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Processual SEMOMAP : an application and evaluation of the accident investigation model in passenger ship accidents

Yogender Singh
World Maritime University

WORLD MARITIME UNIVERSITY

Malmö, Sweden

PROCESSUAL SEMOMAP:

An application and evaluation of the accident investigation model in passenger ship accidents

By

YOGENDER SINGH
India

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2014

DECLARATION

I certify that all the material in this dissertation that is not my own work has been identifies, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

(Signature): …………………………………

(Date): ……………………………..….

Supervised by: Dr. Jens-Uwe Schröder-Hinrichs
World Maritime University

Assessor:
Institution/organisation:

Co-assessor:
Institution/organisation:

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ABSTRACT

Title of Dissertation: Processual SEMOMAP: An application and evaluation of the accident investigation model in passenger ship accidents

Degree: MSc

This dissertation is an exploratory application and evaluation of the SEquential MOdel of the Maritime Accident Process (SEMOMAP) accident investigation model. SEMOMAP is uniquely positioned in the academic literature by virtue of its focus on the accident process. The dissertation aims to reveal insights into why some unfolding processes help the system to achieve a safe operative state, while others lead to a mitigated or total loss.

Fifteen publicly available accident investigation reports from Maritime Administrations and investigating bodies are analysed utilising the SEMOMAP. The accident investigation reports are coded with the help of two taxonomies – Human Factors Analysis and Classification Systems (HFACS) and a taxonomy inspired by the Technique for the Retrospective and Predictive Analysis of Cognitive Errors (TRACEr). These taxonomies complement the SEMOMAP and provide a comprehensive perspective to accident investigation.

The fifteen reports selected for analysis are of passenger vessel accidents that have taken place after the introduction of the International Safety Management (ISM) code in 1998 presuming the existence of a functional Safety Management System (SMS) ashore and on-board to ensure compliance with the code, including compliance with the Standards of Training, Certification and Watch Keeping (STCW).

The accident reports are examined and the analysis helps to evaluate the SEMOMAP model and its performance. The analysis subjects the model to rigorous analytic evaluation. The purpose of the dissertation is twofold – on the one hand are the results of the analysis obtained after applying the model and on the other is the evaluation of the model itself, highlighting its strengths, weaknesses and unique contribution.

The results are collated and discussed in the penultimate chapter (number 5); conclusions are drawn and recommendations are made in the final chapter 6. The dissertation argues that SEMOMAP with its complementary HFACS and TRACEr inspired taxonomies contributes to an enhanced and comprehensive understanding of the accident processes. The insights from applying the model make a valuable input for system resilience.

KEYWORDS: SEMOMAP, Accident investigation models, HFACS, TRACEr, IMO casualty investigation

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LIST OF ABBREVIATIONS

BRM	Bridge Resource Management
BTM	Bridge Team Management
BSU	Bundesstelle für Seeunfalluntersuchung
CREAM	Cognitive Reliability and Error Analysis Method
CSM	Continuous Survey of Machinery
DNV	Det Norske Veritas
DoD	Department of Defence, the United States of America
ETTO	Efficiency Thoroughness Trade Off
FSA	Formal Safety Assessment
GEMS	Generic Error-Modelling System
HEART	Human Error Assessment and Reduction Technique
HFACS	Human Factors Analysis and Classification Systems
IMO	International Maritime Organisation
ISM	International Safety Management
MaRiSa	Maritime Risk and System Safety
MSC	Maritime Safety Committee
SEMOMAP	SEquential MOdel of the Maritime Accident Process
SMS	Safety Management System
SOLAS	Safety of Life at Sea Convention, 1974, as amended
STCW	Standards of Training, Certification and Watch Keeping Convention, 1978, as amended
TRACEr	Technique for the Retrospective and Predictive Analysis of Cognitive Errors
THERP	Technique for Human Error Rate Prediction
USCG	United States Coast Guard
WMU	World Maritime University
WYLFIWYF	What-You-Look-For-Is-What-You-Find

1. INTRODUCTION

This dissertation analyses passenger ship accident investigation reports with the SEMOMAP model and HFACS and TRACEr inspired taxonomies to explore accident processes that enable a system to achieve a safe system state and those that lead to a mitigated, severe or total loss. The opening chapter provides the background and motivation for the dissertation along with its aim and purpose. The chapter introduces the research problem under investigation and provides an outline structure of the dissertation.

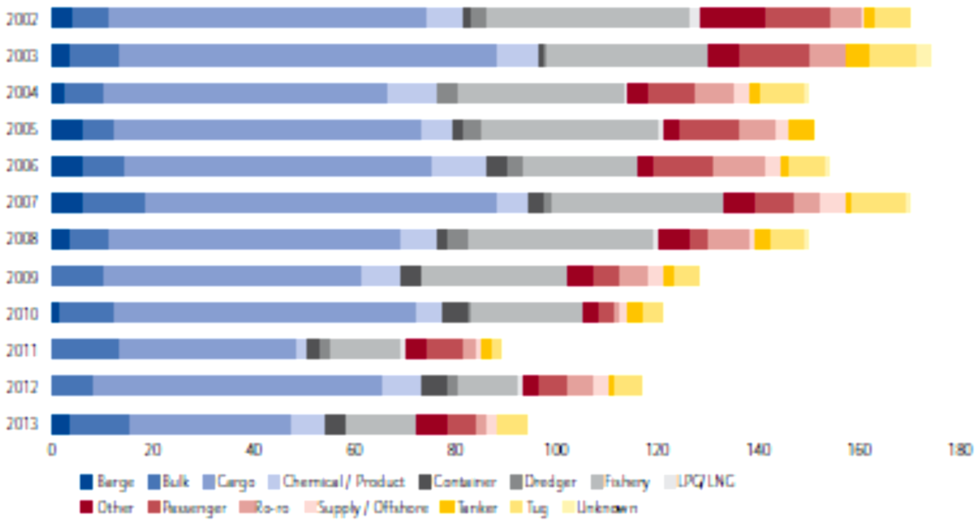
1.1 BACKGROUND

State-of-the-art passenger ships appear like floating residential towers and represent a marvel of scientific advances in technology (for ship fire safety design see, Cooke, 2007). Despite that, even in the 21st-century, we are not immune to serious maritime accidents that have devastating consequences for life, property and the environment. The tragic sinking of the Costa Concordia in the beginning of 2012, a 100 years after the Titanic disaster (see Schröder-Hinrichs et al., 2012) highlights that even in the modern era of advanced technology, (allegedly) safer systems and international regulations, severe maritime accidents continue to occur. Even before the wreck of the Costa Concordia entered the final phase of its salvage operations in July 2014, another accident of a passenger ferry in April 2014 - Sewol captured international headlines with over 300 fatalities. Even though Sewol was a domestic ferry and not an international passenger ship, the accident and the loss of lives is disconcerting.

Passenger ship accidents, that resulted in a total loss (99 ships) account for nearly 6% of all accidents from 2002 to 2013 (AGCS, 2014, p. 8) and this figure increases to

6.38% for 2013 (AGCS, 2014, p. 9). Figure 1 below, depicts the total losses by ship type for the years covering 2002-2013 and Figure 2 depicts the total losses by ship type for 2013. The biggest cause of the total loss was identified as foundering, accounting for 44.5% for the period ranging from 2002-2012 (AGCS, 2014, p. 10). The percentage for foundering increased to 73.4% for all total losses in 2013 (AGCS, 2014, p. 11) (see figure 3).

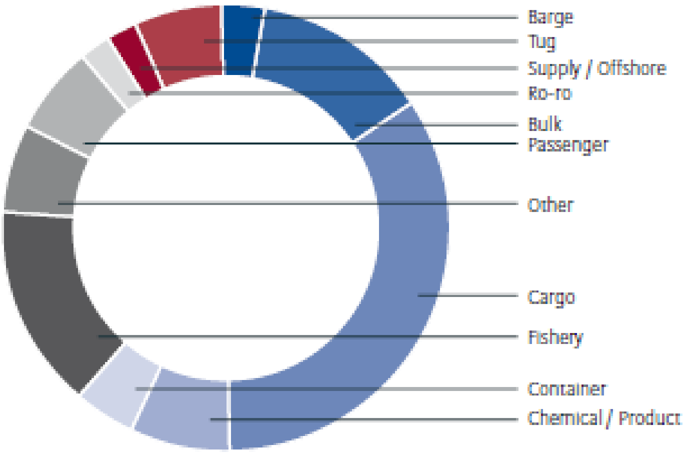
Figure 1: Total losses by vessel type 2002-2013



Period	Barge	Bulk	Cargo	Chemical / Product	Container	Dredger	Fishery	LPG/LNG	Other	Passenger	Ro-ro	Supply/ Offshore	Tanker	Tug	Unknown	
2002	4	7	63	7	2	3	40	2	16	13	6	1	2	7		173
2003	3	10	75	8	1	1	32		6	14	7		5	9	3	174
2004	2	8	58	10		4	33	1	4	9	8	3	2	9	1	152
2005	6	6	61	6	2	4	35	1	3	12	7	3		5		151
2006	6	8	61	11	4	3	23		3	12	10	3	2	7	1	154
2007	6	12	70	6	3	2	34		6	8	5	5	1	11	1	170
2008	3	8	58	7	2	4	37	1	6	4	8	1	3	7	1	150
2009		10	51	8	4		29		5	5	6	3	2	5		128
2010	1	11	60	5	5	1	22		3	3	1	2	3	4		121
2011		13	35	2	3	2	14	1	4	7	3	1	2	2		89
2012		8	57	8	5	2	12	1	3	6	5	3	1	6		117
2013	3	12	32	7	4		14		6	6	2	2		6		94
Total	34	113	681	85	35	26	325	7	65	99	68	27	23	78	7	1,673

Source: Allianz Global Corporate & Specialty (2014, p. 8)

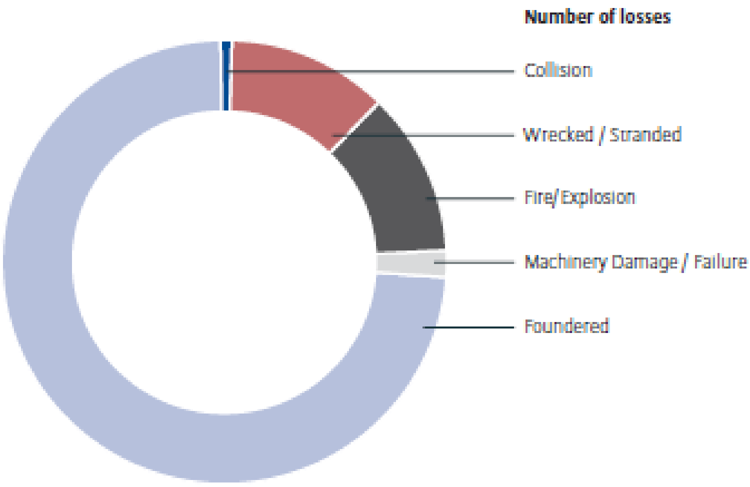
Figure 2: Total losses by vessel type from 1 Jan – 31 Dec 2013



Barge	3
Bulk	12
Cargo	32
Chemical / Product	7
Container	4
Fishery	14
Other	6
Passenger	6
Ro-ro	2
Supply / Offshore	2
Tug	6
Total	**94**

Source: Allianz Global Corporate & Specialty (2014, p. 9)

Figure 3: Causes of total losses from 1 Jan – 31 Dec 2013



Collision	1
Wrecked / Stranded	11
Fire / Explosion	11
Machinery Damage / Failure	2
Foundered	69
Total	**94**

Source: Allianz Global Corporate & Specialty (2014, p. 11)

Passenger ship accidents and accompanying devastating consequences, particularly for human life, capture the public imagination and provide impetus to the International Maritime Organisation (IMO) as a specialised agency of the United Nations (UN) to regulate maritime safety and related issues with the aim of preventing accidents from recurring in the future. The 1914 version of the Safety of Life At Sea Convention

(SOLAS) (IMO, 1974, as amended) was the first version of the convention and a direct response to the Titanic disaster in 1912 which had resulted in over 1500 fatalities. The prominent accident of the Herald of Free Enterprise in 1987 with a loss of 193 lives resulted in the introduction of the ISM code (IMO, 2002). While these come across as essentially reactive IMO actions to serious accidents (Tarelko, 2012), the organisation has done significant work in Passenger Ship Safety from 2000 onwards since the launch of the initiative. The following sub-section (1.1.1) discusses the work of the IMO in relation to passenger ship safety.

1.1.1 IMO and PASSENGER SHIP SAFETY

The initiative on passenger ship safety was launched in Dec 2000 in MSC 72, at the turn of the century to evaluate the adequacy of rules and regulations with respect to large passenger ships as they had been framed before the construction of such ships. The size of the vessels, along with increase in passenger carrying capacity necessitated this initiative especially with respect to crew training and emergency situations. Aspects of the ship, people on board and the environment were to be taken into consideration by the respective subcommittees. It was agreed that future ship design should cater to improved survivability as *"a ship is its best lifeboat"* (IMO, 2000a). Initially the initiative aimed to address safety of large passenger ships in particular. However, subsequently it was considered beneficial for the safety of all passenger ships and accordingly re-titled.

Five pillars have guided the work of the committee in this initiative which are *prevention, improved survivability, regulatory flexibility, operations in areas remote from SAR facilities and health safety and medical care*. A host of amendments were adopted in MSC 82 in 2006 that included amendments on *alternate design, safe areas, safety centres, fire prevention, detection and alarm systems and evacuation and abandonment* post breach of threshold (IMO, 2006, also see IMO, 2010b).

Previously regulations stated that passenger safety drills should take place within 24 hours of departure. However, more recently MSC 91 in 2012 agreed to make passenger safety drills *prior to, or immediately upon departure, mandatory* (IMO, 2012). The same has been adopted into SOLAS regulation III/19 (IMO, 2013b, IMO, 1974, as amended) and are due to enter into force on 1 January 2015. In addition, MSC 92 revised the *recommended interim measures for passenger ship companies to enhance the safety of passenger ships*. Among others, the recommendations include suggestions on *lifejackets* (placement and availability), *emergency instructions to passengers, musters, securing heavy objects* etc. (IMO, 2013c, also see IMO, 1997c).

Despite safety initiatives, passenger ship accidents have continued to take place over the years. In the aftermath of an accident, the investigation process commences, and attempts to examine the accident in-depth and study its varied aspects, including the causes. Learning from accidents is invaluable and the role of the IMO in casualty investigation follows in sub-section 1.1.2.

1.1.2 IMO and CASUALTY INVESTIGATION

The *Code for the Investigation of Marine Casualties and Incidents* was adopted in 1997 noting that *timely and accurate reports identifying the circumstances and causes of casualties and incidents* contribute to enhancing the safety of passengers, crew and the environment. The code recognises the need for a standard approach to incident investigation (Resolution A.849(20), IMO, 1997a). However, no methodology is provided in the code, but the appendix of resolution A.849 (20) enumerates the guidelines to assist investigators in the implementation of the code.

Noteworthy is that in 1997, IMO adopted the Human Element vision (Resolution A.850(20) IMO, 1997b). This is reflected in the Amendments to the Code for the Investigation of Marine Casualties and Incidents in 1999 (Resolution A.884(21) IMO, 2000b). The amendments provide *Guidelines for the Investigation of Human Factors* in marine accidents. Herein, the IMO has made reference to accident causation models

– the Hybrid model (Liveware, Hardware, Software, Environment: SHEL and Swiss Cheese) and Generic Error Modelling System (GEMS) of Reason (1990). The SHEL model is borrowed from the aviation industry (Hawkins, 1987). Accident investigation models are discussed in depth in the literature review chapter (number 2). More recently, resolution A.1075(28) (IMO, 2014a) revokes both resolutions A.849(20) and A.884(21) mentioned above.

The *Code of the International Standards and Recommended Practices for a Safety Investigation into a Marine Casualty or Marine Incident* was adopted in MSC 84, 2008 vide Resolution MSC.255(84). The code was made mandatory with inclusion into the SOLAS convention (chapter XI-1/6) vide Resolution MSC.257(84) and came into effect in 2010. The main objectives of the code are to provide a *common approac*h for the conduct of investigations to promote learning and prevent such incidents from recurring in the future (MSC-MEPC.3/Circ.2, IMO, 2008). *Revised Harmonised Reporting Procedures* for *reports required under the SOLAS I/21 and XI-1/6 and MARPOL* (Marine Pollution, (IMO, 1973/1978) *articles 8 and 12* are given in MSC-MEPC.3/Circ.4 (IMO, 2013a).

