage plan Bow-tie



Ineffective passage plan FRAM

11.1.8 Process of Planning the Resilient Safety system to Prevent Poor Learning

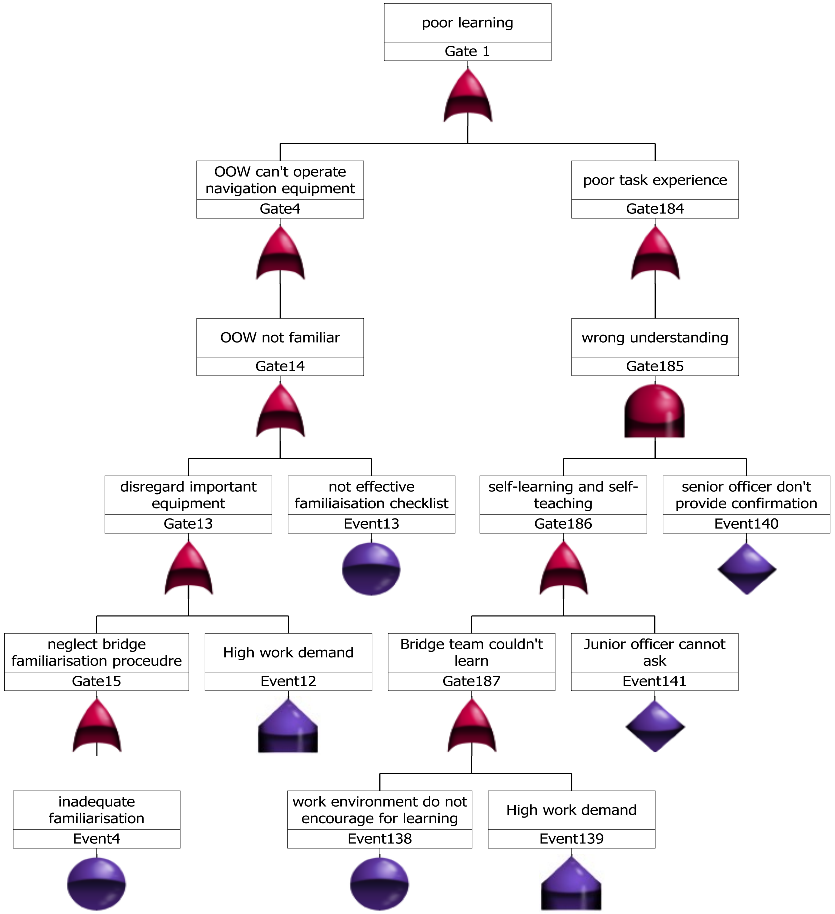


Figure 11-22 Poor Learning FTA

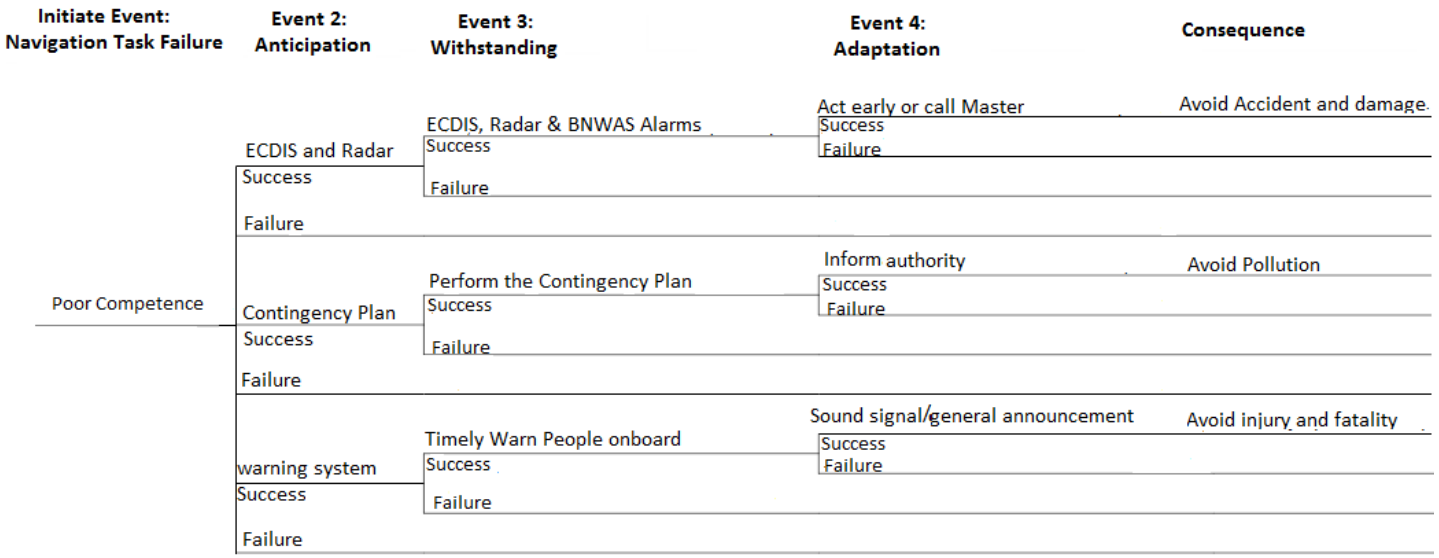


Figure 11-23 Poor Learning ETA

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Poor Learning) **Lack of familiarisation and training onboard (poor language skills)**	Prevent capacity error	Bridge team must communicate unambiguously	Anticipation	Ensure bridge team are able to communicate effectively	Procedure: organisation validate the language
	Prevent performance error	captain observe and validate bridge team communication	Monitoring	Ensure crew communicate clearly during emergency drills	Method: emergency drill procedure
	Prevent lack of communication	Bridge team must be comply with the IMO Standard marine communication phrases (SMCP)	Learning	Ensure clear two-ways communication by applying the SMCP	Procedure: operation checklists
	Prevent unsafe act	captain must inform the organisation about any member of crew has poor language skills (replace him)	Responding	Develop producer about crew member that has poor language	Procedure: organisation

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Poor Learning) **Lack of familiarisation and training onboard (poor task experience)**	Prevent capacity error	Bridge team must have experience related tasks	Anticipation	Ensure the bridge team have the bridge operation experience	Procedure: organisation validate OOW's knowledge
	Prevent performance error	Bridge team should have experience related tasks or an experience help them to familiar themselves	Monitoring	Master should check bridge team experience	Procedure: organisation
	Prevent lack of communication	Bridge team must be familiar with bridge procedure	Learning	Ensure bridge have guidelines and procedure and they could be reached easily	Procedure: organisation
	Prevent unsafe act	Master must inform the organisation about any member of crew that has poor experience (replace him)	Responding	Ship operation should have the capacity to deal with poor experience	Procedure: organisation

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
(Poor Learning) **Lack of familiarisation and training onboard (inadequate familiarisation)**	Prevent capacity error	bridge team are responsible for effectively familiarise new members	Anticipation	Master and bridge team must have the knowledge to provide familiarisation to new members	Procedure: familiarisation checklist
	Prevent performance error	bridge team must follow familiarisation procedure	Monitoring	ensure familiarisation checklist is effective (plan, check and verify)	Procedure: familiarisation checklist
	Prevent lack of communication	familiarisation muse cover small detail	Learning	Provide small checklists to cover each system (E.g. ECDIS, control systems)	Procedure: familiarisation checklist
	Prevent unsafe act	OOW must ask master or other officers in the case of doubt	Responding	Ensure the bridge has learning environment allow bridge team to ask and discuss	Procedure: familiarisation checklist