The IMO sub-committee on Flag State Implementation in its 19th session in Dec 2010 included the *study on human and organisational factors by WMU*, under the category of *casualty statistics and investigations* (IMO, 2010a). The WMU study was based on a PhD study by Ghirxi (2010), (also see Schröder-Hinrichs et al., 2010). The committee noted WMU’s findings that the errors committed by operators at the sharp end were over represented and organisational and supervisory factors were scarcely identified in the investigation reports. This led to the conlusions that the investigators either are, not completely aware of the casualty investigation guidelines or have difficulty in applying them. Some accident investigation reports were found to have been prematurely terminated which did not allow for supervisory and organisational factors to be identified. Guidance on the importance of organisational factors and their identification were absent which could have contributed to the findngs of the study which were skewed towards operators at the sharp end. Lack of harmonisation in the reports across flag states was also identified as reports were of varying levels of detail. This dissertation focuses on exploring the accident processes and not solely on the inclusion of human factors, however, this study will reveal findings on identification of human factors in passenger ship accidents as this study utilises the HFACS taxonomy, similar to Ghirxi (2010) and Schröder-Hinrichs et al. (2010). A study by Korolija and Lundberg (2010) has revealed the differing and emergent meanings of human factors for professional investigators in transport sector in Sweden, including maritime. This points to the lack of harmonisation in the understanding of the concept of human factors.

The background of the dissertation has been presented in section 1.1 and the aim, purpose and motivation for the dissertation is presented in the folowing section (1.2).

1.2 AIM, PURPOSE AND MOTIVATION FOR THE DISSERTATION

The motivation for this dissertation stems from the tragic passenger ship accidents that continue to take place even in the 21st-century. In line with the aim of Schröder (2004), this dissertation aims to evaluate accidents to understand and identify why certain unfolding processes during an accident situation lead to a safe system state while others lead to a mitigated loss and some tragically result in a total loss involving fatalities. The purpose of the dissertation is twofold, on the one hand, the project studies accident investigation reports to analyse the processes in-depth while on the other, the project is an evaluation of the SEMOMAP model itself. The research questions identified for the dissertation are provided in the following subsection.

1.2.1 RESEARCH QUESTIONS

In continuation of Schröder (2004), the research aims to study the complex unfolding of the accident process and will increase the knowledge of accident processes for specific maritime accident categories (fire, flooding and grounding) and the barriers, if any, that shaped the path and influenced the accident outcome from a near miss to a mitigated loss to a total loss. The research questions addressed in the dissertation are provided below.

- Is the maritime industry specific SEMOMAP suitable to explore maritime accidents?
- What is it about the unique unfolding of the accident process on board and the shipboard behaviours and barriers, if any, that can lead to different accident outcomes for different accidents.
- What are the common processes in emergency situations on-board in case of fire, grounding and foundering?
- How much time is available to recover from an emergency situation during the different phases of the accident?
- How realistic is the time limit of 30 minutes required for abandoning ship, post breach of threshold.

1.3 STRUCTURE OF THE DISSERTATION

This dissertation is divided into six chapters. The first chapter of the study introduced the background, aims, objectives and the motivation for the dissertation. The chapter presented the research problem against the backdrop of IMO's work on passenger ship safety as well as casualty investigation. The chapter also presented the research questions of the dissertation and provided an overview of the structure of the study.

Chapter 2 is the literature review chapter which reviews prevalent accident causation models, investigation methods and related taxonomies for coding data. This chapter also makes a comment about the state-of-the-art of maritime accident investigation methods in particular. This chapter provides a background to the SEMOMAP model and justifies its need in the accident investigation domain.

Chapter 3 presents the methodology adopted in the dissertation. It presents the SEMOMAP model in great detail. The chapter also presents the two complementary taxonomies that support the SEMOMAP model and lend a comprehensive focus to the model, while at the same time integrating the human factors in accident investigation.

Chapter 4 is an empirical findings chapter. The chapter clarifies the model and the taxonomy with the help of a case study example that takes the reader step-by-step through the application of the SEMOMAP model. The chapter presents the findings from the analysis of fifteen passenger ship accident investigation reports. Reports are examined and analysed with the application of the model; data is coded step-by-step using the taxonomies and the analysis is iterated as required by the accident processes depicted in the report. The findings for the different categories of maritime accidents are collated and presented in chapter 4.

Chapter 5 reflects on the dissertation results and SEMOMAP model.

Chapter 6, the final chapter concludes the dissertation, presents the impact of the findings for IMO, academia, industry and seafarers. The chapter provides the conclusions of the dissertation and makes appropriate recommendations as required.

2. ACCIDENT CAUSATION MODELS – A LITERATURE REVIEW[1]

This chapter presents a state-of-the-art of accident causation models (sequential, epidemiological, socio-technical and systemic) and analysis methods. This chapter also refers to the pertinent taxonomies that support accident investigation. This chapter identifies the gaps in the literature and justifies the need for SEMOMAP in maritime accident investigation domain.

Shipping is regarded as a high risk industry similar to aviation, nuclear, chemical and the like. The high-risk nature of the industry and the consequential huge losses make it imperative that accident investigation is robust to serve its purpose. The need for accident investigation as a learning opportunity is widely recognised and lessons can be drawn to prevent recurrences in the future. Accident causation models, investigation methods and taxonomies are the tools at the disposal of investigators to commence their analysis in the aftermath of an accident. Accident investigation is also a moral responsibility of the administrations towards citizens.

15 years prior to the Costa Concordia accident Rasmussen (1997, p.183), in the context of risk management has asked whether, *'we actually have adequate models of accident causation in the present dynamic society?'* He argues for a, *'model of behaviour shaping mechanisms in terms of work system constraints, boundaries of acceptable performance and subjective criteria guiding adaptation to change'* (1997, p.183). The adequacy and suitability of accident investigation models continues to be open for academic deliberation.

[1] The student has presented a version of the state of the art of accident investigation models in MSEA 252 course assignment on Risk Management.

Accident causation models for investigating the causes of industrial accidents began with Heinrich (1931). Accident investigation models, supportive taxonomies, safety, risk and reliability analyses have evolved over the major part of the century. Today several models and analysis methods are currently in use (Hollnagel, 1998, Kirwan, 1994, Reason, 1990, Reason, 1997a, Kristiansen, 1995, Hollnagel, 2004, Reason, 2008, Qureshi, 2007). The IMO, in its work promotes the investigation of casualties and incidents (IMO, 1997a, IMO, 2000b, IMO, 2013a, IMO, 2014a) to promote learning and stop accidents from recurring. Learning from accidents, contributes to the 'collective memory' that has been identified as 'missing' by Schröder-Hinrichs (2013). Organizations in the Maritime domain need to learn from risk (Manuel, 2012) in order to mitigate it. The following section (2.1) reviews the prominent sequential, epidemiological and systemic models of accident causation that shape subsequent investigations.

2.1 SEQUENTIAL, EPIDEMIOLOGICAL AND SYSTEMIC MODELS

This section discusses the three types of accident causation models characterized by Hollnagel (2004) as sequential, epidemiological and systemic. The section provides an overview of the models and their suitability to the different kinds of accidents under investigation.

Models of accident causation, inform the choice of the related methods suitable for accident investigation and they should complement each other (Katsakiori et al., 2009, Underwood and Waterson, 2013). In a Maritime context, the investigating body requires a suitable model for the focus of its investigation. A taxonomy suitable to the model is chosen/adapted/developed to inform the data gathering methods for analysis as done by Schröder-Hinrichs, Baldauf & Ghirxi (2011) and Schröder-Hinrichs et al. (2013). Accident investigation methods are different from accident causation models. The methods are the tools that help in data gathering in line with the philosophy of the models. A state of the art of accident investigation methods has been carried out by several authors (Hollnagel and Speziali, 2008, Sklet, 2004, Katsakiori et al., 2009).

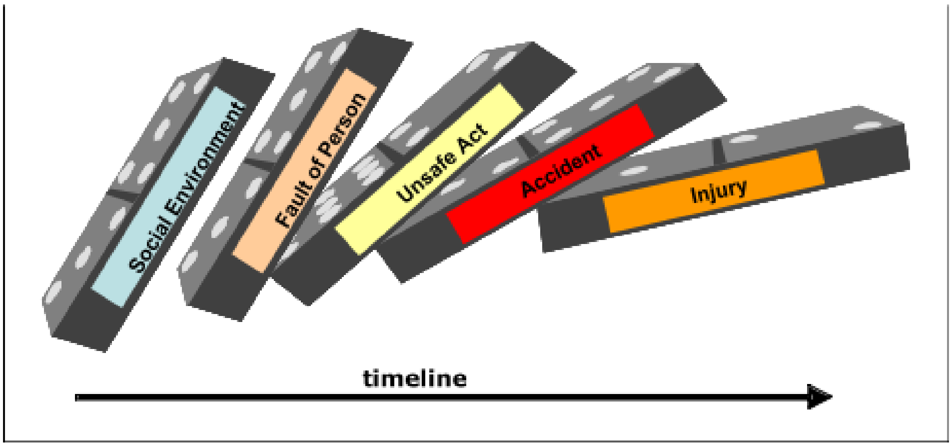
Accident causation models have been divided into three main groups, 'general models of the accident process', 'models of human error and unsafe behaviour' and 'models of human injury mechanics' (Lehto and Salvendy, 1991). However, this dissertation, utilizes the characterization by Hollnagel (2004) that addresses accident causation as a whole and does not differentiate between the models on the basis of human injury, human error, behaviour and process.

2.1.1 SEQUENTIAL MODELS OF ACCIDENT CAUSATION

Sequential accident causation models are the simplest models that describe the 'one after the other' linear order of the sequence of events. The sequential model is suitable when there are specific causes of the accident and well-defined links between the events. The sequential models recognize that the accident can be prevented by removing any one of the factors in the sequence (Hollnagel, 2004). Two prominent examples of the sequential models are the Domino theory of Heinrich (1931, Heinrich, 1980) and fault trees.

Figure 4: Heinrich's Domino Model of Accident Causation

Source: Qureshi (2008, p.11)

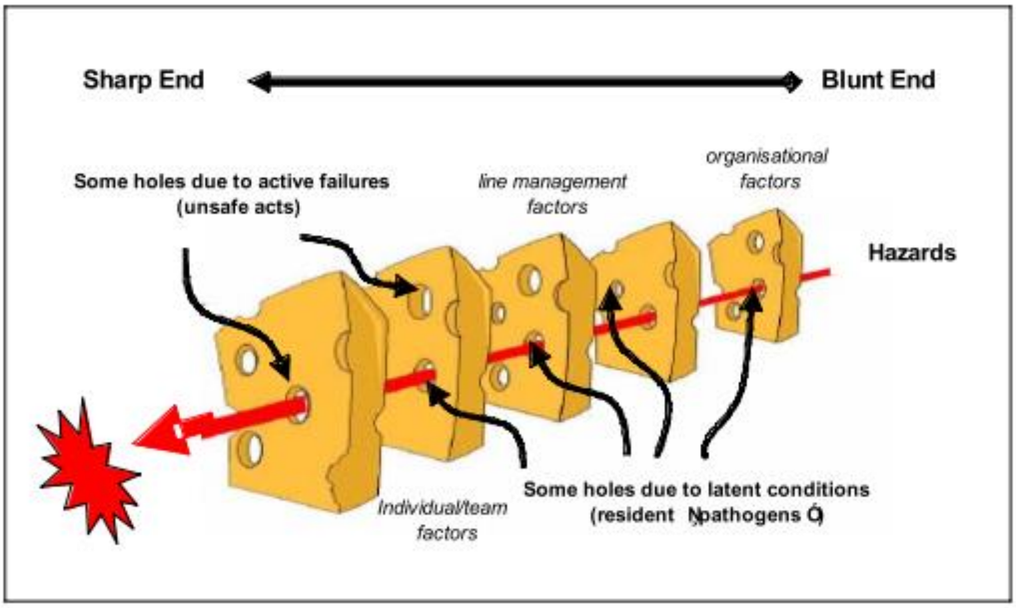


2.1.2 EPIDEMIOLOGICAL MODELS OF ACCIDENT CAUSATION

The term 'epidemiological' comes from the bio-medical domain and describes accident causation like the, 'spreading of a disease' (Hollnagel, 2004, p.54). Epidemiological models acknowledge that accidents have several contributory factors and take into account the latent conditions (pathogens), barriers, environmental conditions together with contributory causes of the accident. A prominent example of the epidemiological model is Reason's Swiss cheese model (1997b). It is complex linear in outlook and when the holes align, barriers are breached and accidents occur.

Figure 5: Swiss Cheese Model

Source: Reason (1997)



The Swiss cheese model takes into account the attributing *'blunt end factors far removed in space and time'* and the *'sharp end factors at work here and now'* (Hollnagel, 2004, p.63). The decision-makers, line management, preconditions for unsafe acts, defences and/or barriers, unsafe acts taken together provide the anatomy of the accident. Accidents are considered to be preventable by strengthening defences/barriers.

2.1.3 SYSTEMIC MODELS OF ACCIDENT CAUSATION

Systemic models address the system as a whole. Accident investigation models have evolved from identifying single causes to multiple causes of accidents to unforeseen complex emergent outcomes (Perrow, 1984). Systems need to be understood in their entirety to maintain the health of the system and prevent accidents. An understanding of the complex interactions and combinations is required with respect to the mutually interacting variables. Accident investigation models have evolved from a *'person approach'* holding an individual responsible to a *'system approach'* where the focus is not on *'who blundered, but how and by the defences failed'* (Reason, 2000). The nature and perception of risk has evolved over time. Risk needs to be understood to be mitigated and understanding risk is difficult in increasingly complex socio-technical systems (Hollnagel, 2008).

In 'Normal Accidents', Perrow (1984) discusses interactions and coupling in a system. A nuclear power plant is the most complex intractable system with a very tight degree of coupling. Hollnagel (2008) discusses the suitability of accident causation models based on the degree of coupling and tractability/manageability. He argues that System – Theoretical Model of Accidents (STAMP) (Leveson, 2004) and Functional Resonance Accident Model (FRAM) (Hollnagel, 2004) are suitable for tightly coupled intractable systems, while Cognitive Reliability and Error Assessment Method (CREAM) (Hollnagel, 1998) is more suitable for retractable, tightly coupled systems. Another example of a system model is ACCIMAP (Rasmussen, 1997). Figure 6 on page 15 depicts the Risk Management Framework of Rasmussen (1997) and Figure 7, also on page 15 depicts the Interaction/coupling chart of Perrow (1984).