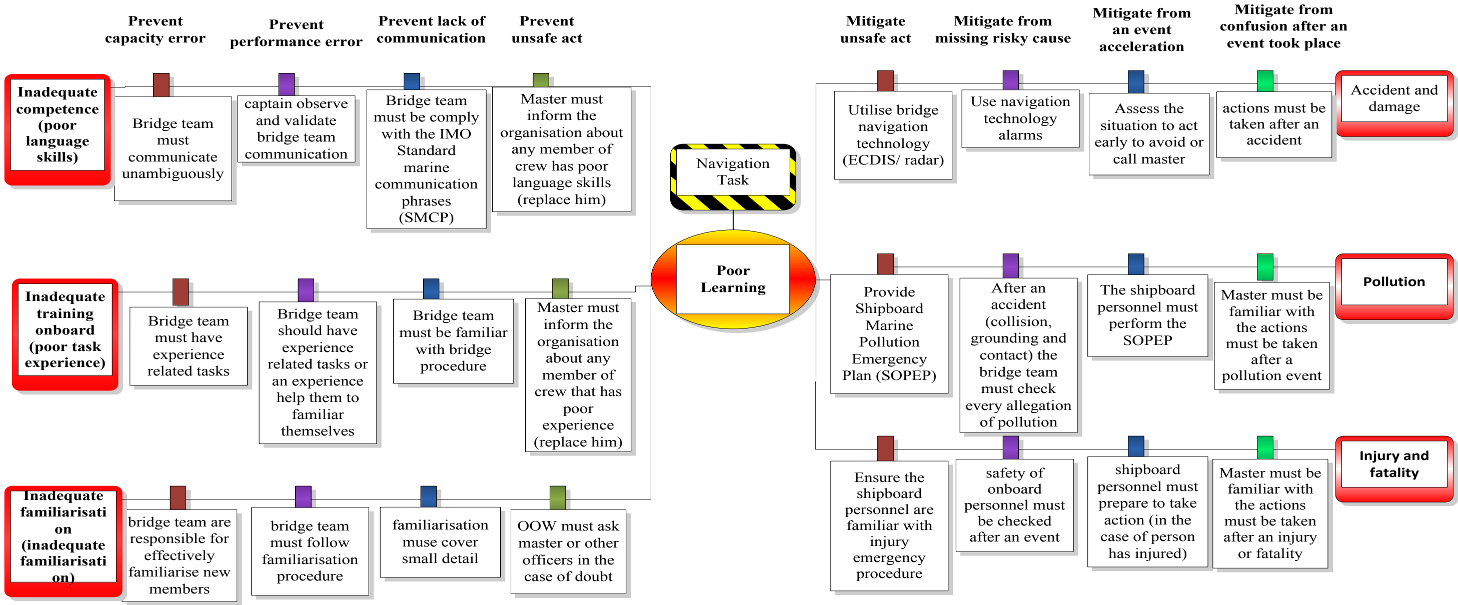
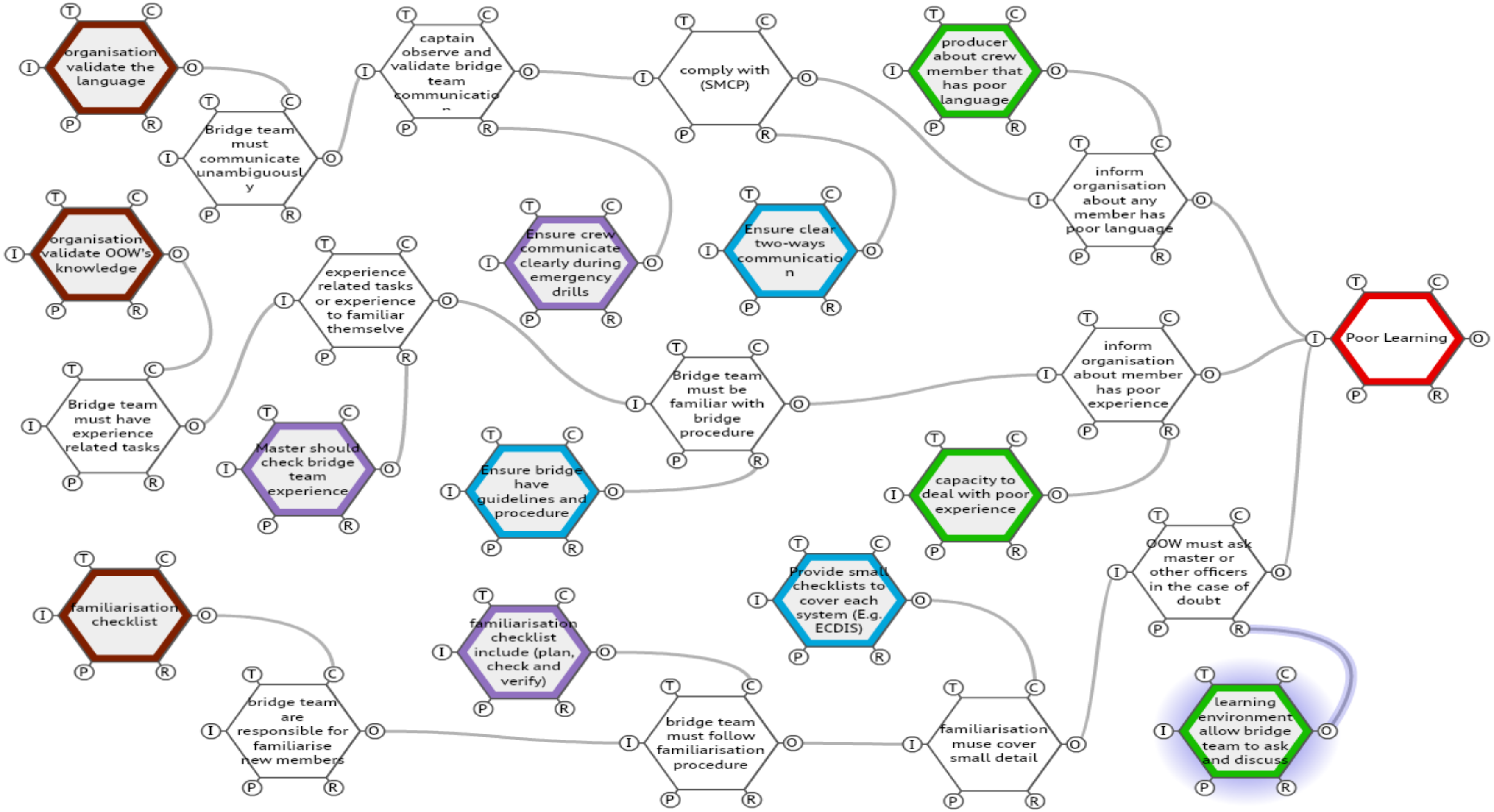


Figure 11-24 Poor Learning Bow-tie



Poor Learning FRAM

11.1.9 Process of Planning the Resilient Safety system to Mitigate Tasks Failure

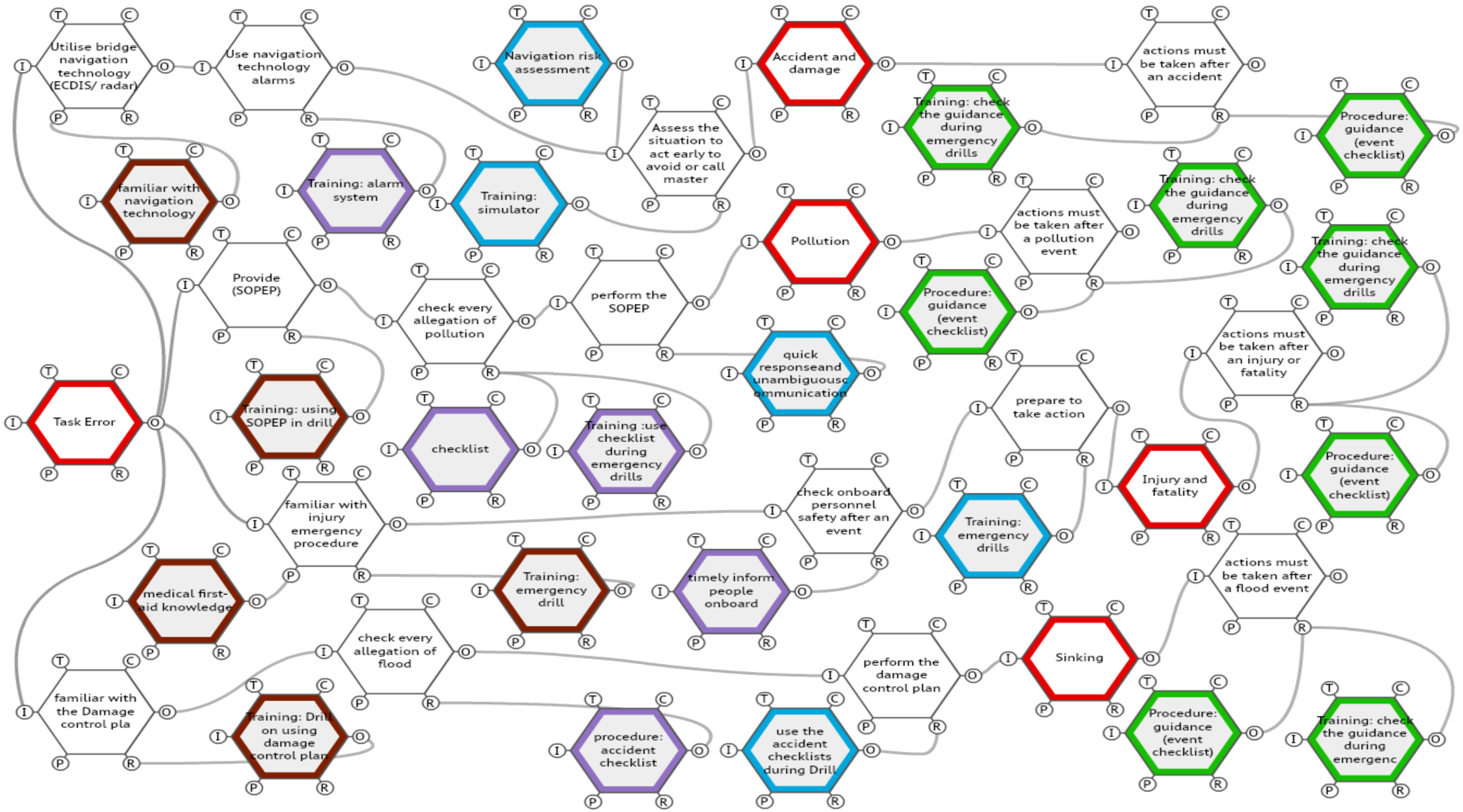
Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
Mitigate from Accident and damage	Mitigate unsafe act	Utilise bridge navigation technology (ECDIS/ radar)	Plan /prepare	Bridge team familiar with navigation technology	Procedure: organisation and master validate the knowledge
	Mitigate from unnoticed risky cause	Use navigation technology alarms	Absorb	OOW able to deal with alarms	Training: alarm system
	Mitigate from an event acceleration	Assess the situation to act early to avoid or call master	Recover	Navigation risk assessment and able to take action	Training: simulator Method: (E.g. drop anchor ready , emergency stop)
	Mitigate from confusion after an event took place	actions must be taken after an accident	Adaptation	provide a guidance of the actions must be taken after an accident	Procedure: guidance (event checklist) Training: check the guidance during emergency drills

Safety Performance			Resilience Enhancement		
Purpose	**Barriers Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
Mitigate from Pollution	Mitigate unsafe act	Provide Shipboard Marine Pollution Emergency Plan (SOPEP)	Plan /prepare	Develop and update the SOPEP regularly and provide SOPEP equipment, the emergency drills onboard ship must cover different types of pollutions	Procedure: organisation validate shipboard personnel knowledge Training: using SOPEP in drill
	Mitigate from unnoticed risky cause	After an accident (collision, grounding and contact) the bridge team must check every allegation of pollution	Absorb	Ensure the collision, grounding and contact checklists cover the pollution aspect and searching for pollution signs (E.g. ship both sides and the engine	Procedure: checklist Training :using the checklist during emergency drills

				room bilges)	
	Mitigate from an event acceleration	The shipboard personnel must perform the SOPEP	Recover	Ensure the response is quick and the communication is unambiguous with maintaining the BRM	method: develop assessment system for emergency drills performance
	Mitigate from confusion after an event took place	Master must be familiar with the actions must be taken after a pollution event	Adaptation	organisation must provide guidance of pollution response (E.g. inform authority, organisation, collect sample)	Procedure: guidance Training: check the guidance during emergency drills

Safety Performance			**Resilience Enhancement**		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
Mitigate from Injury and fatality	Mitigate unsafe act	Ensure the shipboard personnel are familiar with injury emergency procedure	Plan /prepare	-Ensure shipboard personnel have medical first-aid knowledge -Develop emergency plan for injury -first-aid equipment that include the reporting, communication and transfer from ship	Procedure: provide guidance Training: emergency drill
	Mitigate from unnoticed risky cause	safety of onboard personnel must be checked after an event	Absorb	Develop procedure for timely inform people onboard	Procedure: Guidance
	Mitigate from an event acceleration	shipboard personnel must prepare to take action (in the case of person has injured)	Recover	Ensure the response is quick and the communication is unambiguous, and maintain the BRM	Training: emergency drills
	Mitigate from confusion after an event took place	Master must be familiar with the actions must be taken after an injury or fatality	Adaptation	organisation must provide guidance of injury or fatality response	Procedure: guidance Training: check the guidance during emergency drills

Safety Performance			Resilience Enhancement		
Purpose	**Barrier Type and function**	**Barrier elements**	**Resilience ability**	**Resources**	**Control**
Mitigate from Sinking	Mitigate unsafe act	Master and OOW must be familiar with the Damage control plan	Plan /prepare	Ensure the master and the OOW are familiar with the damage control plan	Training: Drill on using damage control plan
	Mitigate from unnoticed risky cause	After an accident bridge team must check every allegation of flood and other ship safety in the case of collision	Absorb	check every allegation of flood (E.g. internal inspection, tank sounding, check the bilge and close all watertight)	Bridge procedure: accident checklist
	Mitigate from an event acceleration	Master and OOW must perform the damage control plan	Recover	- Using Damage assessment checklist after grounding and ensure the response is quick and the communication is unambiguous, and maintain the BRM	Training: use the accident checklists during Drill
	Mitigate from confusion after an event took place	Master must be familiar with the actions must be taken after a flood event	Adaptation	The organisation must provide a guidance of the actions must be taken after a flood event (E.g. complete the report inform authority, organisation)	Procedure: guidance Training: check the guidance during emergency drills



The impact of the Events FRAM

11.2. APPENDIX B - The Scenarios Checklists

A

Bridge familiarisation checklist

1. Has the operation of the following equipment been studied and fully understood?	☐
bridge and deck lighting	☐
navigation and signal lights, including	☐
searchlights, signalling lamp, morse light	☐
sound signalling apparatus, including	☐
whistles	☐
LSA equipment including pyrotechnics, EPIRB and SART	☐
bridge fire detection panel	☐
general and fire alarm signalling arrangements	☐
emergency pump, ventilation and water-tight door controls	☐
internal ship communications facilities including	☐
portable radios	☐
emergency 'battery less' phone system	☐
public address system	☐
external communication equipment, including	☐
VHF and GMDSS equipment	☐
alarm systems on bridge	☐
echo sounder	☐
electronic navigational position fixing systems	☐
gyro compass/repeaters	☐
magnetic compass	☐
off-course alarm	☐
radar including ARPA	☐
speed/distance recorder	☐
engine and thrusters controls	☐
steering gear, including manual, auto-pilot and emergency changeover and testing arrangements	☐
ECDIS and electronic charts	☐
Location and operation of ancillary bridge equipment (e.g. binoculars, signalling flags, meteorological equipment)?	☐
Stowage of chart and hydro graphic publications?	☐
AIS	☐

A

Departure checklist

1. passage plan	☐
2. Has the following equipment been checked and found ready for use?	☐
Anchors	☐
bridge movement book/course and engine movement recorder	☐
echo sounder	☐
electronic navigational position fixing systems	☐
gyro/magnetic compass and repeaters	☐
radar(s)	☐
speed/distance recorder	☐
clocks	☐
3 Has the following equipment been tested, synchronised and found ready for use?	
bridge and engine room telegraphs including	☐
rpm indicators	☐
emergency engine stops	☐
thrusters controls and indicators, if fitted	☐
controllable pitch propeller controls and indicators if fitted	☐
Communications facilities including	☐
Bridge to engine room/mooring station communications	☐
Portable radios	☐
VHF radio communications with port authority	☐
Navigation and signal lights, including	☐
sound signalling apparatus, including	☐
whistles	☐
steering gear, including manual, auto-pilot and emergency changeover arrangements and rudder indicators	☐
window wiper/clear view screen arrangements	☐
Are the pilot disembarkation arrangements in place?	☐

A

Restricted visibility check list

1. Has the following equipment been checked to ensure that it is fully operational?	☐
Radar, ARPA or other plotting facilities	☐
VHF	☐
For signalling apparatus	☐
Navigation lights	☐
Echo sounder, if in soundings	☐
2. Have lookout(s) been posted and is a helmsman on standby?	☐
3. Have the Master and engine room been informed, and the engines put on standby?	☐
4. Are the COLREGS being complied with, particularly with regard to rule 19 and proceeding at a safe speed?	☐
5. Is the ship ready to reduce speed, stop or turn away from danger?	☐

A

Pilot / pilotage check list

1. Has it been agreed which side the pilot will embark/disembark?	☐
2. Have the pilot embarkation/disembarkation arrangements been checked and found ready for use?	☐
3. Has a deck officer been nominated to meet the pilot and conduct him to/from the bridge?	☐
4. Immediately on arrival on the bridge, has the pilot been informed of the ship's heading speed, engine setting and draught?	☐
5. Has the pilot been informed of the location of lifesaving appliances provided on board for his use?	☐
6. Have details of the proposed passage plan been discussed with the pilot and agreed with the master, including	☐
Radio communications and reporting requirements	☐
Bridge watch and crew stand-by arrangements	☐
Deployment and use of tugs	☐
Berthing/anchoring arrangements	☐
Expected traffic during transit.	☐
Pilot change-over arrangements, if any	☐
Fender requirements	☐
7. Has a completed Pilot Card and been handed to the pilot and has the pilot been referred to the Wheelhouse Poster?	☐
8. Are the progress of the ship and the execution of orders being monitored by the master and officer of the watch?	☐
9. Are the correct lights, flags and shapes being displayed?	☐

PILOT CARD

Ship's name ______________________ Date ____________

Call sign ____________ Year built ____________ Deadweight _____ tonnes

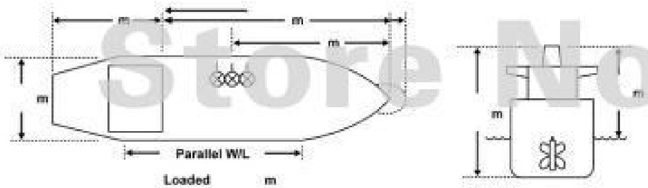
Draught aft _____ m/ ___ ft ___ in. Forward _____ m/ ___ ft ___ in. Displacement _____ tonnes

SHIP'S PARTICULARS

Length overall _____ m. Anchor chain: Port _____ shackles. Starboard _______ shackles.