Figure 6: Risk Management Framework

Source: Rasmussen (1997)

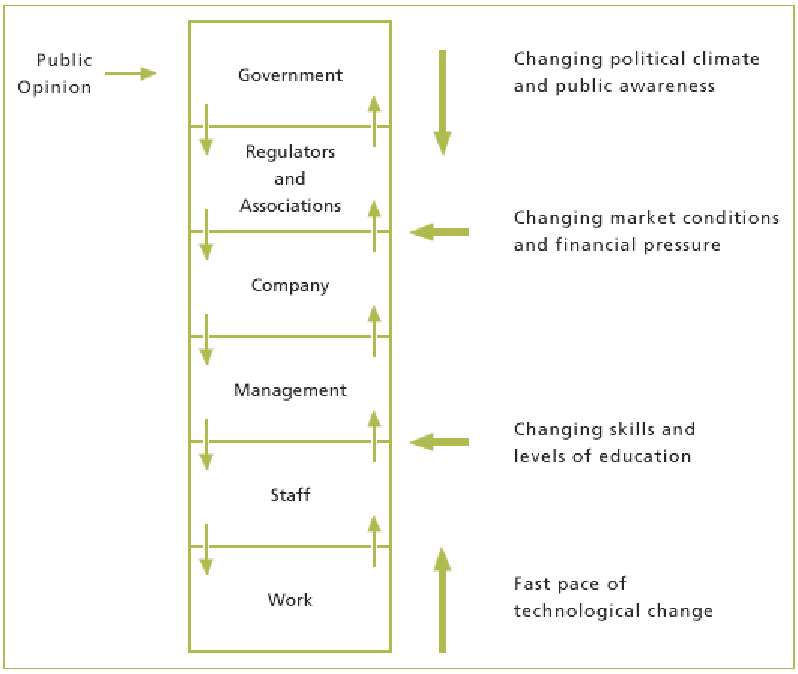
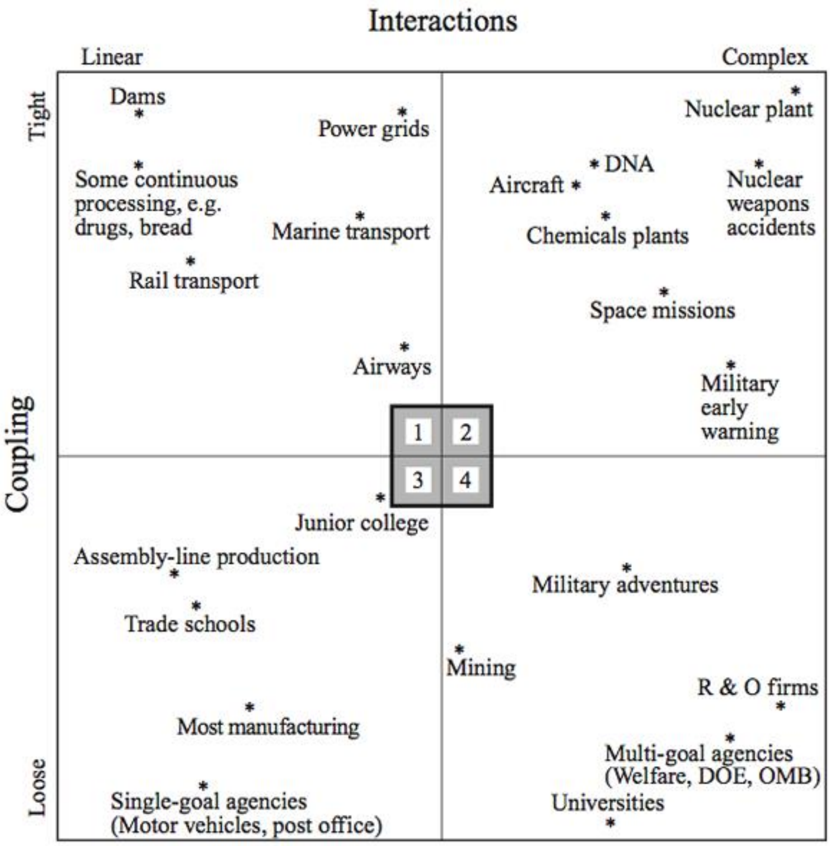


Figure 7: Interaction / coupling chart

Source: Perrow (1984, p.327)



2.2 EVALUATION OF SEQUENTIAL, EPIDEMIOLOGICAL AND SYSTEMIC MODELS: ADVANTAGES AND DISADVANTAGES

The simple linear cause-and-effect models fail to depict the complexity of accident causation and therefore are unsuitable for the purpose of analysing complex accidents. The Swiss cheese model has been considered suitable to analyze accidents in domains which are tightly coupled and tractable/manageable as in the case of Maritime transport (Hollnagel, 2008), which features in the first quadrant of Perrow (1984, p.327) and is considered less complex than a nuclear power plant. The Swiss cheese model can provide a comprehensive picture of the accident under several categories of unsafe acts, conditions, supervision and organizational. Therefore, the epidemiological model is suitable in analysing complex accidents (Le-Coze, 2013). The aim is not to state which model is better, but to identify the model which is fit for purpose/suitable with respect to the accident investigation. The sequential model is simplistic, it cannot address complexity, multiple actors or multiple factors. The sequential model is suitable for loosely coupled, tractable simple systems. The sequential model provides an identification of the active causes of the accident and does not address the underlying latent contributory factors. Therefore the sequential model does not do justice to the accident investigation of complex accidents. Neither does the sequential model identify all the information for the investigator(s) and nor does it promote learning from the accident to prepare the organization if a similar accident were to recur in the future

> *"if Maritime safety is to be sustainably improved, a systemic focus must be adopted in future accident investigations"* (Schroder-Hinrichs and Hollnagel, 2012, p.1)

Accident models have evolved into systemic that follow a holistic system approach. This approach considers the fallibility human beings and the focus has shifted from identifying individual human errors to barriers, safe guards and defences to understand why they failed (Reason, 2000). A systemic model addresses the complexity in critical and complex socio – technical systems made up of regularly interacting interrelated interdependent components.

2.4 MARITIME SPECIFIC MODELS

Schröder (2004), provides a state of the art regarding the 'models and approaches used for maritime casualty analysis'. He finds that some models are generic, while the others – CASMET, TRIPOD (Reason, 1997a), Loss Causation Model (DNV) focus on accidents from the organisational perspective. Schröder (2004) expands on the SEMOMAP model developed by him and the related taxonomy, particularly for the maritime industry (also see Schroder and Hahne, 2003). The SEMOMAP explores the accident process and focuses on the question, *'why some accidents develop into total losses and while others can be successfully mitigated at a certain level of the accident processes'*. Schröder (2004) presents promising preliminary results for SEMOMAP. The identified gap in the academic literature is that the maritime industry has hitherto utilised generic models for analysing accidents in the maritime domain and the maritime industry specific models in existence presently, have an overtly organisational focus. In the dissertation, the student aims to work towards the validation of the SEMOMAP model as it offers a sharp maritime industry specific focus while addressing Rasmussen's (1997) question regarding the existence of adequate models in dynamic society. Maritime accident and investigation is applied in real-world research. The model is unique as it exclusively focuses on the Maritime accident investigation domain and is not generic in its outlook. After reviewing the available models, it can be argued that the maritime industry requires improved accident investigation models that can better aid accident investigators in analysing complex accidents. Despite being sequential, SEMOMAP with it two complementary taxonomies provides a suitable answer in this respect as it is capable of capturing complexity with a comprehensive focus. SEMOMAP focuses on the accident process and acknowledges heroic contributions, if any, that helped a system to recover, which is overlooked by most models as they are reactive in focus. SEMOMAP is a sequential model, however, it is complex linear in outlook due to its comprehensiveness.

2.6 TAXONOMY FOR CODING DATA

An accident investigation requires an accident causation model in line with the focus of inquiry, which encompasses the philosophy of the accident. Furthermore, a taxonomy related to the model is required for data analysis (Schröder, 2003). Reason (1997b) had not provided a taxonomy for the accompanying Swiss cheese model. The HFACS taxonomy specifically developed by Wiegmann and Shappell (2003) in aviation is in line with the philosophy of the Swiss cheese model. Apart from aviation, the HFACS has been adapted for use in diverse areas like railroad, mining etc. HFACS has been adapted for exploring machinery space fires in Schröder-Hinrichs et al. (2010) and for evaluating the inclusion of maritime human factors in IMO policy (Schröder-Hinrichs et al., 2013). A detailed overview of the adapted taxonomy for this dissertation is given in chapter 3 on Methodology. This dissertation also utilizes a second taxonomy that is inspired by TRACEr (Shorrock and Kirwan, 2002) as the dissertation looks at the accident processes which involve human-machine interaction and therefor the HFACS alone is not considered sufficient for this study. The TRACEr inspired taxonomy helps to evaluate the different accident phases while taking into account the human-machine interaction. The adapted HFACS taxonomy and the TRACEr inspired taxonomies are discussed in detail in chapter 3 of the dissertation and are provided in the accompanying appendices.

2.7 CONCLUSION

As a responsible Maritime Administration, learning from accidents is a crucial aspect to prevent future recurrences. Accidents such as the Costa Concordia go beyond the organisation and impact the national, supranational and the international domain (Schröder-Hinrichs et al., 2012). 'What-You-Look-For-Is-What-You-Find' and 'What-You-Find-Is-What-You-Fix' are two principles discussed by Hollnagel (2008 cited in Schröder-Hinrichs, Hollnagel & Baldauf, 2012). These two principles show the limited outcome of traditional accident investigations. Identifying and holding individuals responsible in complex accidents such as the Costa Concordia, defeats the very purpose of accident investigations and does not benefit society in the long run. The limited viewpoint does not help to learn from the accident and the industry might witness another similar accident in the future, as in the case of the Costa Concordia which occurred a century after the Titanic, and the disastrous Sewol ferry accident which took place in 2014 before the final salvage operation for the Costa Concordia could be completed.

The efficiency – thoroughness trade – off (ETTO) (Hollnagel, 2009) principle is faced by the workers in their day-to-day lives and it is the duty of the investigating body to ensure the practices and the conditions leading to the safety culture on-board are identified together with their complexity. Reason (2000) argues that the culture of High Reliability Organizations (HRO) helps to make the system robust and resilient. High reliability organizations have an enhanced safety culture which is supported by an effective reporting culture and a just culture (Reason, 1998). The recurrence of accidents highlights that organizations don't learn from accidents. An enhanced safety culture is the need of the Maritime domain which will enhance resilience and contribute to *heroic recoveries at the edge of error* (Reason, 2008).

Research on accident causes (for MaRCAT, see Cafferty and Baker, 2006, Caridis, 1999) does not capture the in situ unfolding of the accident process with a focus on human machine interface (HMI) while at the same time identifying the HFACS factors that impact on-board human operators and technical subjects as SEMOMAP.

This literature review chapter has discussed the state of the art of accident causation models and evaluated their suitability for investigating the different domains. The chapter also discussed maritime specific models and identified that SEMOMAP is the only model with a maritime focus that enables the study of the unfolding accident process. The chapter also discussed the need for an appropriate taxonomy to support data analysis in line with the vision of the model. This chapter has justified the need for SEMOMAP in maritime investigations. Chapter 3 on research methods utilised for the dissertation, follows after the review of literature.

3 RESEARCH METHODOLOGY

This chapter pertains to the research methodology adopted in the study and particularly to the application of the SEMOMAP accident investigation model with the help of a case study example.

3.1 RESEARCH METHODOLOGY AND SAMPLE SELECTION

The research methodology adopted in the study involves the analyses of fifteen accident investigation reports along the philosophy of the SEMOMAP model. Each individual report is studied in detail and coded according to the two taxonomies of HFACs and a taxonomy inspired by TRACEr. The HFACs taxonomy was initially developed in aviation by Wiegmann and Shappell (2003). HFACS primarily deals with underlying causal human factors of an accident, while TRACEr, also from aviation (Shorrock and Kirwan, 2002) takes into account the human machine interface and is useful for both the *retrospective* and the *predictive* analysis of issues in accidents. HFACs has been adapted for the maritime domain previously in the investigation of *machinery space fires and explosions* by Schröder-Hinrichs et al. (2010). This dissertation takes the application of SEMOMAP further to passenger ship accidents.

The sample selection of the accident investigation reports for the dissertation requires further enumeration. The fifteen reports selected for the study are of passenger ship accidents that have taken place from 1998 onwards. The benchmark year of 1998 has been selected as it was the year of the introduction of the ISM code and in this respect it would be safe to assume that the ships would have a functional SMS on board to comply with the regulations. In addition, the training requirements for personnel in crowd management and control for assisting passengers during emergency situations, including for evacuation (IMO, 1997c) as given in the STCW code, Chapter V, would also be reflected in the sample after the introduction date of January 1999. Table 12 on page 46 lists the sample of fifteen accident investigation reports of passenger ship accidents analysed in this dissertation.

3.2 SEMOMAP

SEMOMAP was developed during the PhD research study of Schröder (2004). SEMOMAP poses the question and seeks to answer *why some processes in an accident lead to a recovery of the safe system state while others lead to a mitigated or a total loss?* SEMOMAP is inspired by human recovery and error management. The philosophy behind SEMOMAP is that the outcome of an incident hinges on a number of critical processes. Catastrophic events can be averted if these processes are correctly accomplished at any point, before or after the commencement of the accident timeline. Depending upon when the incident is averted, the vessel can suffer various degrees of loss, or even, no loss at all.

SEMOMAP specifically focusses on the accident process, emergency management and within it, the human operator. SEMOMAP has evolved significantly from 2004 when it was conceptualised. The SEMOMAP model from 2004 is depicted in figure 8 and the current 2014 model is depicted in figure 9. SEMOMAP has evolved significantly as a model, is sharper in focus and comprehensively embraces the accident process. The accompanying taxonomy of SEMOMAP has also evolved significantly and will be discussed subsequently in the chapter.

Previously SEMOMAP sub-divided the accident processes into 6 stages/results; *dangerous situation, beginning accident, near miss, accident, mitigated loss and total loss* (see figure 8). The current model (figure 9) clearly differentiates between the 4 phases of the accident (contributory factors, beginning of the accident, accident and evacuation) and the 5 results/outcomes of the processes (recovery, mitigated/severe/ total loss with and without casualties).

Figure 8: SEMOMAP in 2004

Source: Schröder (2003 cited in 2004)

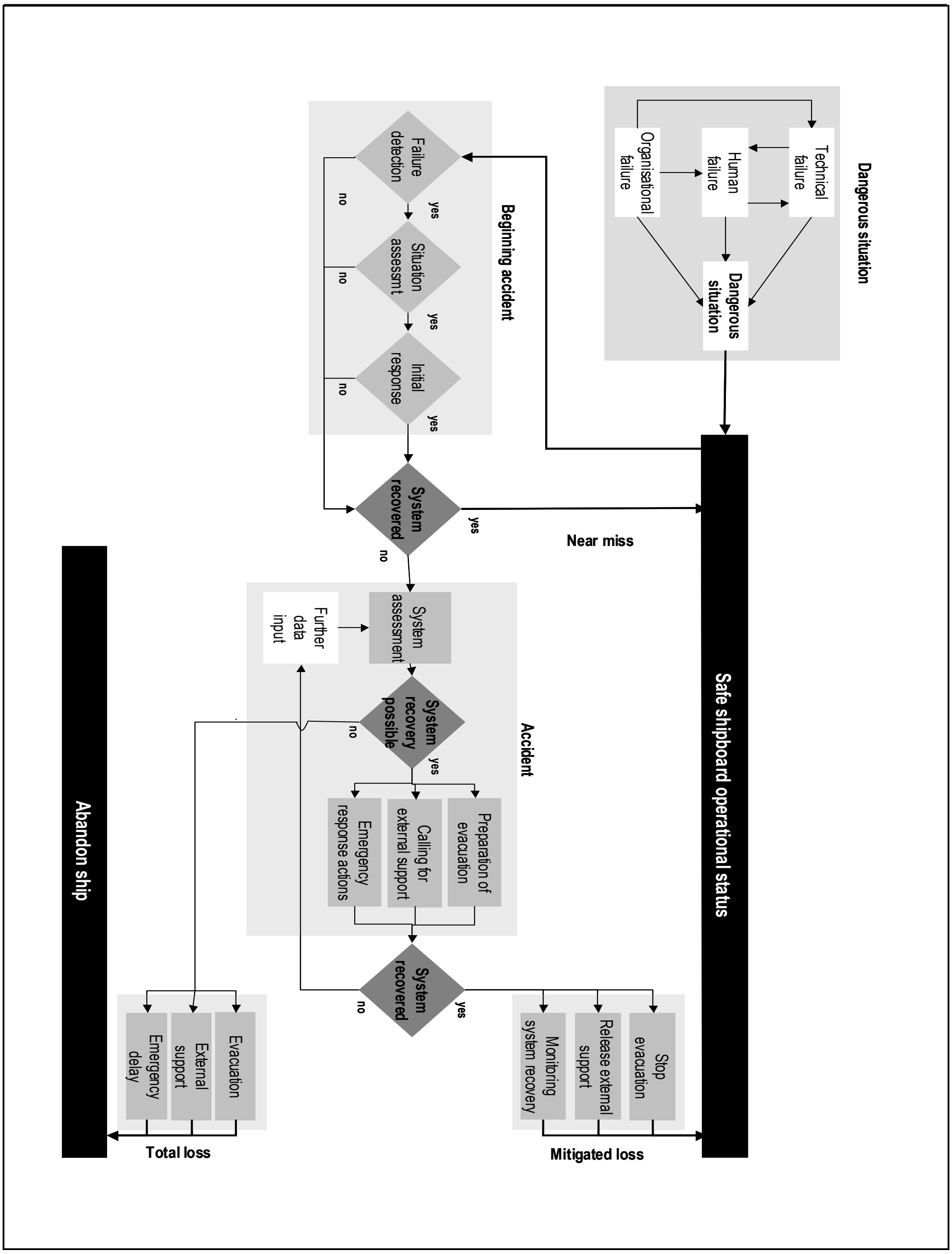
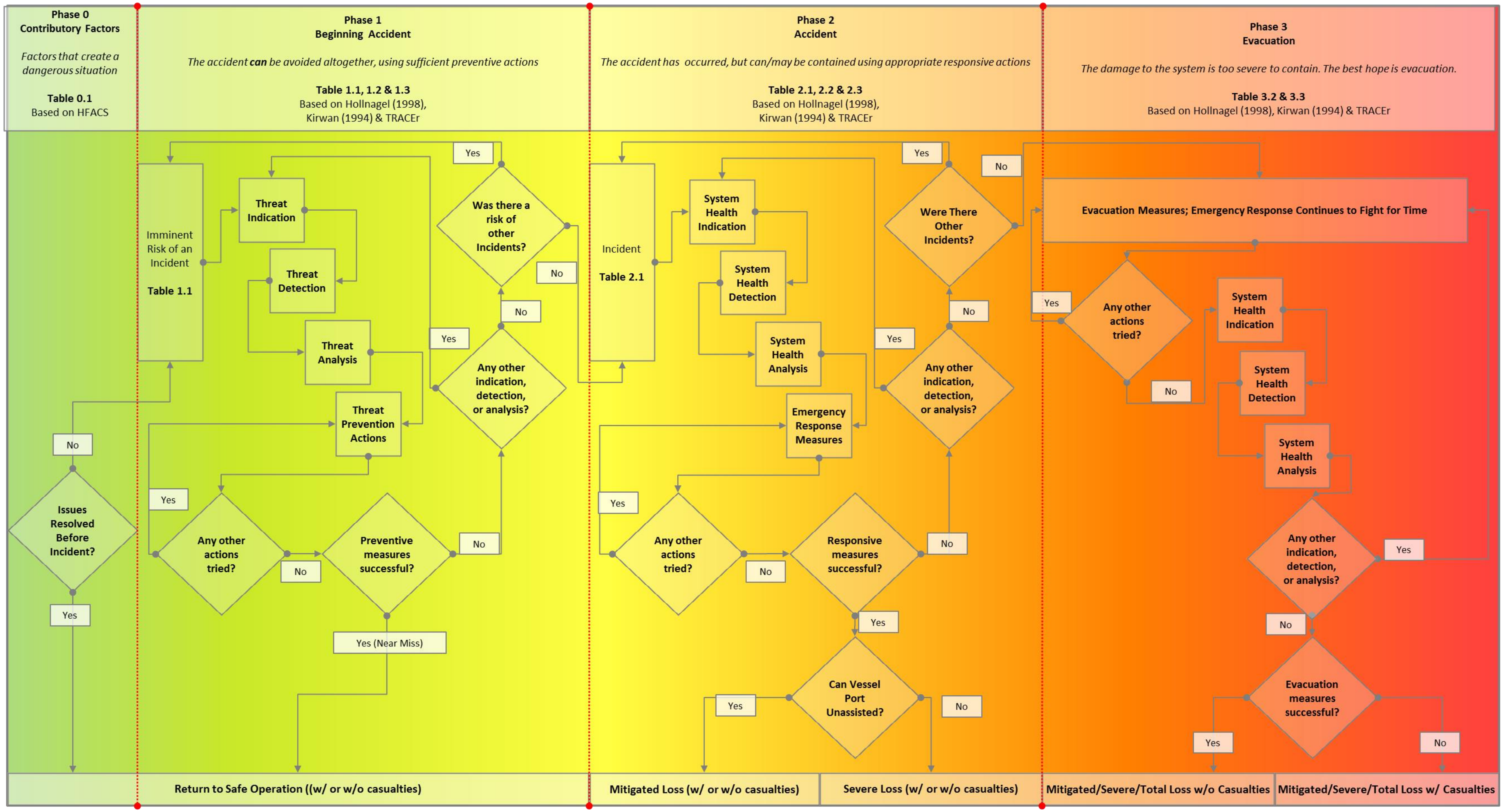


Figure 9: SEMOMAP in 2014; **Source:** Schröder-Hinrichs (2014)



The 4 phases of the current SEMOMAP Model (figure 9) are provided along the top. They are: *phase 0 - contributory factors* that led to a dangerous situation on board, phase 1 - *beginning of the accident*, phase 2 - *accident* itself and phase 3 - *evacuation*. The results/outcomes are given along the bottom. The five results/outcomes of the accident process in SEMOMAP are the *return to safe operation* after taking appropriate action to mitigate the threat; depending upon the time of threat detection, analysis and threat mitigation actions, the outcomes can range from a *mitigated loss* to a *severe loss*; the extreme outcome of an accident is *total loss* of the vessel, *with* and *without causalities*.

3.2.1 SEMOMAP 'PHASE 0' – CONTRIBUTORY FACTORS

The 2014 SEMOMAP model regards the first phase of the accident as phase 0, in which the contributory factors that led to the creation of a dangerous situation on-board are identified. At this juncture, the adapted HFACS taxonomy is used to help identify the latent conditions and contributory factors of the accident. This phase occurs prior to the incident. The evaluation of the issues suggests that if the issues have been resolved then the incident does not take place and the vessel is considered safe. However, if the evaluation reveals that the issues have not been resolved then the accident enters the second phase. The adapted HFACS taxonomy used in the study is discussed in detail in section 3.3.

3.2.2 SEMOMAP 'PHASE 1' – BEGINNING ACCIDENT

The second phase of the SEMOMAP is referred to as phase 1 which looks at the beginning of the accident. At this stage, the accident is considered to be preventable by performing suitable and adequate preventive actions that can help to recover from the incident. Phase 1 commences as there is an imminent risk of incident due to the unresolved issues from the preceding phase 0. To return to a safe system state, indicated threat of imminent risk needs to be detected, analysed and appropriate preventive actions need to be undertaken. If the actions are successful then the system returns to safe operations and if unsuccessful, then the model evaluates if any further measures were tried. If ‘Yes’, the loop iterates back and if, ‘No’, the model evaluates if there is a risk of other incidents. If ‘Yes’, the loop iterates back and if, ‘No’, the model enters the third phase of the accident. Incident categories can go together as in the case of collision and foundering in the Costa Concordia accident. SEMOMAP allows for studying accident processes as it enables the iteration to explore further threats to the ship system. SEMOMAP is a sequential model, but its iterative investigative capacity makes it complex linear in outlook. Phase 1, 2 and 3 of the accident utilise the taxonomy based on Hollnagel (1998), Kirwan (1994) and TRACEr.

3.2.3 SEMOMAP ‘PHASE 2’ – ACCIDENT

The third phase of the SEMOMAP is the accident phase, in which the incident has occurred. It is referred to as phase 2. At this stage, the accident could still be contained to limit losses. Once the incident has occurred at the beginning of phase 2, the system health indication needs to be detected, analysed and appropriate emergency response measures need to be taken. If the emergency response measures are successful, the model helps assess, if the vessel can sail unassisted to port - If ‘Yes’, it is a mitigated loss and if, ‘No’, it is a severe loss. If emergency response measures are unsuccessful, then the model evaluates if any further measures were tried. If ‘Yes’, the loop iterates back and if, ‘No’, the model evaluates if there is a risk of other incidents. If ‘Yes’, the loop iterates back and if, ‘No’, the model enters the final phase of the accident. SEMOMAP allows comprehensive iteration to evaluate the existence of other related threats in phase 1 and 2 of the accident process.

3.2.4 SEMOMAP ‘PHASE 3’ – EVACUATION

The final phase of the accident is phase 3 in which evacuation and related emergency response is the best option under the circumstances. At this stage casualties to human life can be limited to zero with appropriate evacuation processes and procedures. In this phase the evacuation measures are put in place and emergency response actions continue to fight for time. System health indication in the final accident phase needs to be detected and analysed. If other measures are tried, the loop iterates back and if no further measures are tried and evacuation measures are successful, there is a degree of loss without casualties. If evacuation measures are not successful, there is a degree of loss with casualties. The model is comprehensive and allows for analysing complex accidents. The following sub-section discusses the SEMOMAP taxonomy in detail.

3.3 SEMOMAP TAXONOMY

The SEMOMAP model utilises a very comprehensive taxonomy for data coding and analysis. The full taxonomy along with the accompanying codes is provided in the codebook in the appendix.

3.3.1 SEMOMAP TAXONOMY APPLICABLE TO ACCIDENT 'PHASE 0'

Table 0.1 of the taxonomy is applicable to phase 0 of the accident (see appendix). It is based on HFACS and suitable for identifying the factors that led to the dangerous situation on-board. The taxonomy allows for a four level coding for each of the four identified contributory aspects (*unsafe acts, pre-conditions for unsafe acts, supervision* and *organisational influence*). The operators (human subjects) and equipment (technical subjects) affected need to be identified and coded first. See table 2 for the 5 contributory aspects and first three levels of coding. The complete taxonomy table with the fourth level of detail is given in the appendix.

Table 1: Subjects affected by influencing factors (applicable to phase 0)

Source: Table 0.1 SEMOMAP Taxonomy Codebook (see appendix)

Human Subjects	Captain & Officers	Captain, 1^{st}/Chief; 2^{nd}; 3^{rd}; Other Officer,
	Navigators	Helmsman, Pilot
	Other crew	AB, Bosun, OS
	Engineers	1^{st}/Chief Engineer, 2^{nd}/Other Engineer
Technical Subjects	Bridge & Deck	Steering equipment, Navigation aids (AIS, ECDIS, GPS etc.), Communication equipment, Alarm panels & system
	Engine room	Main / auxiliary engine, engine control panel, fuel / ballast water pumps, generators, boilers
	Ship structure & design	Hull, separators

Table 2: SEMOMAP Taxonomy 'phase 0'; factors leading to the dangerous situation; adapted HFACS

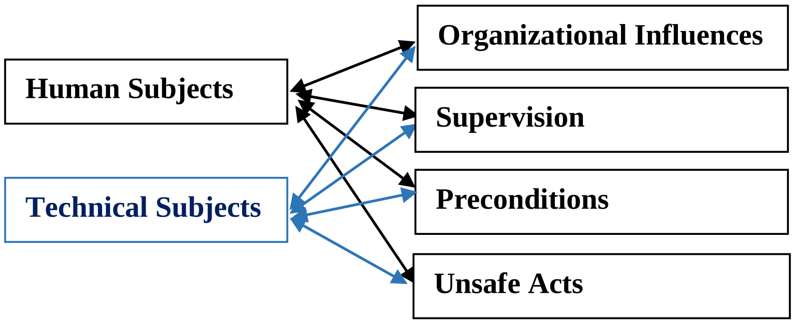
Source: Table 0.1 SEMOMAP Taxonomy Codebook (see appendix)

Organizational Influences I	Resource Management	Lack of human resources
		Poor technological resources
		Poor equipment / facility resources
	Organizational climate	Disorganized structure
		Inadequate policies
		Poor work culture
	Organizational process	Poorly designed operations
		Inappropriate procedures
		Lack of oversight
	Statutory factors	Poor international / national standards
		Inadequate flag state implementation
Supervision II	Inadequate supervision	Poor shipborne and shore supervision
	Planned inappropriate Operations	Poor shipborne operations
	Failed to correct known problems	Shipborne related shortcomings
	Supervisory Violations	Shipborne violations
Preconditions III	Environmental Factors	Poor physical environment
		Poor technical environment
	Crew Condition	Negative cognitive factors
		Poor physiological state
	Personnel Factors	Poor crew interaction
		Poor personal readiness
Unsafe Acts IV	Errors	Skill based errors
		Decision and judgment errors
		Perceptual Errors
	Violations	Routine
		Exceptional

A further, fourth level of detail of table 2 is provided in the taxonomy codebook in the appendix. Table 1 and 2 are part of the phase 0 taxonomy of SEMOMAP and enable the identification and coding of factors that led to the creation of a dangerous situation on-board in line with HFACS. A unique aspect in this instance is that SEMOMAP allows for the identification and coding of the factors against each of the human and technical subjects individually for an accident, thus leading to a more comprehensive evaluation. Figure 10 below depicts the relation between the phase 0 taxonomy depicted in table 1 and 2.

Figure 10: Relationship between Table 1 and 2 of taxonomy applicable to phase 0

Source: Student, based on taxonomy



3.3.2 SEMOMAP TAXONOMY APPLICABLE TO ACCIDENT 'PHASE 1'

It is noteworthy that the taxonomy utilised in accident phase 1, 2 and 3 are inspired by Hollnagel (1998), Kirwan (1994) and TRACEr. Phase 1 pertains to the beginning of the accident. Taxonomy tables 1.1, 1.2 and 1.3 are applicable to this phase (see codebook in appendix) The SEMOMAP taxonomies allow for the identification of barriers, recovery processes, human-machine interaction and threat mitigation actions undertaken during the unfolding accident situation. Table 3 (taxonomy table 1.1) essentially pertains to the risk faced by the system

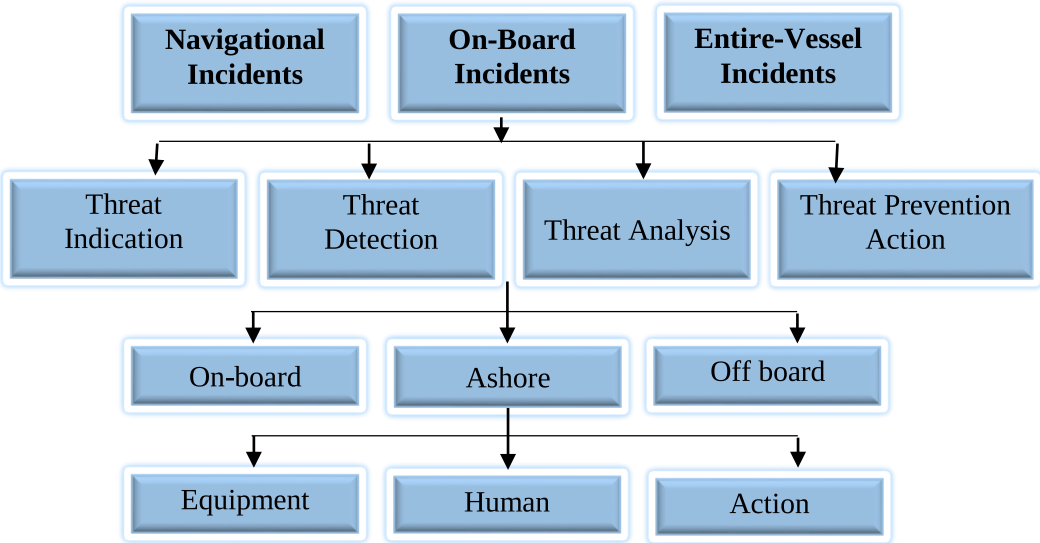
Table 3: 'Risk of' incident; taxonomy table 1.1 Applicable to 'phase 1'

Source: Table 1.1 SEMOMAP taxonomy codebook (appendix 2)

Navigational Incidents	Collision Grounding Contact
Onboard Incidents	Fire Explosion Structure Failure Engine Failure Loss of Control Equipment Damage
Entire Vessel Incidents	Capsize/Listing; Flooding/Foundering
Personnel Incidents	Occupational accident

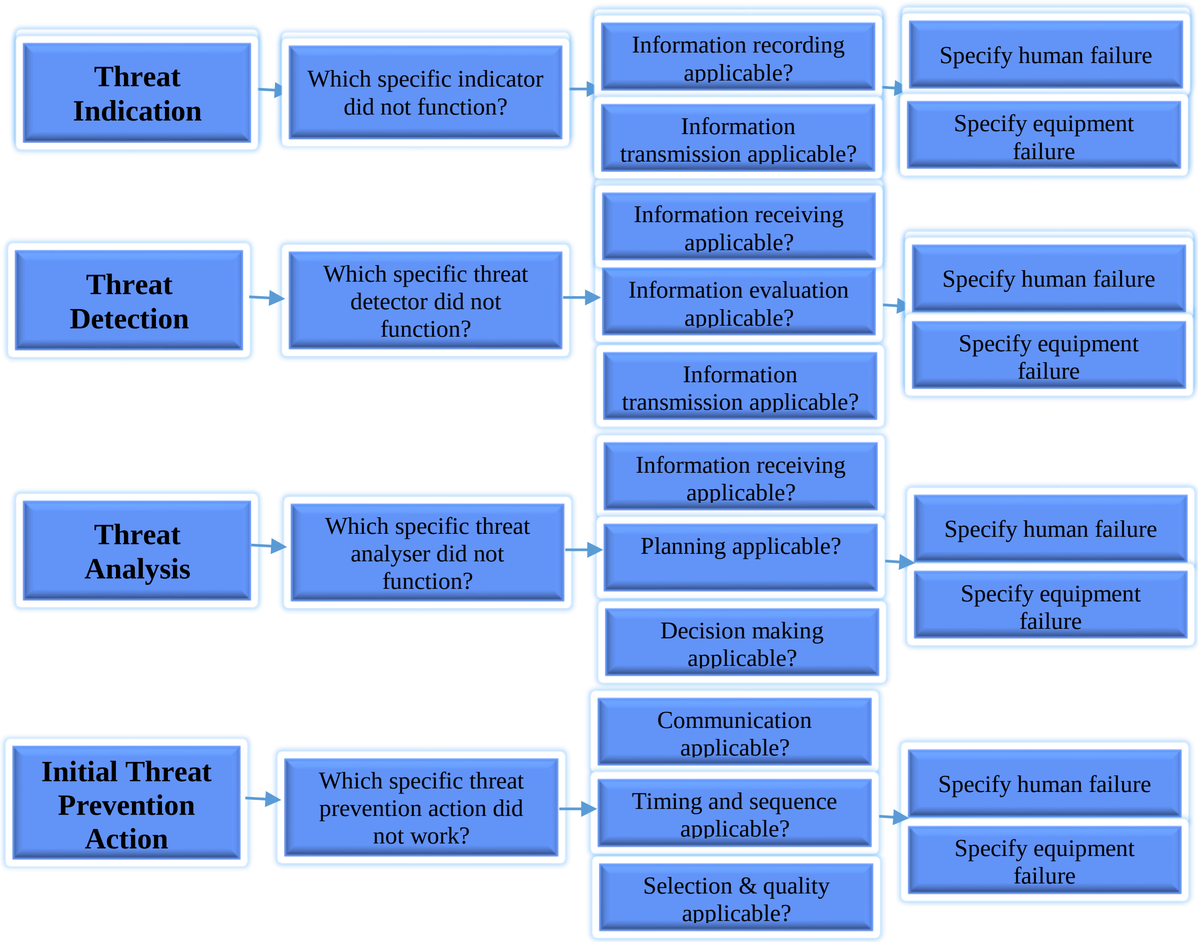
In the first instance, the threat faced by the system is ascertained. Thereafter taxonomy table 1.2 is applicable, which is the data table for phase 1 of the accident and is subdivided into three main categories – *navigational incidents, on-board incidents and entire vessel incidents.* Accordingly threat indication has to be detected, analysed and appropriate preventive action undertaken. Table 1.2 allows for five levels of coding (see appendix). Taxonomy table 1.2 is graphically depicted in figure 11 below. The taxonomy (1.2) includes the *equipment (objects), persons* and *actions* that were involved in the phase.