Breadth ________ m. Stern ______ shackles.

Bulbous bow Yes / No (1 shackle= ______ m/ _______ fathoms)



Type of engine	Maximum power	kW (	HP)
Manoeuvring engine order	Rpm / pitch	Speed (knots) Loaded	Speed (knots) Ballast
Full ahead			
Half ahead			
Slow ahead			
Dead slow ahead			
Dead slow astern		Time limit astern ________ min	
Slow astern		Full ahead to full astern ________ s	
Half astern		Max. no. of consec. starts ________	
Full astern		Minimum RPM ______ ______ knots Astern power ________ % ahead	

STEERING PARTICULARS

Type of rudder

Type of rudder ____________ Maximum angle ______ °

Hard-over to hard-over ____________ s

Rudder angle for neutral effect ____________ °

Thruster: Bow ________ kW(______ HP) Stern ________ kW(________ HP)

CHECKED AND READY

Anchor ☐

Whistle ☐

Radar ☐ 3cm ☐ 10cm

ARPA ☐

Speed log ☐ Doppler: Yes / No

Water speed ☐

Ground speed ☐

Dual-axis ☐

Engine telegraph ☐

Steering gear ☐

Number of power units operating ☐

Rudder indicator ☐

Rpm / pitch indicator ☐

Rate of turn indicator ☐

Compass system ☐

Constant gyro error ± ______ °

VHF ☐

Elec. pos. fix. system ☐

Type ____________

OTHER INFORMATION

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____

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J-Marine P1011

A

Arrival check list

1. Passage plan for arrival, and pilot arrangement	☐
2. Has the ETA been sent with all relevant information required by local regulations (e.g. details of dangerous/hazardous goods carried)?	☐
3. Has the following equipment been prepared and checked?	☐
course and engine movement recorders	☐
clock synchronization	☐
communications with the engine control room and mooring stations	☐
signalling equipment, including flags/lights	☐
deck lighting	☐
mooring winches and lines including heaving lines	☐
pressure on fire main	☐
anchors cleared away	☐
stabilizers and log tubes housed, if fitted	☐
Has the steering gear been tested, and has manual steering been engaged in sufficient time for the helmsman to become accustomed before manoeuvring commences?	☐
Have the engines been tested and prepared for manoeuvring?	☐
Has the Pilot card (see annex A3) been completed and are the pilot embarkation arrangements in hand?	☐
Have VHF channels for the various services (e.g. VTS, pilot, tugs, berthing instructions) been noted and a radio check carried out?	☐
Has the port been made fully aware of any special berthing requirements that the ship may have?	☐

B

Bridge familiarisation checklist

⊘This step must be completed before go to the next

👍 This step must be done by close communication methods (Plan, Execute and verify)

Bridge, deck, navigation and signal lights switches	👍	☐
LSA equipment including pyrotechnics, EPIRB and SART	👍	☐
bridge fire detection panel	👍	☐
general and fire alarm signalling arrangements	👍	☐
emergency pump	👍	☐
portable radios	👍	☐
emergency ‘battery less’ phone system	👍	☐
public address system	👍	☐
internal ship communications facilities including	👍	☐
alarm systems on bridge	👍	☐
gyro compass/repeaters	👍	☐
magnetic compass	👍	☐
VHF and GMDSS	👍	☐
off-course alarm	👍	☐
speed/distance recorder	👍	☐
engine and thrusters controls	👍	☐
steering gear, including manual, auto-pilot and emergency changeover and testing arrangements	👍	☐
Location and operation of ancillary bridge equipment (e.g. binoculars, signalling flags, meteorological equipment)	👍	☐
Stowage of chart and hydro graphic publications	👍	☐
AIS function how to update the information	👍	☐
GPS	👍	☐
echo sounder setting depth and alarm	👍	☐
Radar checklist	👍	☐
ECDIS checklist	👍	☐

B

Bridge familiarisation checklist

⊘ This step must be completed before go to the next

👍 This step must be done by close communication methods (Plan, Execute and verify)

The ECDIS and its backup fail procedures	👍	☐
The power supply modes and On and off switch	👍	☐
Operation function (controls, switches, cursor and selection menu)	👍	☐
Day/night modes, brightness, contrast and colour adjustment	👍	☐
Check ship's information (dimensions)	👍	☐
Safety contour and depth	⊘	☐
Deep and shallow area display	👍	☐
Alarms and alerts and acknowledgement	⊘	☐
Range and bearing (VRMs and EBLs)	👍	☐
Parallel Index lines	⊘	☐
The orientation modes (eg, North Up, Head Up, Course Up)	👍	☐
The motion modes (ship position on Relative Motion)	👍	☐
Route Monitoring display (position, heading, course, speed and time)	⊘	☐
The trackkeeping autopilot	👍	☐
The LOP	⊘	☐
The DR mode	👍	☐

Radar Familiarisation Checklist (Industry Recommendations from The Nautical Institute)

B

Bridge familiarisation checklist

⊘ This step must be completed before go to the next

👍 This step must be done by close communication methods (Plan, Execute and verify)

S and X band	👍	☐
Range	👍	☐
Tuning STC (sea clutter), FTC (rain clutter)	⊘	☐
Day/night modes, brightness, contrast and colour adjustment	👍	☐
Display orientation (head-up, North-up, course-up)	⊘	☐
Mode of display (radar-tracked targets and AIS-acquired targets)	👍	☐
Offset VRMS and EBLS (range and bearing)	👍	☐
Parallel indexing lines (monitor cross-track distance	⊘	☐
Range and bearing (VRMs and EBLs)	👍	☐
Zone guard	👍	☐

B

Departure CHECK LIST

🛇 This step must be completed before go to the next

👍 This step must be done by close communication methods (Plan, Execute and verify)

Engine room is informed about when to ready		☐
passage plan (checklist is completed and confirm by master)	🛇	☐
ECDIS setting		☐
ECDIS passage plan	🛇	☐
ECDIS alarms		☐
radar(s) are on including the backup	🛇	☐
electronic navigational position fixing systems	🛇	☐
gyro/magnetic compass and repeaters		☐
echo sounder Depth Alarm	🛇	☐
VHF radio communications with port authority		☐
Navigation and signal lights	🛇	☐
whistles		☐
The automatic identification system (AIS) information is updated	🛇	☐
The telegraphs and the rpm indicators test	👍	☐
Steering gear and rudder indicators test	👍	☐
The master brief the bridge team about the manoeuvring plan	👍	☐
The master asked the bridge team about their concern	👍	☐
Master or OOW must provide a briefing to the lookout about what he could expect	👍	☐
The master is remind about the important of out loud thinking	👍	☐
The master remind about the important of two ways communication	👍	☐
The pilot checklist completed		☐

B

Restricted visibility check list

⊘ This step must be completed before go to the next

👍 This step must be done by close communication methods (Plan, Execute and verify)

Inform the master		☐
Inform the engine room		☐
The engine is standby for manoeuvring and reduce the speed	👍	☐
lookout and helmsman on standby	👍	☐
VHF channel and sound	⊘	☐
ECDIS cross track and safety contour alarms is on	⊘	☐
Radar alarms is on	⊘	☐
AIS information		☐
Echo sounder alarms is on		☐
Fog sound signalling		☐
Bridge team complied with COLREGS rule 19 (safe speed and manoeuvring)		☐
Check for the future risk on the chart		☐
Master or OOW must provide a briefing to the lookout about what he could expect	👍	☐
The master remind about the important of out loud thinking	👍	☐
The master remind about the important of two ways communication	👍	☐

B

Pilot / pilotage check list

⊘ This step must be completed before go to the next

👍 This step must be done by close communication methods (Plan, Execute and verify)

The side of embark/disembark the pilot	👍	☐
The pilot embarkation/disembarkation arrangements	👍	☐
Master and bridge team define what pilot must know about bridge condition	👍	☐
Complete Pilot Card	⊘	☐
Discusses the passage plan with the pilot	👍	☐
Radio communications and reporting requirements		☐
Berthing/anchoring arrangements		☐
Pilot navigation lights, flags and shapes	⊘	☐
Master and OOW understand that the pilot is a part of bridge team (inform pilot)	👍	☐
OOW and master must communicate with the pilot and challenging his decisions	👍	☐
OOW should perform normal watch as possible and remain active during pilotage	👍	☐
Inform the pilot about the location of lifesaving appliances	👍	☐
Master not leaves bridge before OOW is ready for the watch	👍	☐

PILOT CARD

Ship's name ________________ Date ________

Call sign ________ Year built ________ Deadweight ______ tonnes

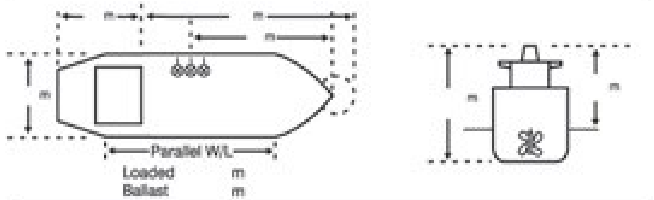
Draught aft ____ m/ ___ ft ___ in. Forward ____ m/ ___ Ft ___ in. Displacement ______ tonnes

SHIP'S PARTICULARS

Length overall ______ m. Anchor chain:Port ______ shackles. Starboard ______ shackles.