Figure 11: Diagrammatic representation of taxonomy table 1.2 applicable to 'phase 1'
Source: Student, based on taxonomy



Taxonomy table 1.3 (see appendix), allows in-depth coding of the human machine interaction and the accident processes that occurred in the *beginning accident* phase. The table allows for five levels of coding and addresses the aspects of *threat indication, threat detection, threat analysis* and *initial threat prevention action* undertaken in the beginning accident phase. *This phase covers how an accident could have been avoided altogether*. The taxonomy of this phase evaluates the functioning of specific threat *indicator*, *detector*, *analyser* and *action* with respect to human and/or equipment failure. The graphical representation of taxonomy 1.3 is given in figure 12.

Figure 12: Diagrammatic representation of taxonomy table 1.3 applicable to 'phase 1'
Source: Student, based on taxonomy

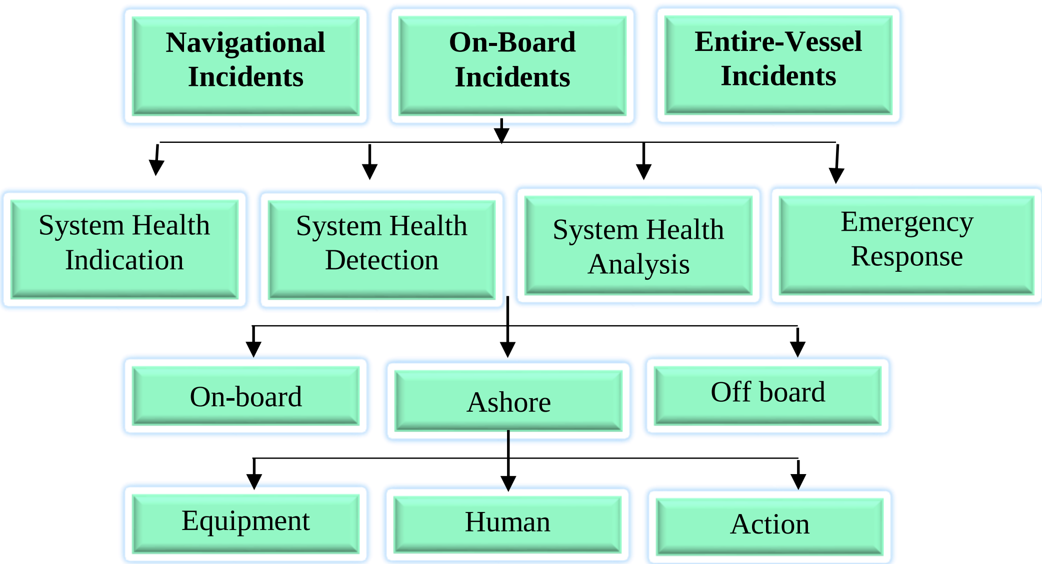


The coding of taxonomy table 1.3, goes deeper and comprises 5 levels. If in level 3, an aspect is applicable but not successful, then the failure is identified in level 4 and further elaborated in level 5.

3.3.3 SEMOMAP TAXONOMY APPLICABLE TO ACCIDENT 'PHASE 2'

Once the accident enters the second phase, taxonomy tables for the second phase (2.1, 2.2 and 2.3 see appendix) are applicable. In the beginning of phase 2, the accident in the system is identified and acknowledged utilising a similar taxonomy given in table 3 on page 28. In this phase, the accident has taken place and system health needs to be ascertained. First the system health needs to be indicated, detected, analysed and appropriate emergency response needs to be taken. The 2.2 taxonomy includes the *equipment (objects), persons* and *actions* that were involved in the phase.

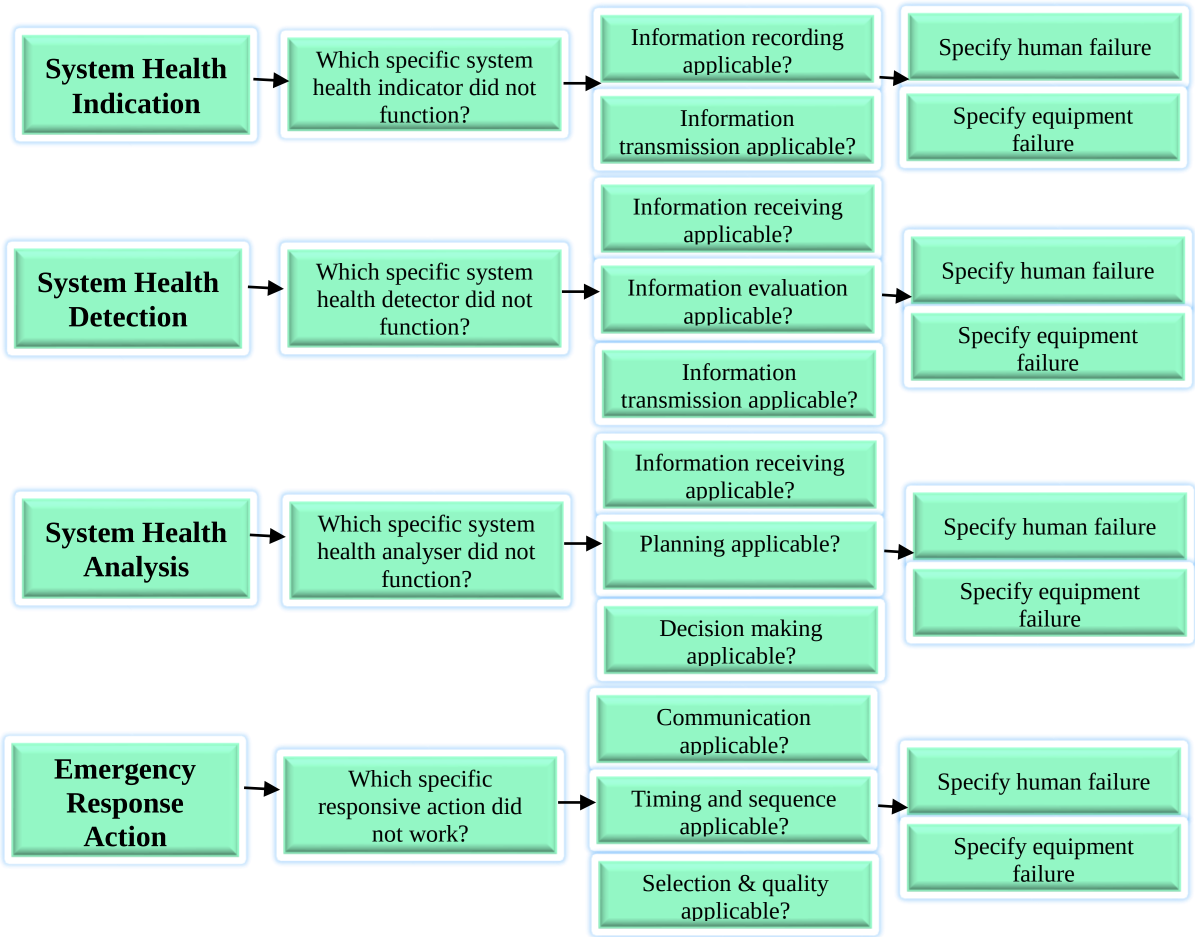
Figure 13: Diagrammatic representation of taxonomy table 2.2 applicable to 'phase 2'
Source: Student, based on taxonomy



Taxonomy table 2.3 pertains to *how an accident could have been contained in the face of danger*. Taxonomy table 2.3 is depicted graphically in figure 14. The taxonomy delves deep to specify the details of human and equipment failure which occurred due to applicable but unsuccessful outcomes. This taxonomy table answers why certain aspects were unsuccessful in the context of the accident.

Figure 14: Diagrammatic representation of taxonomy table 2.3 applicable to 'phase 2'

Source: Student, based on taxonomy



3.3.4 SEMOMAP TAXONOMY APPLICABLE TO ACCIDENT 'PHASE 3'

Once the accident enters phase 3, evacuation is necessary to limit loss of life and emergency and evacuation procedures get underway. Taxonomy tables 3.2 and 3.3 (see appendix) are applicable in phase 3 of the accident. Taxonomy table 3.2 is depicted diagrammatically in figure 15 and contains the objects, persons and actions involved in the final phase. Taxonomy table 3.3 is given in figure 16 and covers how an accident could have been contained to limit losses in the face of danger. In the evacuation phase, the crucial aspect is to protect human lives and limit fatalities. In the final phase of the accident emergency response and evacuation takes precedence over system health indication, detection and analysis.

Figure 15: Diagrammatic representation of taxonomy table 3.2 applicable to 'phase 3'

Source: Student, based on taxonomy

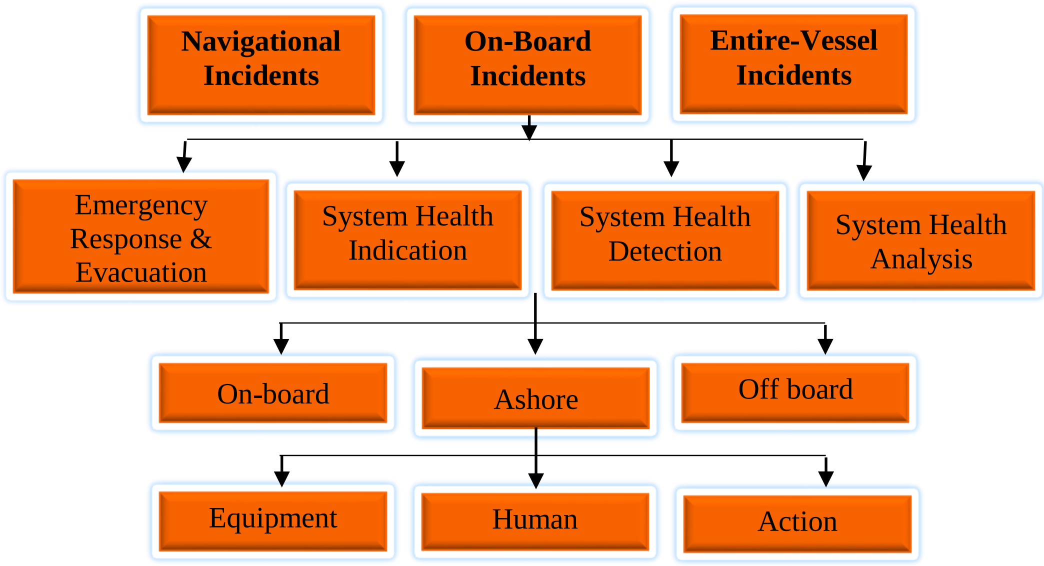
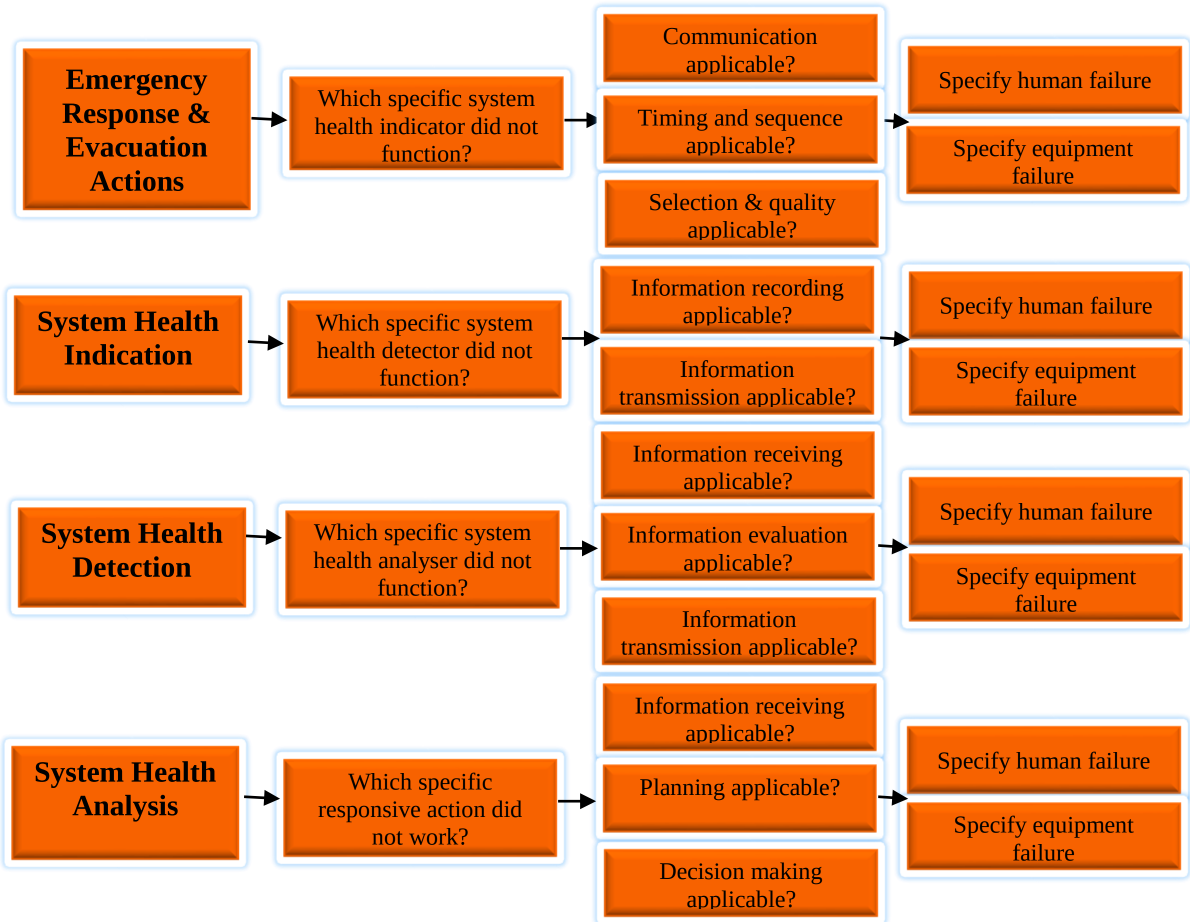


Figure 16: Diagrammatic representation of taxonomy table 3.3 applicable to 'phase 3'

Source: Student, based on taxonomy



In the third and final phase of the accident in SEMOMAP, emergency and evacuation actions and procedures are well underway and the personnel fight for time.

SEMOMAP reflects the Simple Model of Cognition given by Hollnagel (1998) (see figure 17) in which the data observed/identified impacts the interpretation, and the planning/choice of action/execution, though not necessarily in order. SEMOMAP also draws upon Wickens' Model of Human Information processing (see figure 18).

Figure 17: SMoC – Simple Model of Cognition

Source: Hollnagel (1998)

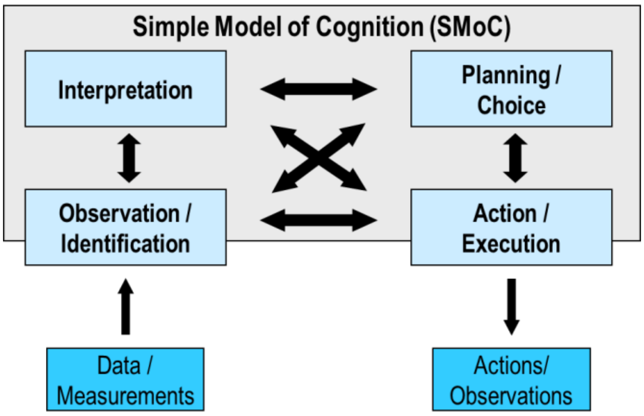
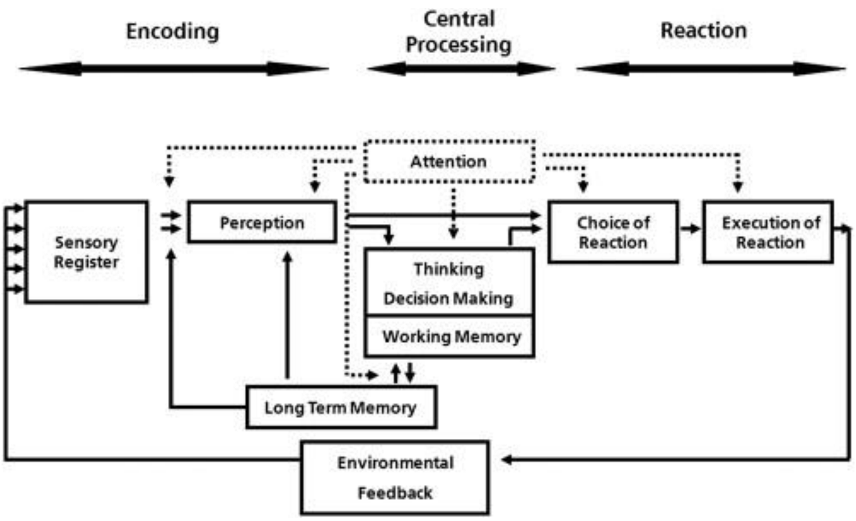


Figure 18: Wickens' Model of Human Information Processing

Source: Liebl et al., 2011



3.4 CONCLUSIONS

This chapter has discussed the research methodology adopted for the dissertation. The rationale for the sample selection is also discussed. This chapter has presented the SEMOMAP model in great detail. The chapter has enumerated the model's four comprehensive accident phases (0, 1, 2 and 3) and the results / outcomes of the maritime incident. The chapter has also discussed in detail the SEMOMAP taxonomy applicable to each of the phases and the philosophy behind the taxonomy.

In addition to exploring the accident process in great detail, *SEMOMAP helps to obtain quantitative data that allows for the creation of fault trees, event trees, risk contribution trees and related risk assessment diagrams. The data from the SEMOMAP analysis can also potentially be used to create improved decision support systems, which take into account the actions, inaction and time periods to provide adequate and appropriate support to shipboard personnel* (see appendix, SEMOMAP codebook).

After a discussion of the research methodology in chapter 3, the following chapter presents the findings of the study.

4 ANALYSIS OF ACCIDENT INVESTIGATION REPORTS

Chapter 4 presents the findings of the analysis of the accident investigation reports. A total of fifteen publicly available investigation reports of passenger ship accidents were analysed utilising the SEMOMAP model and accompanying taxonomies. The list of accident investigation reports analysed in this dissertation is given in table 12. A more detailed list including the narratives of the accident is included in the appendix. The breakdown of the analysed accident investigation reports is given in table 4.

Table 4: Breakdown of accident investigation reports analyzed
Source: Student

Accident Category	Fire	Grounding	Flooding	Total
Reports analyzed	8	6	1	15

The chapter opens with a solved case study example which depicts the step by step application of the taxonomy to code an accident investigation report in line with the philosophy of the SEMOMAP model.

4.1 SEMOMAP SOLVED CASE STUDY EXAMPLE

The accident investigation report chosen for the step-by-step application of the SEMOMAP taxonomy is *Monarch of the Seas*, a Norwegian flagged ship which grounded on the Proselyte reef in Great Bay, Philipsburg, St. Maarten, Netherlands in 1998. The result of the incident was major damage to the vessel; there was no loss of life and minor pollution resulted from the incident. The brief narrative of the accident, from the investigation report is provided to familiarise the reader with the casualty. Thereafter, the step-by-step walk-through of the taxonomy application is given.

Summary

At approximately 0030 hours on the night of 15 December 1998, the passenger vessel MONARCH OF THE SEAS arrived outside of Great Bay, St. Maarten in order to evacuate a sick passenger to a shore side medical facility. At 0125 the vessel's crew completed the passenger evacuation evolution and the MONARCH OF THE SEAS departed St. Maarten, taking a South-South-easterly departure route with the intention of safely passing to the east of the Proselyte reef obstruction. At approximately 0130 hours the MONARCH OF THE SEAS raked the Proselyte Reef at an approximate speed of about 12 knots without becoming permanently stranded. Almost immediately emergency and abandon ship signals were sounded and the crew and passengers were mustered at their abandon ship stations. At 0235 the vessel was intentionally grounded on a sandbar in Great Bay, St. Maarten. By 0515 hours all 2,557 passengers were safely evacuated ashore by shore based tender vessels.

4.1.1 MONARCH OF THE SEAS 'PHASE 0' ACCIDENT CODING

Phase 0 of an accident deals with factors that led to the creation of a dangerous situation on board. The involved human and technical subjects are identified and the HFACS aspects pertaining to them are coded first. In the chosen case study report the three human subjects identified are the captain, staff captain, second officer and the one technical subject identified is the navigational aids. The breakdown of the coding for the human and technical subjects against the organisational influences, supervision, preconditions and unsafe acts is given in table 5 on the following page. The coding is done in accordance with the SEMOMAP taxonomy table 0.1 (in line with HFACS) which is discussed in detail in chapter 3, section 3.3.1 (pp. 26 – 28).

In the coding for this phase the captain appears 37 times followed by the second officer who is coded 19 times and the staff captain who features 11 times. Navigational aids as technical subjects have one mention.

Table 5: *Monarch of the Seas* ‘phase 0’ HFACS coding
Source: Student

category L1	Sub category L2	Sub-sub category L3	Subject breakdown*	Total
Organizational Influences	Resource management	Lack of human resources	1 M; 1 SC; 1 2/O	3
	Organizational climate	Disorganized structure	1 M; 1 SC;	2
		Poor work culture	1 M; 1 SC; 1 2/O	3
	Organizational process	Poorly designed operations	2 M; 1 2/O	3
		Inappropriate procedures	1 M	1
	Statutory factors	Poor international/ national standards	1 M	1
Organizational Influence sub-category total - 13				
Supervision	Inadequate supervision	Poor shipborne and shore supervision	3 M; 2 SC; 1 2/O	6
	Planned inappropriate operations	Poor shipborne operations	2 M; 2 SC; 2 2/O	6
	Failed to correct known problems	Shipborne related shortcomings	2 M; 1 SC; 1 2/O	4
	Supervisory violations	Shipborne violations	2 M; 1 SC; 1 2/O	4
Supervision sub-category total - 20				
Preconditions	Environmental factors	Poor technological environment	2 M; 2 2/O; 1 B&D	5
	Crew condition	Negative cognitive factors	4 M; 2 2/O	6
		Poor physiological state	3 M	3
	Personnel factors	Poor crew interaction	3 M; 2 SC; 1 2/O	6
		Poor personal readiness	1 M; 1 2/O	2
Preconditions sub-category total - 22				
Unsafe Acts	Errors	Skill based errors	4 M; 2 2/O	6
		Decision and judgment errors	1 M	1
	Violations	Routine	2 M; 2 2/O	4
		Exceptional	1 M; 1 2/O	2
Unsafe Acts sub-category total - 13				
			Coding Total	**68**

*Subject breakdown legend: M – Master; SC – Staff Captain; 2/O – 2nd Officer; B&D – Bridge & Deck (technical subject – navigational aids)

4.1.2 MONARCH OF THE SEAS ‘PHASE 1’ ACCIDENT CODING

The factors influencing the creation of a dangerous situation on board are identified in the phase 0 coding. Phase 1 of the accident pertains to beginning of the accident. This phase first involves the identification of the threat to the vessel. On board, it requires that the threat is indicated, detected, analysed and appropriate threat mitigation action, undertaken. If suitable timely action is taken in this phase, the accident can be avoided altogether. The coding for this phase is done in line with chapter 3, section 3.3.2 (pp. 28 – 30). In the very first instance, the imminent threat to the vessel is coded, which in the case of the *Monarch of the Seas* is the threat of the navigational incident of grounding.

Table 6: *Monarch of the Seas* 'phase 1' coding (SEMOMAP taxonomy table 1.1)
Source: Student based on taxonomy codebook

Risk of	
Navigational incident	Grounding

After the threat to the vessel is identified, taxonomy table 1.2 and 1.3 are applicable which evaluate the threat indication, detection, analysis, and threat prevention action with respect to the incident applicable to the vessel. The relevant aspects on board, ashore and off-board are evaluated with respect to the equipment involved, human involvement and actions undertaken. If an aspect is applicable and not successful, it is further evaluated and the human or equipment failure is specified accordingly. In phase 1 of the *Monarch of the Seas* grounding accident, the vessel disembarked a sick passenger and contrary to procedure, proceeded east of the reef. The staff captain was surprised by the master's choice, however did not say anything.

Table 7: *Monarch of the Seas* 'phase 1' coding (SEMOMAP taxonomy table 1.2, 1.3)
Source: Student based on taxonomy codebook

Navigational Incident - Grounding	**First iteration**	Threat Indication	**Onboard**		No threat indication	
		Threat Detection		**Human** Staff Captain	Information transmission applicable but failed	Human failure – No threat evaluation transmitted. SC did not challenge Master's decision.
		Threat Analysis			No threat analysis	
		Threat Prevention Action			No threat prevention action	
	2nd	Threat Indication		**Equipment** Sea Charts	Information recording applicable but failed	Human failure – No threat information recorded. OOW failed to plot position

In the case of the *Monarch of the Seas*, the threat is not analysed and no threat mitigation action is undertaken which moves the accident into phase 2. Noteworthy is that within the same phase, iterations can be carried out based on the number of actions.

4.1.3 MONARCH OF THE SEAS 'PHASE 2' ACCIDENT CODING

In phase 2, the accident occurs and losses can be limited by timely and appropriate action. In phase 2 for the *Monarch of the Seas*, the first item to be coded is the nature of the accident that has taken place which is the navigational incident of grounding. Coding for this phase is carried out according to the phase 2 taxonomy tables discussed in detail in chapter 3, section 3.3.3 (pp. 31-32).

Table 8: *Monarch of the Seas* 'phase 2' coding (SEMOMAP taxonomy table 2.1)
Source: Student based on taxonomy codebook

Accident	
Navigational incident	Grounding

Subsequent to the accident SEMOMAP taxonomy tables 2.2 and 2.3 are applicable. The system health needs to be indicated, detected, analysed and suitable emergency response needs to be carried out. For system health indication, detection, analysis and emergency response action, the aspects that did not function are identified. If an aspect is applicable but unsuccessful, then the equipment or human failure is specified. Depending upon the number of emergency actions undertaken in the phase, several iterations of taxonomy coding can be carried out.

After the grounding with the reef, in phase 2 of the accident, the system health is regularly evaluated and emergency response measures undertaken. Several emergency response actions were taken as the vessel faced an added threat of flooding. The watertight doors were closed, the speed was reduced and the master decided deliberately to ground the vessel on the sandbank to protect lives. The actions were successful and the accident entered into the final evacuation phase.

Table 9: *Monarch of the Seas* ‘phase 2’ coding (SEMOMAP taxonomy table 2.2 and 2.3)
Source: Student based on taxonomy codebook

Navigational Incident - Grounding	First iteration	**System Health Indication**	Onboard		No system health indication Recording applicable – Failed Transmission applicable - Failed	Human failure – No info recorded/ transmitted Ignore system health – inadequate risk assessment. Omitted action – position not plotted, failed to monitor
		System Health Detection		**Human** OOW	Information receiving, evaluation & transmission applicable	Successful
		System Health Analysis		**Human** SC	Information receiving, planning & decision applicable	Successful
		Emergency Response Action		**Action** ECR	Communication, timing & sequence and selection & quality applicable	Successful
	2nd Iteration	**System Health Indication**		**Human** SC	Information recording & transmission applicable	Successful
		System Health Detection		**Human** Master	Information receiving, evaluation & transmission	Successful
		System Health Analysis		**Human** Master	Information receiving, planning & decision applicable	Successful
		Emergency Response Action		**Action** (Safety Officer)	Communication, timing & sequence and selection & quality applicable	Successful
	3rd iteration	**System Health Indication**		**Equipment** Water level indicators	Information recording & transmission applicable	Successful
		System Health Detection		**Human** Safety Officer	Information receiving, evaluation & transmission	Successful
		System Health Analysis		**Human** Master	Information receiving, planning & decision applicable	Successful
		Emergency Response Action		**Action** (ECR)	Communication, timing & sequence and selection & quality applicable	Successful

4.1.4 MONARCH OF THE SEAS 'PHASE 3' ACCIDENT CODING

The *Monarch of the Seas* entered into the final evacuation phase of the accident after the deliberate grounding of the vessel by the master. In this phase SEMOMAP taxonomy tables 3.2 and 3.3 are applicable and are discussed in detail in chapter 3, section 3.3.4 (pp. 32-34). In this phase emergency response and evacuation come foremost and system health indication detection and analysis continue as required. Human, equipment and action components both on-board and ashore are evaluated and when an aspect is applicable but not successful, then the human or equipment failure is clearly specified. All crew and passengers are mustered in this step and taken ashore by shore based tenders. The outcome of the accident is that there is severe damage to the vessel, however there is no loss of life. After the accident, the timely and suitable actions of the master, staff captain, officer of the watch, safety officer, chief engineer and crew helped to recover from an otherwise potentially dangerous situation which could have resulted in loss of lives (Reason, 2008).