Breadth ______ m. Stern ______ shackles.

Bulbous bow Yes/No (1 shackle = ______ m/ ______ fathoms)



Type of engine	Maximum power	KW(	HP)
Manoeuvring engine order	Rpm/pitch	Speed (knots)	
		Loaded	Ballast
Full ahead			
Half ahead			
Slow ahead			
Dead slow ahead			
Dead slow astern		Time limit astern ______ min	
Slow astern		Full ahead to full astern ______ s	
Half astern		Max. no. of consec.starts ______	
Full astern		Maximum RPM ______ ______ knots Astern power ______ % ahead	

STEERING PARTICULARS

Type of rudder ______ Maximum angle ______ °

Hard-over to hard-over ______ s

Rudder angle for neutral effect ______ °

Thruster: Bow ______ KW(______ HP) Stern ______ KW(______ HP)

CHECKED AND READY

Anchors	☐	Rudder indicator	☐
Whistle	☐	Rpm/pitch indicator	☐
Radar ☐ 3cm	☐ 10cm	Rate of turn indicator	☐
ARPA	☐	Compass system	☐
Speed log ☐	Doppler: Yes/No	Constant gyro error	± ______
Water speed	☐	VHF	☐
Ground speed	☐	Elec. Position fix. System	☐
Dual-axis	☐	Type ______	
Engine telegraph	☐		
Steering gear	☐		
Number of power units operating	☐		

OTHER INFORMATION

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B

Arrival check list

⊘ This step must be completed before go to the next

👍 This step must be done by close communication methods (Plan, Execute and verify)

Passage plan for arrival include the sailing directions	⊘	☐
Available port information	👍	☐
Latest weather reports	⊘	☐
Tides & currents for port / adjacent areas	👍	☐
The ETA been sent with all relevant information	⊘	☐
Inform engine room (standby time)	👍	☐
Course and engine movement recorders		☐
Mooring stations standby	👍	☐
pressure on fire main		☐
anchors cleared away	👍	☐
steering gear teste		☐
engines teste		☐
VHF channels for the various services (e.g. VTS, pilot, tugs)		☐
The master brief the bridge team about the manoeuvring plan	👍	☐
The master asked the bridge team about their concern	👍	☐
Master or OOW must provide a briefing to the lookout about what he could expect	👍	☐
The master is remind about the important of out loud thinking	👍	☐
The master remind about the important of two ways communication	👍	☐
The pilot checklist completed		☐

11.3. APPENDIX C - Evaluation forms for the bridge simulator experiment

Bridge Performance Evaluation

On a scale from 1 (extremely poor) to 5 (very good)

First scenario, Familiarisation, normal operation and departure checklist	**1**	**2**	**3**	**4**	**5**
2- Bridge team ability to perceive ship behaviour **(Judgement task)**	○	○	○	○	○
6- Bridge team qualification (experience and familiarisation) **(task Performance)**	○	○	○	○	○
8- Communication or coordination (two way communication between OOW and lookout) **(Bridge Resources Management and Lookout tasks)**	○	○	○	○	○
11- Bridge team ability of technology utilization **(Judgement task)**	○	○	○	○	○

Second scenario, Passing agreement	**1**	**2**	**3**	**4**	**5**
4- Bridge team ability to perceive traffic risk **(Judgement task)**	○	○	○	○	○
8- Communication or coordination (two way communication between OOW and lookout) **(Bridge Resources Management and Lookout tasks)**	○	○	○	○	○
11- Bridge team ability of technology utilization **(Judgement task)**	○	○	○	○	○
15- COLREG's application, OOW avoid using the VHF radio for collision avoidance **(judgement and Situational Awareness tasks)**	○	○	○	○	○
17- Excessive work load condition, OOW communication with crew **(Bridge team judgement and Situational Awareness tasks)**	○	○	○	○	○

Third scenario, Restricted visibility	**1**	**2**	**3**	**4**	**5**
2- Bridge team ability to perceive ship behaviour **(Judgement task)**	○	○	○	○	○
4- Bridge team ability to perceive traffic risk **(Judgement task)**	○	○	○	○	○

	1	2	3	4	5
8- Communication or coordination (two way communication between OOW and lookout) **(Bridge Resources Management and Lookout tasks)**	○	○	○	○	○
12- Bridge team ability of using equipment alarms **(Alarm Management task)**	○	○	○	○	○
16- Call Master procedures **(Emergency Response task)**	○	○	○	○	○
17- Excessive work load condition, OOW communication with crew **(Bridge team judgement and Situational Awareness tasks)**	○	○	○	○	○
Fourth scenario, Shallow water affect	**1**	**2**	**3**	**4**	**5**
2- Bridge team ability to perceive ship behaviour **(Judgement task)**	○	○	○	○	○
4- Bridge team ability to perceive traffic risk **(Judgement task)**	○	○	○	○	○
6- Bridge team qualification (experience and familiarisation) **(task Performance)**	○	○	○	○	○
8- Communication or coordination (two way communication between OOW and lookout) **(Bridge Resources Management and Lookout tasks)**	○	○	○	○	○
9- Following passage planning procedures (prepare for shallow water affect) **(passage Planning task)**	○	○	○	○	○
11- Bridge team ability of technology utilization **(Judgement task)**	○	○	○	○	○
12- Bridge team ability of using equipment alarms **(Alarm Management task)**	○	○	○	○	○
17- Excessive work load condition, OOW communication with crew **(Bridge team judgement and Situational Awareness tasks)**	○	○	○	○	○
19- Bridge team diminished motivation knowledge (negligent the watch responsibility) **(Judgement task)**	○	○	○	○	○
Fifth scenario, Pilot onboard	**1**	**2**	**3**	**4**	**5**
2- Bridge team ability to perceive ship behaviour **(Judgement task)**	○	○	○	○	○

6- Bridge team qualification (experience and familiarisation) **(task Performance)**	○	○	○	○	○
8- Communication or coordination (two way communication between OOW and lookout) **(Bridge Resources Management and Lookout tasks)**	○	○	○	○	○
9- Following passage planning procedures (prepare for shallow water affect) **(passage Planning task)**	○	○	○	○	○
18- Bridge team ability to follow Pilot procedures (inform pilot about bridge condition) **(Situational Awareness task)**	○	○	○	○	○
19- Bridge team diminished motivation knowledge (negligent the watch responsibility) **(Judgement task)**	○	○	○	○	○

11.4. Appendix D

Presents the assessed items in the questionnaire including the addressed levels and abilities

Topic	Level	Ability
Clear description of responsibilities	Multiparty Team	Anticipate
Ability (other party, team, individual, assets) to deal with unforeseen operational demands	Multiparty Team Individual Technical assets	Anticipate
Shared safety culture with other party	Multiparty	Monitor
Communication (with other party, between team members)	Multiparty Team	Monitor Respond
Monitoring of (other parties, organizational, team, individual, technical) resources	Multiparty Organisation Team Individual Technical assets	Monitor
Lessons learned during operation	Multiparty Organisation Team Individual Technical assets	Learn
Shared compliance with safety standards regulation	Multiparty	Anticipate
Multiparty risk assessment	Multiparty	Anticipate
Shared methodologies for safety assessment, reporting and monitoring	Multiparty	Anticipate Monitor
Shared training programs with other party	Multiparty	Anticipate
System knowledge	Multiparty	Anticipate

	Organisation Team Individual Technical assets	Learn
Changes; technical, organisational, external	Multiparty Organisation Team Individual	Monitor
Focus on safety (safety versus other issues)	Multiparty Organisation Team Individual	Monitor
Human resources oversight (internal/external)	Multiparty Organisation	Monitor
Adequate external decision support (also before incident)	Multiparty	Respond
Organisational support during preparation	Organisation	Anticipate
Organisational support during performance	Organisation	Monitor Respond
Company culture	Organisation	Monitor
Information about risk through e.g. courses & documents	Organisation	Anticipate
Information about the quality of safety barriers	Organisation Technical assets	Anticipate
Information about the quality of barrier support functions	Organisation Technical assets	Anticipate
Discussion of HSE issues/status in regular meetings	Organisation	Anticipate
Communicating risk at all levels of the organisation	Organisation	Anticipate
Risk/hazard identification	Organisation	Anticipate
Trends in reported events and quality of barriers	Organisation	Monitor
Early warnings (e.g. from whistle blowers)	Organisation	Monitor
Adaptability of training (timely revision of training material)	Organisation	Respond
Handling of exceptions (beyond day to day operations)	Organisation Team	Respond
Flexibility of organizational structure	Organisation	Respond
Timely procedures	Organisation	Respond
Organisational robustness (backup functions)	Organisation	Respond
Adequate resource allocation and staffing (inc. buffer capacity)	Organisation	Respond
Adequate decision support staffing (availability & knowledge/ experience)	Organisation	Respond
Criteria for safe operation well defined and understood	Organisation Team Individual	Respond
Understanding and willingness to use external support	Organisation Team Individual	Respond
Redundancy of decision support functions	Organisation	Respond

Reporting of incidents, near-misses and accidents	Organisation	Learn
Safety performance matters requested by senior management	Organisation	Learn
Learn from other's experiences & accidents	Organisation Team	Learn
Communicating risk at all levels of the organisation	Organisation Team Individual	Learn
Performance of roles, tasks and responsibilities	Team Individual	Monitor Respond
Process disturbances; control and safety system actuations	Team Individual	Monitor
Bypass of control and safety functions	Team Individual	Monitor
Activity level / simultaneous operations	Team Individual	Monitor
Training (simulators, table-top, preparedness..)	Team Individual	Respond
Ability to make (correct) decisions	Team Individual	Respond
Robustness of responsible function	Team Individual	Respond
Learn from own experiences & accidents	Team Individual	Learn
Task, role and responsibilities	Individual	Anticipate Respond
Redundancy in skills; multiple skills	Individual	Respond
Individual ability to deal with unforeseen operational demands	Individual	Monitoring, Responding
Ability to make (correct) decisions	Team, Individual	Respond
Availability technical assets	Technical assets	Anticipate Monitor
Technical assets being operational	Technical assets	Anticipate Monitor
Adequate ICT systems (timely updating of information)	Technical assets	Respond
Adequate decision support systems (and use)	Technical assets	Respond
Redundancy in information processing	Technical assets	Respond

The Resilience Assessment Tool questionnaire

This Resilience Assessment Tool aims to support Safety Managers in performing a resilience assessment. It should be applied to specific operational processes within the company, such as lifting, mooring, embarking, loading, navigation, etc.
When you read 'complex or time critical situations' this can refer to different things that you might think of. For instance: port operations (e.g. loading/ discharging, lashing and securing), emergencies, transits in navigation, sea passage in bad weather or harbor imposed work or demands.
This questionnaire is composed by four parts and aims to collect information on all activities.
Please read the statements in the questionnaire and indicate whether you agree or disagree with the statement using the following 6-point scale across all items
1 = strongly disagree,
2 = disagree,
3 = agree nor disagree,
4 = agree,
5 = strongly agree
6 = do not know

Database Organisation Level

1. What is your fleet size? Answer: number of ships in company
2. Is there a record of training certificates as required by STCW?
3. Have you implemented the 2012 Manilla amendments regarding training certificates and watchkeeping in your company? Answer: yes/no
4. Is there a record of incident and accident reports? Answer: yes/no
5. Is this record up to date? Answer: yes/no
6. How many incident reports have been shared with other ships in the past two years? Answer: number
7. How many incidents have been investigated in the past two years? Answer: number
8. How many near misses have been reported in the past two years? Answer: number

9. How many accidents did occur in the past two years? Answer: number
10. How many port state control or other inspections have been conducted on your fleet in the past two years? Answer: number
11. How often did these inspections lead to sanctions in the past two years? Answer: number
12. Does your company have a clearly described matrix of functions and responsibilities? Answer: yes/no
13. Does your company have a safety management system in place? Answer with one of the following: available, implemented, effectively implemented.
14. What type of operations do you carry out (e.g., tankers, liquid bulk, solid bulk, off-shore, heavy lifting, passengers, etc. multiple answers possible)
15. Is a record of job experience available? Answer: yes/no
16. Are the records of job experience up to date? Answer: yes/no
17. Is a record of years in function available? Answer: yes/no
18. Are the records of years in function up to date? Answer: yes/no

Database Ship Level

1. How many different nationalities are represented on your ship? Answer: number
2. Is language competence of crew members recorded in a database? Answer: yes/no
3. What is the ship's complement (number of people required to crew a ship)? Answer: number
4. What is the age of your ship? Answer: number
5. What is the estimated average number of sailing hours per year of your ship? Answer: number
6. Are toolboxes provided for all jobs during normal operations? Answer: yes/no
7. Are all watch handover documents available? Answer: yes/no
8. Are the records of watch handover documents up to date? Answer: yes/no
9. Are all ship logs documented? Answer: yes/no
10. Are the records of ship logs up to date? Answer: yes/no
11. Are debriefings documented and accessible for all personnel? Answer: yes/no
12. Are all safety instructions documented? Answer: yes/no
13. Are the safety instructions available for the crew members at their workplace? Answer: yes/no

14. Are all records of working hours and rest hours available (STCW requirement)? Answer: yes/no
15. Are all records of working hours and rest hours up to date (STCW requirement)? Answer: yes/no
16. How many operations are carried out under extreme environmental conditions? Answer: number
17. How many evaluations of operations have been carried out by port captains in the past year? Answer: number

Multiparty Level

Anticipate

1. Responsibilities of external parties (e.g. stevedores, clients, agents, fleetmanagement, sucontractors) involved are clearly described
2. Contractors that work for the company conform with the safety regulations related to the operation at hand
3. Before safety critical operations are carried out a risk assessment is performed including all relevant participants
4. Permits to work are used by internal and external parties
5. Standard reporting systems are used by internal and external parties parties
6. External parties involved in an operation follow a shared training program (e.g. drills, toolboxes, whale & bird watching)

Monitor

7. External parties share the same safety culture
8. The quality of multi-party resources (people, materials) is monitored after the operation (e.g. by the port captain)
9. During complex or time critical situations someone monitors whether external parties get the correct information
10. During complex or time critical situations someone monitors whether the crew receives the right information from external parties
11. During high workload situations someone monitors whether the expertise of stakeholders is used

React

12. During complex or time critical situations assistance is requested of an expert

13. During high workload situations a cross-organization crew is formed to smooth political tensions that arise during periods of high stress
14. During complex or time critical situations information is shared with relevant stakeholders
15. During complex or time critical situations measures are taken when information sharing is suboptimal
16. During complex or time critical situations relevant parties are involved in developing solutions to resolve the emerging situation

Learn

17. Lessons about multi-party cooperation are learned during the operation
18. Lessons learned about multi-party cooperation are documented after the operation
19. Lessons learned about multi-party cooperation are shared after the operation
20. Lessons learned about multi-party cooperation are implemented after the operation

Organization Level

Anticipate

1. The operation is pre-planned by using method statements (step plans in 3D)
2. The operation is prepared by using safety analyses (e.g. standard or customized HAZIDS)
3. The company applies predefined criteria for safe operations (e.g. sea state limits on directions, wind speed or wavelengths)
4. The company anticipates the availability of its (broad) resource networks during complex or time critical situations (e.g. fleet operations, service suppliers, manufacturers, vessel managers or port captains)
5. The company sufficiently supports the preparation of the operation
6. The company engages in dialogue with staff about current and emerging HSE issues
7. Risk information is available through various channels e.g. meetings, safety alerts, bulletins, etc.
8. Risk information can be easily understood by all levels in the company
9. The company regularly identifies risks and hazards

10. There are enough crew members and material resources in the crew to respond properly to unexpected situations and events
11. The company develops multi-skilled crew members
12. Pre-task briefs are being held on a regular basis
13. Real time risk assessments are being carried out to address emerging situations
14. Management is committed to safety
15. Selection of employees is driven by safety principles and SMS
16. Roles, tasks and responsibilities of crew members are clearly defined
17. Technical assets (e.g. thrusters, cranes, power supply) are sufficient to meet operational demands
18. The training curriculum is revised and updated when necessary in a timely fashion
19. The operation is pre-planned by using simulation
20. The operation is prepared by using safety cases
Not Know
21. The organization has defined criteria for safe operations
22. Information about risk is properly communicated at all levels in the organization

Monitor

23. The quality of company resources (people, materials) is monitored during the operation
24. The company makes careful considerations between safety and other goals
25. The company has oversight of human resources to ensure staff has appropriate qualifications and training
26. Company support is sufficient during the operation
27. The company reports trends in event reporting
28. Staff feel free to report problems and issues even when it might be controversial
29. By-passing or disabling safety functions / barriers/ defenses is actively controlled and corrected
30. Safety performance data are requested by senior management and acted upon if needed