Table 10: *Monarch of the Seas* 'phase 3' coding
(SEMOMAP taxonomy table 3.2 and 3.3)
Source: Student based on taxonomy codebook

Navigational Incident - Grounding	**First iteration**	**Emergency Response & Evacuation Action**	**Onboard**	**Action** Muster Personnel (Emergency Team)	Communication, timing & sequence and selection & quality applicable	Successful
		System Health Indication		**Human** OOW	Information recording & transmission applicable	Successful
		System Health Detection		**Human** Master	Information receiving, evaluation & transmission	Successful
		System Health Analysis		**Human** Master	Information receiving, planning & decision applicable	Successful
	2nd Iteration	**Emergency Response & Evacuation Action**		**Action** Drop anchor	Communication, timing & sequence and selection & quality applicable	Successful
		System Health Indication		**Human** OOW	Information recording & transmission applicable	Successful
		System Health Detection		**Human** Master	Information receiving, evaluation & transmission	Successful
		System Health Analysis		**Human** Master	Information receiving, planning & decision applicable	Successful

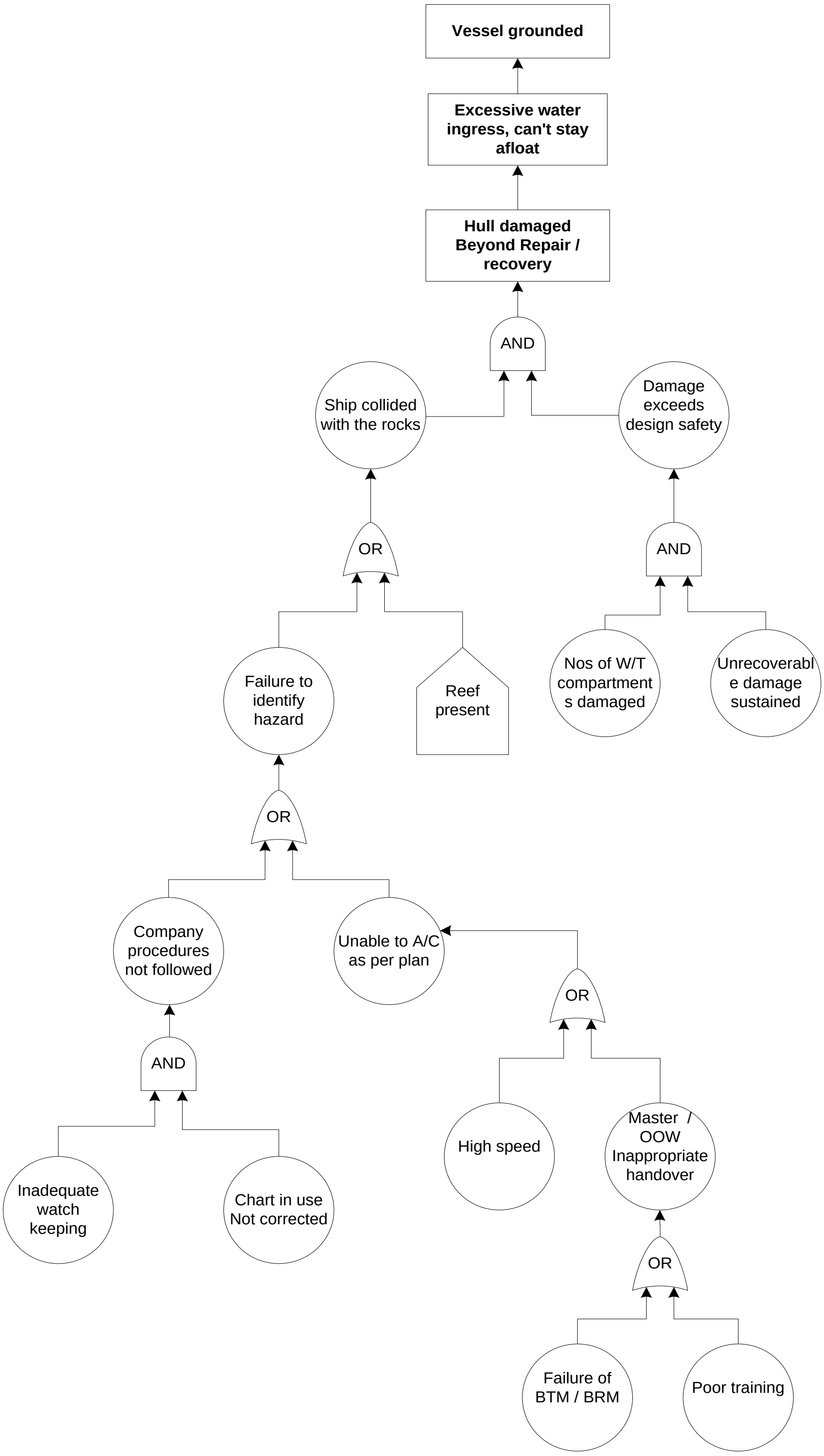
	3rd iteration	**Emergency Response Action**		**Action** Call SAR services	Communication, timing & sequence and selection & quality applicable	Successful
		System Health Indication		**Human** OOW	Information recording & transmission applicable	Successful
		System Health Detection		**Human** Master	Information receiving, evaluation & transmission	Successful
		System Health Analysis		**Human** Master	Information receiving, planning & decision applicable	Successful
	4th iteration	**Emergency Response Action**		**Action** (local agents)	Communication, timing & sequence and selection & quality applicable	Successful
		System Health Indication		**Human** OOW	Information recording & transmission applicable	Successful
		System Health Detection		**Human** Master	Information receiving, evaluation & transmission	Successful
		System Health Analysis		**Human** Master	Information receiving, planning & decision applicable	Successful
	5th iteration	**Emergency Response Action**		**Action** Contain hull damage	Communication, timing & sequence and selection & quality applicable	Successful
		System Health Indication		**Human** OOW	Information recording & transmission applicable	Successful
		System Health Detection		**Human** Staff Captain	Information receiving, evaluation & transmission	Successful
		System Health Analysis		**Human** Master	Information receiving, planning & decision applicable	Successful

The coding is conducted based on the available information in the accident investigation report by the student. Graphical breakdown and results are shown for levels 1 to 4a of the taxonomy. Level 4b and 5 have not been analysed graphically, as they are reliant and dependant on coder reliability, i.e. different people might disagree with the taxonomy options selected for level 4b and 5; instead, however, levels 4b and 5 are described and discussed very broadly and subjectively.

An indicative fault tree diagram is created for the *Monarch of the Seas*, by the student and is presented on the following page. The diagram reflects the data that can be generated by the SEMOMAP model and accompanying taxonomy. SEMOMAP generates a more comprehensive output than the fault tree analysis as it is supported by two strong accompanying taxonomies.

Figure 19: FTA *Monarch of the Seas*

Source: Student



4.2 DISSERTATION RESULTS

The step-by-step coding of the sample case study of the *Monarch of the Seas* in section 4.1 is followed by the results of the dissertation. As previously mentioned, this dissertation contains the analysis of 15 publicly available accident investigation reports, of which 8 on fire, 6 on grounding and 1 on flooding. 14 of the 15 investigated reports pertained exclusively to their accident category in question, while *Monarch of the Seas* discussed in 4.1 above was the only one that faced an additional threat of flooding after grounding with the reef. To mitigate the threat of flooding and protect lives it was decided to deliberately ground the vessel on the sandbank.

The breakdown of the accident outcomes is given below in table 11

Table 11: Accident outcomes of analysed passenger ship investigation reports
Source: Compiled by Student

Fire		Grounding		Flooding
7 Mitigated loss	**1 Severe loss**	**4 Mitigated loss**	**2 Severe loss**	**1 Near miss**
8		6		1

None of the passenger ship accidents analysed, resulted in a total loss; no lives were lost in these accidents. Table 12 on the following page presents a list of the accident investigation reports analysed in the study together with the online sources for the reports. This section (4.2) first presents category wise findings specific to Fire, grounding and flooding before moving onto overall findings which encompass all the three categories.

SEMOMAP allows for the study of actions and processes in the accident context and helps identify human contribution, involved equipment and actions that contributed to the accident outcomes. Further on in the chapter the findings are collated and presented and a separate section is dedicated to the evaluation of the SEMOMAP model itself.

Table 12: List of accident investigation reports analyzed
Source: Student

No.	Ship Name	IMO No	Flag	Classification	Nature of accident	Report Source
1	M.V. Zenith	8918136	Malta	Germanischer Lloyds	Fire	https://mti.gov.mt/en/Pages/MSIU/Safety-Investigations-2014.aspx
2	M.V. Azamara Quest	9210218	Malta	Lloyds' Register	Fire	https://mti.gov.mt/en/Pages/MSIU/Safety-Investigations-2012.aspx
3	M.V. Carnival Spirit	9188647	Malta	Lloyds' Register	Fire	https://mti.gov.mt/en/Pages/MSIU/Safety-Investigations-2012.aspx
4	M.V. Carnival Splendor	9333163	Panama	Lloyds' Register	Fire	https://homeport.uscg.mil/mycg/portal/ep/contentView.do?channelId=-18374&contentId=460088&programId=21431&programPage=%2Fep%2Fprogram%2Feditorial.jsp&pageTypeId=13489&contentType=EDITORIAL
5	RMS Queen Mary 2	9241061	United Kingdom	Lloyds' Register	Fire	http://www.maib.gov.uk/cms_resources.cfm?file=/QM2Report.pdf
6	M.V. Royal Princess	9210220	Bermuda	NA	Fire	http://www.bermudashipping.bm
7	M.V. Star Princess	9192363	Bermuda	RINA	Fire	http://www.maib.gov.uk/cms_resources.cfm?file=/star%20princess.pdf
8	M.V. The Calypso	NA	Cyprus	Lloyds' Register	Fire	http://www.maib.gov.uk/publications/investigation_reports/2007/calypso.cfm?view=print&
9	M.V. Saga Sapphire	7822457	Malta	Germanischer Lloyds	Flooding	https://mti.gov.mt/en/Pages/MSIU/Safety-Investigations-2014.aspx
10	M.V. Lauren L	9246827	Malta	Germanischer Lloyds	Grounding	https://mti.gov.mt/en/Pages/MSIU/Safety-Investigations-2013.aspx
11	M.V. Clipper Adventure	NA	Bahamas	NA	Grounding	http://www.tsb.gc.ca/eng/rapports-reports/marine/2010/m10h0006/m10h0006.asp
12	M.V. Deutschland	9141807	Germany	Germanischer Lloyds	Grounding	http://www.bsu-bund.de
13	M.V. Van Gogh	7359400	Marshall Island	Det Norske Veritas	Grounding	http://www.atsb.gov.au/publications/investigation_reports/2008/mair/pdf/mair252_001.pdf
14	M.V. Astor	8506373	Bahamas	Germanischer Lloyds	Grounding	http://www.atsb.gov.au/publications/investigation_reports/2004/mair/mair200.aspx
15	M.V. Monarch of the Seas	8819500	Norway	Det Norske Veritas	Grounding	http://marinecasualty.com/documents/monarch.pdf

4.2.1 FLOODING CATEGORY OVERVIEW

This section discusses the findings from the flooding accident category, of which only one report was coded. Table 13, shows the 'phase 0' HFACS coding for the flooding accident that led to the creation of a dangerous situation on-board.

Table 13: Flooding accident category 'phase 0' HFACS overview
Source: Student based on taxonomy codebook

	Sub-Category L2	Sub-Sub Category* L3	Operator breakdown	Total
Organizational Influences	**Resource Management**	Lack of human resources	1 C	1
	Organizational Climate	Disorganized structure	1 C	1
		Poor work culture	1 C	1
	Organizational Process	Poorly designed operations	1 C	1
		Inadequate procedures	1 C	1
		Lack of oversight	1 C	1
				Category total: 6
Supervision	**Inadequate Supervision**	Poor shipborne and shore supervision	2 C	2
	Planned inappropriate operations	Poor shipborne operations	1 C; 1 OO; 1 OE	3
	Supervisory Violations	Shipborne violations	2 C; 1 OO	3
				Category total: 8
Preconditions	**Environmental Factors**	Poor technological environment	2 C	2
	Crew Condition	Negative cognitive factors	1 C; 1 OO; 1 OE	3
				Category total: 5
Unsafe Acts	**Errors**	Skill based errors	1 C; 1 OO	2
		Decision and judgment errors	1 C	1
	Violations	Routine	1C; 1 OO	2
				Category total: 5
				Coding Total 24

*Operator: C – Captain; OO – Other Officer; OE – Other Engineer

Figure 20: Flooding 'phase 0' operator overview

Source: Student

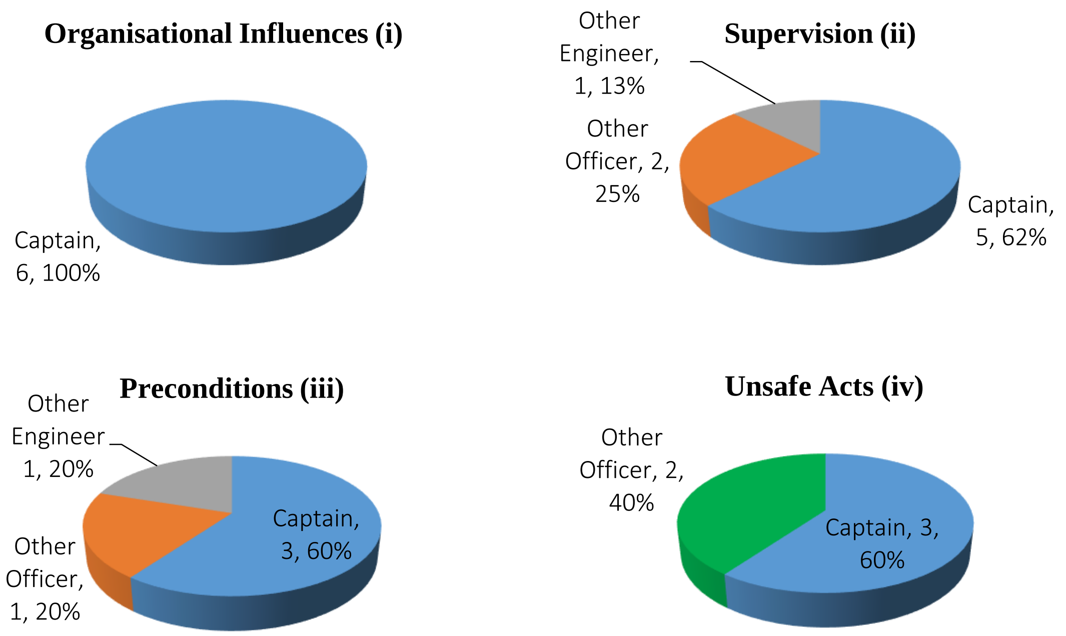


Table 13 on the preceding page depicts the flooding category overview for HFACS coding and figure 20, offers the operator breakdown for each category. The Captain in figure 20 appears under all HFACS categories and occupies a large share of each category, as can be expected given his overall role on-board. The other operators that feature are the Other Officer (exact rank not given in report, but the Officer of the Watch) and Other Engineer (most probably the Engine Officer on duty). This finding also points to the level of detail included in accident investigation reports regarding operators involved.

The background to the creation of a dangerous situation on-board included the poor operational practice of utilising the Officer of the Watch for the purpose of ballast operations, which was further compounded by a poor hand/take over, thereby compromising safety. There was inadequate monitoring from both the deck and the engine department. Inadequate SMS guidelines for the operation and inadequate risk assessment, led to the dangerous situation of flooding, and the move into phase 1.

4.2.1.1 FLOODING 'PHASE 1' OVERVIEW

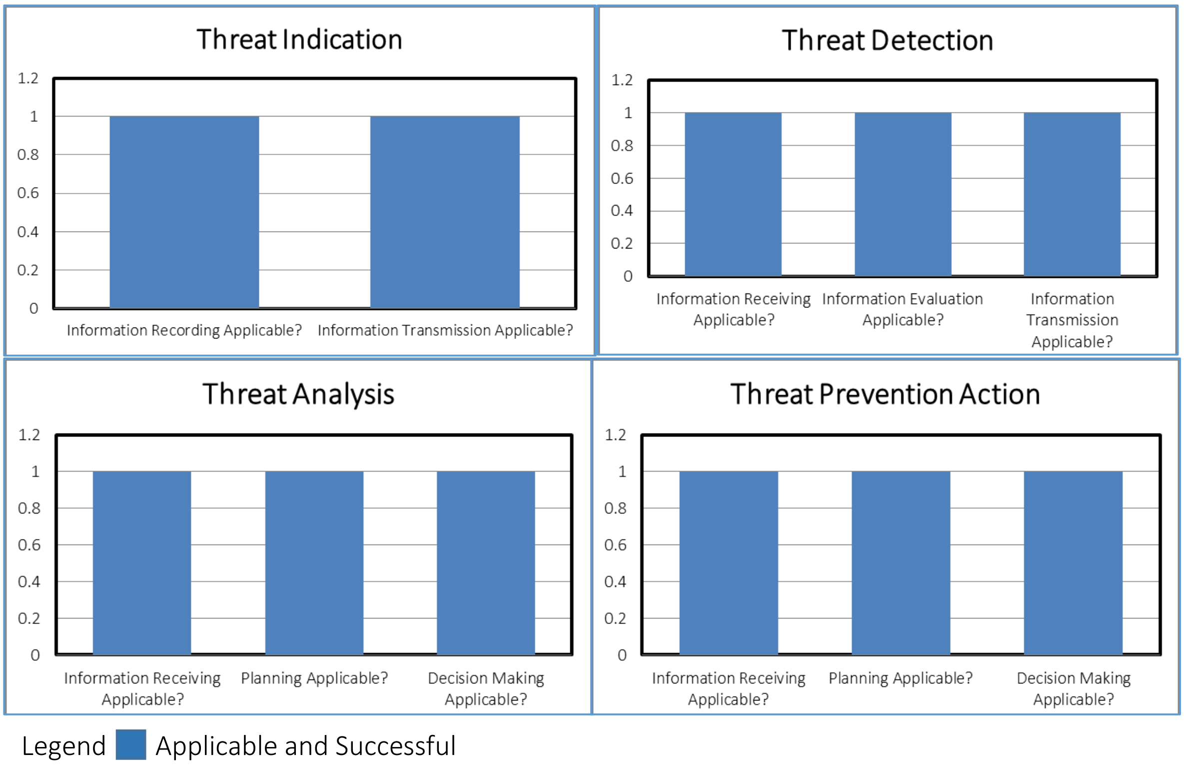
The flooding had begun, however the accident had not taken place per se and the threat indication, detection, analysis and prevention were successfully carried out.