React

31. The company responds well to any exceptions/ unexpected circumstances

32. The company structure is sufficiently agile and flexible to change in response to demand
33. The company can change procedures in a timely fashion when necessary
34. There are always enough knowledgeable people available to ask for advice when needed
35. Ship staff takes action on the safety issues that are raised
36. During complex or time critical situations the company uses its (broad) resource networks (e.g. fleet operations, service suppliers, manufacturers, vessel managers or port captains)
37. During complex or time critical situations additional buffers are added to diminish the workload
38. During complex or time critical situations additional resources are allocated (e.g. an extra crew member) to deal with physical and mental stressors
39. ICT systems available on board are adequate to perform operational duties (e.g. communication devices, weather information software)
40. There is enough redundancy in the systems on board to secure information flow and decrease errors
41. Staff is confident that the company will respond to and act upon early warnings

Learn

42. The company learns lessons from previous critical incidents like accidents, near misses and non-conformities (good and bad)
43. The company documents lessons learned after the operation
44. The company shares lessons learned after the operation
45. The organization reports incidents, near-miss and accident data for continuous improvement and **learning**
46. The operation is evaluated using debriefings
47. Critical questions are asked to trigger learning when work is done

Team Level

Anticipate

1. Crews involved in the operation follow a shared training program
2. Crews are trained to respond to foreseen risk scenarios
3. Crews are trained to respond to unforeseen risk scenarios

4. Crews are trained to respond to emergency scenarios
5. Crew training in making critical decisions is sufficient
6. Crew members periodically work at the frontlines to keep their skills fresh

Monitor

7. The crew actively shares information about (potential) technical failures of equipment (e.g. electrical systems, power systems, sensor systems)
8. The crew actively shares information about (potential) loss of control during operational activities
9. During complex or time critical situations the crew checks that the shared information is clearly understood
10. During complex or time critical situations the members in the crew adequately discuss the allocation of tasks and responsibilities
11. During complex or time critical situations the members in the crew ask each other critical questions to get a clear idea of the situation and their tasks
12. During complex or time critical situations the members in the crew share relevant information in time
13. During complex or time critical situations the members in the crew share relevant information on their own initiative
14. During complex or time critical situations crew members address each other when they have different understanding about what is going on
15. During complex or time critical situations the members in the crew speak out openly when they think differently about the solution
16. During complex or time critical situations flaws in the teamwork (e.g. bad coordination and collaboration)are actively monitored and addressed
17. During complex or time critical situations scenarios of unwanted incidents are explored
18. During unexpected situations a shared decision making process takes place
19. During unexpected situations diverse perspectives are included
20. During unexpected situations there are procedures or agreements to let crew members know to each other about the activities they are doing
21. During complex or time critical situations, the crew monitors if procedures / work orders are followed the right way

React

22. During complex or time critical situations the level of communication between crew members is sufficient
23. The information provided by other crew members is understandable for all crew members involved
24. The crew has sufficient people and materials to respond to exceptions
25. Crew support in making critical decisions is sufficient
26. During complex or time critical situations competing goals are shifted to only perform the critical tasks at hand
27. During complex or time critical situations roles within the crew are shifted to only perform the critical tasks at hand
28. During complex or time critical situations the crew adheres to established work orders/ procedures
29. During complex or time critical situations if procedures are not followed the right way this is corrected by the crew
30. During complex or time critical situations tasks are shed by not doing, postponing, doing less frequently, or moving tasks to other crew members
31. During complex or time critical situations attention is redirected to perceived priorities
32. During complex or time critical situations the crew has the authority to add tools or move objects
33. During complex or time critical situations it is easy to escalate issues to the attention of management
34. ICT systems provide up to date information about the status of technical assets (e.g. thrusters, cranes, power supply) to the crew members
35. During complex or time critical situations an additional crew is formed during the period that the system is stretched close to its limits for heightened state of coordination and help

Learn

36. Lessons learned about crew performance are used for similar future operations
37. Lessons learned about crew performance are documented after the operation
38. Lessons learned about crew performance are shared after the operation
39. Instructional duties are shared around within the crew

40. Regular crew meetings are held to discuss (safety related) issues

41. There is an open communicative climate (transparent and reciprocal) within the crew

Individual Level

Anticipate

1. Knowledgeable crew members are made available to meet unforeseen demands (e.g. corrective maintenance, 24h shifts)
2. Enough crew members are made available to meet unforeseen demands
3. Crew members know the important safety procedures
4. Crew members know the risks of their work
5. Crew members have followed the proper safety training
6. Redundancy and diversity in skills of crew members is sufficient, also during complex and time critical situations
7. Crew members are aware of the impact on safety that can be generated by a change in the technical systems
8. Crew members know who are formally responsible for what
9. Crew members understand the technical systems they work with
10. Crew members share safety-related information with each other

Monitor

11. Any changes in the operation (e.g. technological, organizational, external) are actively monitored for potential negative effects
12. Any changes in the operation (e.g. technological, organizational, external) are carried out in a safe manner
13. The crew is committed to safety
14. The crew makes careful considerations between safety and other goals
15. Compliance to safety functions (e.g. safety procedures) is monitored during the operation
16. In periods with high activity or a high number of simultaneous operations, crew members perform additional risk assessments to control for potential negative side effects

17. In periods with high activity or a high number of simultaneous operations, crew members monitor (potential) unexpected interactions between operations and/ or activities
18. During complex or time critical situations the captain steps back from (or out of) his/ her usual role to gain a broader perspective on the emerging situation
19. During complex or time critical situations the crew actively searches for information to get a clearer understanding of the situation
20. During complex or time critical situations changes in the risk level are noticed by crew members
21. During unexpected situations a central person provides an integrated picture of the state of the situation and response

React

22. Crew members are able to deal with unforeseen operational demands
23. Crew members conduct exercises to handle unforeseen operational demands at the ship
24. Crew members are well prepared for unforeseen operational demands
25. Crew members have established ' who does what ' during unforeseen operational demands
26. Crew members have sufficient resources to respond to unforeseen operational demands
27. Enough crew members are available to respond appropriately to unforeseen operational demands
28. Criteria for safe operations are well understood by crew members
29. The crew understands that they can ask for external support if needed
30. The crew is willing to use external support if needed
31. Crew members perform their roles, tasks and take responsibilities as described in their job description
32. Crew members have sufficient authority for the execution of their tasks
33. During complex or time critical situations, less experienced crew members are used for less complex work
34. During complex or time critical situations, someone within the crew is responsible for task prioritization

Learn

35. Repetitive routines are trained to provide the first response to any emergency and/ or threat
36. Lessons learned about individual performance are used for future operations
37. Lessons learned about individual performance are documented after the operation
38. Lessons learned about individual performance are shared after the operation
39. There is an open communicative climate (transparent and reciprocal) within the crew
40. People are willing to report safety incidents and occurrences

11.5. Appendix E

11.5.1 Compass

The magnetic compass is a traditional tool for finding the direction by using the effect of the Earth's magnetic field (Figure 11-25). Each ship is equipped with one. During the era of wooden ships, the magnetic compass was not affected by the ship's materials. After the development of steel ships, a high compass platform was required to prevent magnetic interference with the ship's hull. On the other hand, the gyrocompass supports navigation operations by defining the direction in an efficient manner since it works mechanically and is not influenced by the magnetic field like the traditional compasses. It uses the gyroscope effect to find the true north. It provides the correct shipping direction in different sailing weather conditions and sea states. Like any machine, the gyrocompass can encounter errors, such as those that could occur because of fast changes of course and speed, but new developments reduce errors by connecting the system to the GPS system to update the machine data to determine the accurate direction.

Figure 11-25 Navigation compass (from http://www.lighthouselens.com)

11.5.2 Radar

The ship's radar is the most essential navigation tool on the bridge that helps to avoid collisions (Figure 11-26). On its screen, it shows ships and coastal shapes that can be used to define the ship's position by taking bearings from two or more different objects. Radar plotting is necessary for monitoring and assessing the risk of collision. Radar is useful for all sailing conditions but during reduced visibility, it shows more benefit for detecting the risk of colliding with other ships.

Figure 11-26 Radar (from http://www.esimarine.com)

Ships carry two different types of marine radar, which are x-band and s-band. The OOW must be familiar with both types. The x-band radar produces smaller waves that help to increase the sensitivity so that the radar is able to detect small elements. It uses a higher frequency (10 GHz), which provides greater resolution and a crisper image. Furthermore, because of this function, it is able to detect the search and rescue transponders (SARTS). The s-band radar produces longer waves, which makes it sensitive to light precipitation, such as rain or snow. It operates at 3 GHz, which means that it is affected by rain and fog that helps for their detection.

According to SOLAS, ships of 300 gross tonnage and more must carry both types and at least one of them must include an automatic radar plotting aid (ARPA) and operate during navigation. The ARPA uses the radar function and includes software for calculating and plotting the progress of other targets, including course and speed, which that helps to create and keep a track from the other objects. The closest point of approach (CPA) should be defined to assess the risk of collision. The ICS provides guidelines for good radar practice, which includes: keeping the radar fully operating all the time, monitoring the quality of the performance, including the heading marker alignment with the heading compass and ship aft line, not all objects can be detected, careful use of cluster controls during rain and the effect of masts or other structural blind sectors on the display.

11.5.3 Autopilot

The autopilot helps the navigator to steer the ship automatically by using an electro-mechanical system (Figure 11-27). The regulations require that the bridge steering system to have the flexibility to quickly transfer from autopilot mode to manual steering. In the past, the quartermaster was an important person among the command team, who was responsible for steering the vessel according to the master's orders. Later on, the helmsman took over this responsibility after the bridge was developed. When the autopilot was invented, it displaced these professions. It relies on the gyrocompass to determine the heading. The officer must not over-rely on the autopilot since it has limitations that have caused several accidents. During risky conditions, such as restricted visibility or high traffic, it is preferable to engage manual control for steering the ship. The officer is the one who is responsible for the decision. The bridge team is required to test the system from time to time to make sure that it is working in a normal state and in the case of an emergency it can safely change between the two modes. The autopilot systems offer many advantages such as reducing fuel consumption, thus lowering operation costs, and moderating the rudder alterations, which enhances the voyage speed and time. The modern autopilot system has become quite adaptive to the weather and sea conditions and can be connected to the ECDIS to increase the efficiency.

Figure 11-27 Autopilot (from http://www.tokyo-keiki.co.jp)

11.5.4 Speed and Distance Log Device

Figure 11-28 present the Speed and Distance Log Device, which helps to measure the speed and the distance of a ship's voyage. The IMO states that each ship of 50,000 gt and over must carry two devices for measuring both the speed and the distance. One of the devices is able to measure the speed through the water and the other is able to measure the speed over the ground. The term knot is the unit of ship speed, which is a nautical mile per hour. The tools onboard ship that are used to measure speed through the water are known as a log. The name comes from the old days of sailing ships when the crew used to tie a log to a knotted rope and then tossed it into the water from the aft; the number of knots that passed between their hands in a given time was the speed measurement.

Figure 11-28 Speed and Distance Log Device (from: http://www.nauticexpo.com)

11.5.5 Echo Sounder

The echo sounder uses sound pulses to measure the water depth under the ship. It is a kind of sonar device that sends pulses into the water to the seafloor then the pulses are reflected to the device; the time interval between the sending and receiving is used to calculate the depth. The tool has a monitor display to show the seafloor shape and depth. It also comes with an alarm system to warn the bridge navigator about the danger of grounding when the water level becomes low under the keel. The OOW must be familiar with the echo sounder operation and how to set an adequate safe under keel clearance (UKC), which incorporates the minimum water depth for ship passage, including the tidal calculation.

Figure 11-29 Echo Sounder (from: http://www.echomastermarine.co.uk)

11.5.6 Electronic Chart Display Information System

The electronic chart display information system (ECDIS) (Figure 11-30) is one of the most significant advances in maritime navigation since the development of radar (AMSA, 2016). It is a computer-based maritime navigation system that can be used as a substitute for traditional paper charts for the passage planning process. Instead of paper charts, the electronic charts make the navigation process simpler, especially the definition of the ship direction. The information from the Electronic Navigational Charts (ENC) or Digital Nautical Charts (DNC) is used for the system display. The ECDIS can receive data from different navigation equipment to increase the efficiency of the display. It can be integrated with GPS, radar, Navtex, automatic Identification Systems (AIS), echo sounders, heading and speed. The IMO regulation enforces all vessels, regardless of their size, to use nautical charts and publications to plan and display their voyage passage and plot and observe positions, which includes carrying preparations if electronic charts are used, and this system must be updated continuously.

Figure 11-30 ECDIS (from: http://www.nauticexpo.com)

The ECDIS may contain different alarms, such as clearing lines, ship safety contour lines, isolated dangers and danger areas. Many maritime administrations required the system to be approved before it is used on a bridge. The maritime education institutes provide courses for the OOW to gain operation knowledge, which is compulsory before joining a ship that carries ECDIS. One of the important advantages of the system is the fast and simple way of updating the charts, which requires using an external DVD or Internet connection for the system hard disk to perform the updating. Furthermore, it is based on real-time information that shows the OOW the ship location at any time without returning to the paper charts. The ECDIS is economically beneficial by providing the best routes that help to save time and fuel.

According to Gee (2015), from July 2012, all ships 500 GT and above must install an ECDIS, which has the following benefits: improved situation awareness and competence, accessibility of information, improved real -time navigational precision, definite passage-planning, and self and precise chart updating. The ECDIS is central to the safety of vessels, including its efficient management system. New IMO regulations require the ships to carry an ECDIS since it reduces groundings by 30% (JEPPESEN, 2013). JEPPESEN added that the ECDIS is currently used for safe navigation operations yet, in the future, it could be attached to safety and efficiency management for operation systems for voyage planning and enhancement, piracy anticipation, performance observations, port and maintenance arrangements and procedures acquiescence.

11.5.7 Automatic Identification System

The automatic identification system (AIS) is an automatic tracking system and navigation tool that helps to send ship's information and receive the same things from other ships automatically in order to reduce the risk of collisions (Figure 11-31). The information could include the ship name, call sign, the ship state (sailing or anchor), trip information and cargo type. The system can be used on the ship's bridge and VTS stations to identify and monitor the ship's location. It uses VHF radio frequencies for transmitting and receiving. The main sources for the system are nearby vessels, AIS base stations and satellites. The marine radar and the ECDIS could receive information from the AIS about other ships' speed, course, location and identification, which could help to improve the efficiency of collision avoidance. The AIS is an important tool to improve maritime safety and marine protection. It enables the VTS stations and the port authority to manage the shipping traffic around their area. The IMO requires all passenger ships and cargo ships of 300 gt or more to carry an AIS. Nowadays there are many service providers that can offer real-time AIS information online.

Figure 11-31 AIS (from: http://www.nauticexpo.com)

11.5.8 Rudder Angle and Rate of Turn Indicators

Rudder angle indicator shows the ship's rudder angle in the steering control system. It is required to be installed in the steering gear room. It contains a feedback unit that has a transmitter connected to the rudder that sends a signal to the receiver, which is located on the bridge and any other needed position to show the rudder angle. Some regulatory bodies require additional indicators on the bridge, such as the DNV, and the Panama Canal policy demands another one in the ship's wing.

Figure 11-32 Rate of Turn Indicators (from: https://marine-data.co.uk)

The rate of turn indicator (Figure 11-32) shows the ship's rate of turn in degrees per minute. It helps the helmsman to recognise the ship's behaviour when steering towards a specific course. When the rate of turn indicator points to zero, it means the vessel is heading in an exact straight direction. If the ship starts turn the indicator will immediately point to the same direction. Some ships use a digital type, but the mandatory requirement is that each vessel must carry an analogue indicator. The SOLAS regulations require all vessels of 50,000 gt and over to install one on their bridges that is approved by the maritime administration. In some advanced bridges, the rate of turn indicator is connected to the AIS to improve the collision avoidance.

11.5.9 Voyage Data Recorder

The voyage data recorder (VDR) (Figure 11-33) is a safety device and data recording system that helps to record a ship's activities from different sensors over 12 hours, which supports investigators in the case of an accident. The SOLAS Convention requires that passenger ships and other ships of 3,000 gt and more to install one on the bridge. The VDR is a tamperproof unit that is designed to survive from great shock, damage, pressure and heat that could take place in an accident. It could be called the black box of maritime ships and it collects several important pieces of data, such as radio communications, speed, location, ECDIS information, radar, weather, echo sounder, alarms, steering, bridge sound recording, thrust and hull activity (doors). When an event took place the OOW must push the VDR button to avoid overwriting on the saved data. In some functions, it connects with the Emergency Position Indicating Radio Beacon (EPIRB) to float free and be easily found.

Figure 11-33 VDR (from: www.amimarine.ne)

11.5.10 Global Positioning System

Global Positioning System (GPS) (Figure 11-34) is a satellite-based navigation system that helps to identify a ship's position on the Earth. It receives data from a network of 24 satellites that orbit the Earth. Generally, it provides time and location data to the receiver from four or more satellites. The GPS receiver calculates the user's location by finding the difference between the transmitted time of the signal and the receiving time, which give the distance between the sender and the receiver. Through measuring the distance from several satellites, the GPS receiver can determine its location and present it on the screen.

Figure 11-34 GPS (from: www.radioholland.com)