Table 14: Flooding accident category 'phase 1' overview (level L2B)
Source: Student based on taxonomy codebook

L2B	Threat Indication
On-board Human Other	2
L2B	Threat Detection
On-board Human OOW	3
L2B	Threat Analysis
On-board Human OOW	3
L2B	Threat Prevention Action
On-board Action Other	3

Figure 21: Flooding 'phase 1' overview (L3-4)

Source: Student



In phase one of the flooding accident, the on-board human was applicable 11 times and all 11 times was successful. The good practice of on-board safety rounds helped the accident to be averted in a timely manner. The vigilant crew during the safety round, immediately reported the finding of water build up. The cause of the flooding was investigated, ballast operations were stopped and corrective actions taken, which prevented the flooding incident from progressing into phase two of the accident.

4.2.2 GROUNDING CATEGORY OVERVIEW

This sub-section presents the findings of the grounding category of accidents of which 6 accidents were analysed using SEMOMAP, of which 5 were a mitigated loss and 1 a severe loss. The HFACS coding for the grounding category for human operators and equipments is provided on the following pages.

Most grounding accidents appear to have taken place due to poor communication, Bridge Resource Management and Bridge Team Management practices on-board. Inadequate risk assessment, passage planning, navigation chart correction and position monitoring are some of the aspects that feature in the reports as well as the lack of involvement of the personnel on the bridge at the time of the incident (the concerned OOW or the pilot, Staff Captain etc.). For instance, a language barrier was identified in *Astor and Van Gogh* grounding in Australia during departure operations as the crew on-board were communicating in Russian and Ukrainian whereas the pilot was able to understand only English and this was a complete failure of BTM and BRM.

4.2.2.1 GROUNDING CATEGORY ‘PHASE 0’ OVERVIEW

Table 15 on the following page depicts the coding for the human operators involved in the Grounding category according to HFACS and Table 16 presents the technical subjects/equipment involved in the grounding accident category.

Table 15: Grounding accident category 'phase 0' HFACS operator overview; **Source:** Student, according to taxonomy

L1	Sub-Category L2	Sub-Sub-Category L3	Operator Breakdown						Total
			C	CO	2O	OO	Helmsman	Pilot	
Organisational Influences (i)	Resource Management	Lack of Human Resources	6	4	1	1	0	1	13
		Poor Technological Resources	2	0	0	0	0	0	2
	Organisational Climate	Disorganised Structure	1	1	0	0	0	0	2
		Inadequate Policies	1	0	0	0	0	0	1
		Poor Work Culture	8	5	2	3	1	3	22
		Poorly Designed Operations	8	0	1	0	0	0	9
		Inappropriate Procedures	6	0	0	0	0	0	6
	Statutory Factors	Poor International/National Standards	3	0	0	0	0	0	3
		Inadequate Flag State Implementation	1	0	0	0	0	0	1
Supervision (ii)	Inadequate Supervision	Poor Shipborne and Shore Supervision	8	3	2	2	0	0	15
	Planned Inappropriate Operations	Poor Shipborne Operations	13	7	3	2	0	3	28
	Failed to Correct Known Problems	Shipborne Related Shortcomings	8	4	2	0	0	2	16
	Supervisory Violations	Shipborne Violations	11	4	2	2	0	0	19
Preconditions (iii)	Environmental Factors	Poor Physical Environment	1	0	0	0	0	0	1
		Poor Technological Environment	3	0	3	1	0	1	8
	Crew Condition	Negative Cognitive Factors	10	2	3	4	0	1	20
		Poor Physiological State	3	0	0	0	0	0	3
	Personnel Factors	Poor Crew Interaction	6	4	1	1	2	2	16
		Poor Personal Readiness	8	3	1	1	2	0	15
Unsafe Acts (iv)	Errors	Skill-based errors	16	3	2	3	1	3	28
		Decision and judgement errors	10	1	1	0	0	0	12
	Violations	Routine	13	5	4	3	1	1	27
		Exceptional	4	1	1	0	0	1	7
Operator: C-Captain; CO-Chief Officer; 20-2nd Officer; OO; Other Officer		**Total**	150	47	29	23	7	18	274

Table 16: Grounding accident category 'phase 0' HFACS equipment overview; **Source:** Student, according to taxonomy

L1	Sub-Category L2	Sub-Sub-Category L3	Equipment Breakdown			Total
			Steering Equipment	Navigation Aids (AIS, ECDIS, Radar, GPS, etc.)	Other	
Organisational Influences	Resource Management	Poor Technological Resources	0	1	2	3
		Poor Equipment/Facility Resources	1	0	0	1
	Organisational Climate	Disorganised Structure	1	0	0	1
		Inadequate Policies	0	0	1	1
		Poor Work Culture	0	1	2	3
	Organisational Process	Poorly Designed Operations	0	0	1	1
		Inappropriate Procedures	0	0	2	2
Supervision	Planned Inappropriate Operations	Poor Shipborne Operations	1	0	0	1
	Supervisory Violations	Shipborne Violations	1	0	0	1
Preconditions	Environmental Factors	Poor Physical Environment	1	0	1	2
		Poor Technological Environment	1	1	2	4
	Crew Condition	Negative Cognitive Factors	0	0	1	1
		Total	6	3	12	21

Figure 22: Grounding 'phase 0' operator overview

Source: Student

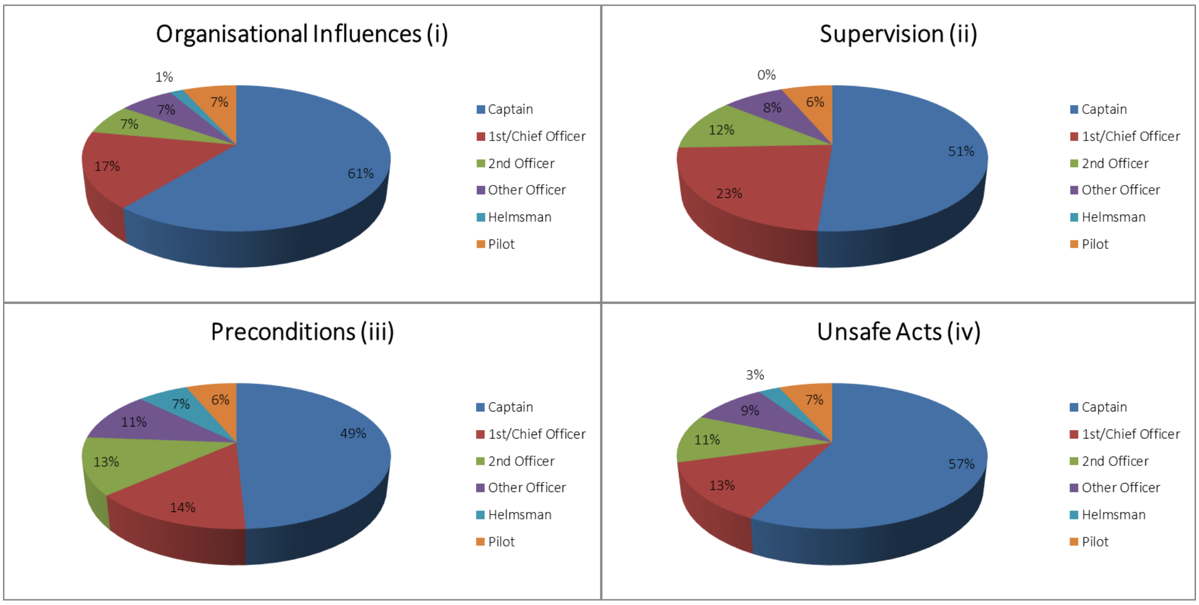
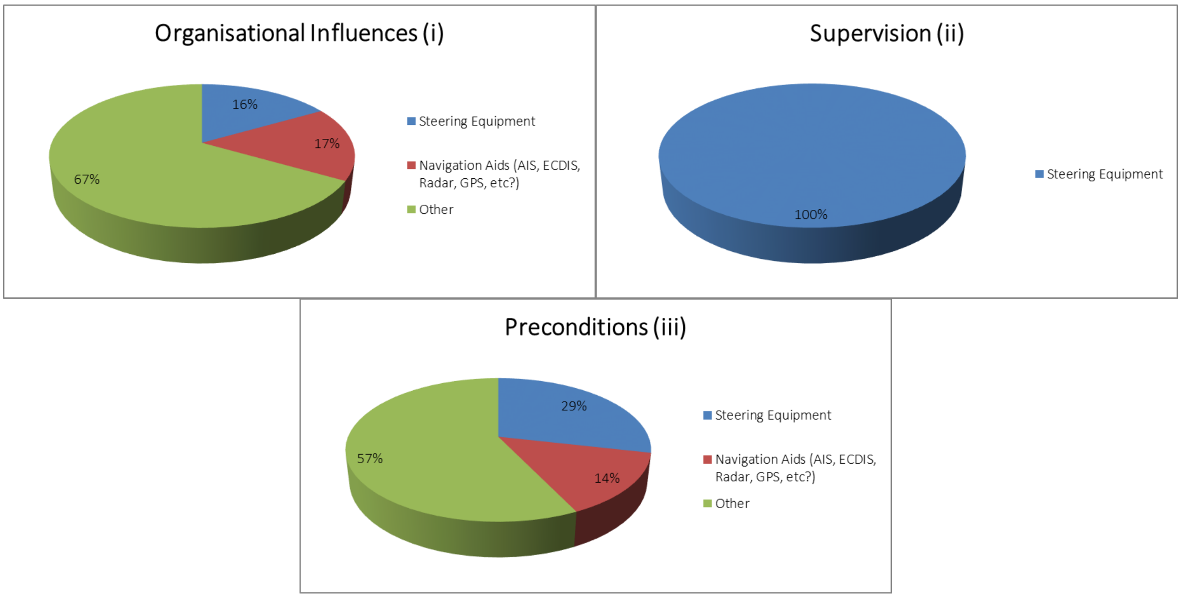


Figure 23: Grounding 'phase 0' HFACS equipment overview

Source: Student



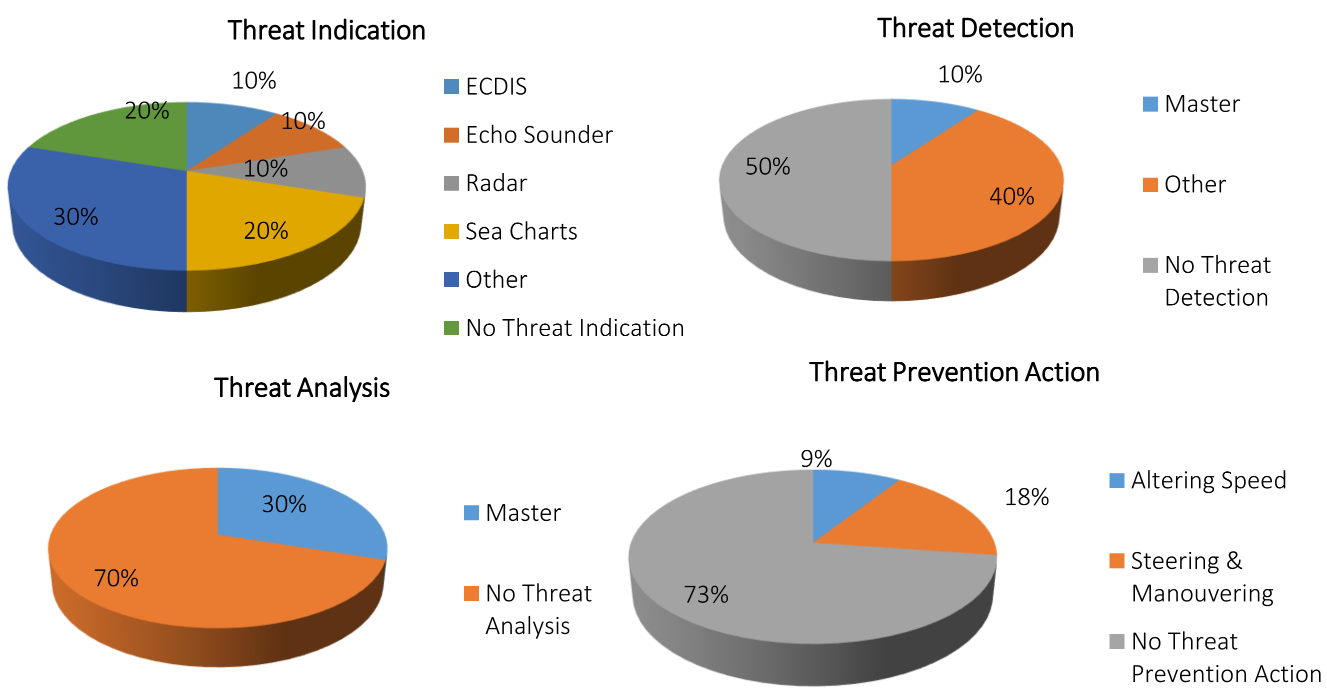
In 'phase 0' of the grounding accident category, HFACS categories are attributed highest to the Captain, followed by the Chief Officer and 2nd Officer. The HFACS categories are largely attributable to the following equipment – steering equipment, navigation aids (AIS, ECDIS, Radar, GPS etc.) among others. The taxonomy can further be expanded to include these in the future.

4.2.2.2 GROUNDING CATEGORY 'PHASE 1' OVERVIEW

The dangerous on board situation contributes to, and leads to the beginning of accident 'phase 1'. In case of a grounding accident, threat indication is attributable to equipment like ECDIS, Echo Sounder, Radar, Sea charts among others. Threat is detected by the human operators – master and others, which includes individuals like the Staff Captain and Pilot. The taxonomy can be expanded to include these personnel for future coding of accidents. Threat analysis is largely carried out by the master and prevention actions include altering speed and manoeuvring.

Figure 24: Grounding 'phase 1' overview (L1-2)

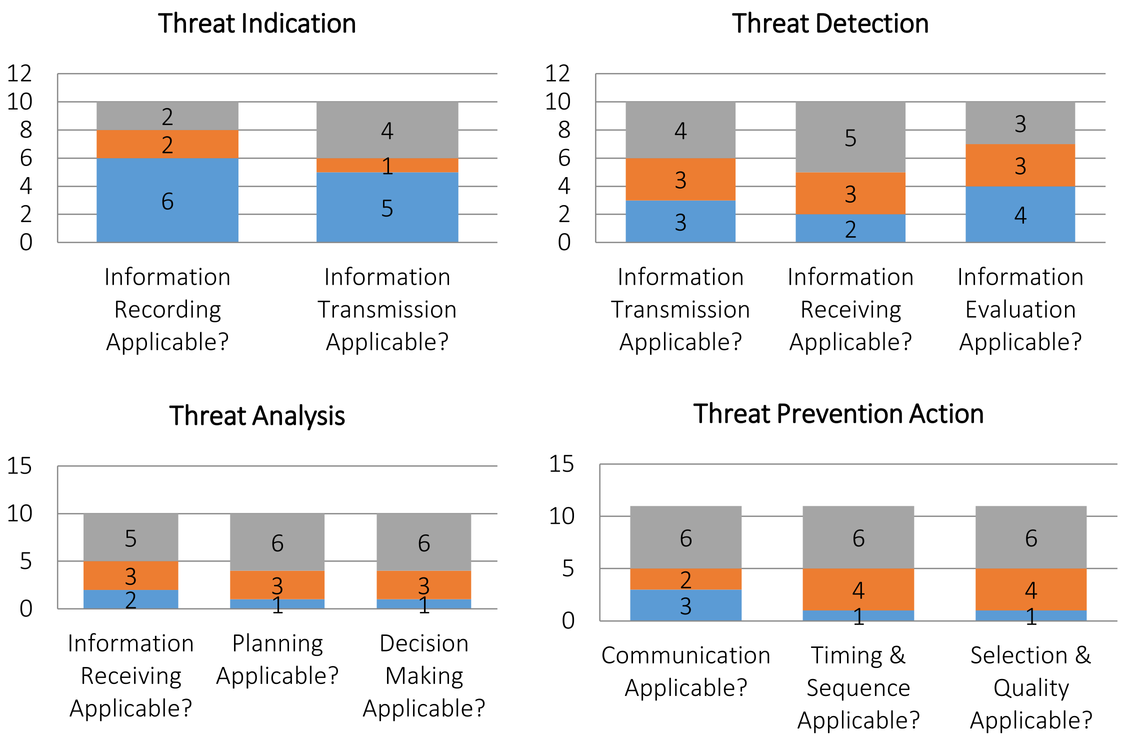
Source: Student based on taxonomy



‘Others’ in ‘threat indication’ refers to Staff captain (2 times) and Pilot (4 times). ‘Others’ in ‘detection’ refers to the Staff captain (6 times) and Pilot (6 times). 73% of the times, threat prevention actions are not taken, which moves the accident into the next phase of the accident. Levels 3-4 of the SEMOMAP depict the applicability and success of threat indication, detection, analysis and threat prevention action.

Figure 25: Grounding ‘phase 1’ overview (L3-4)

Source: Student, based on taxonomy

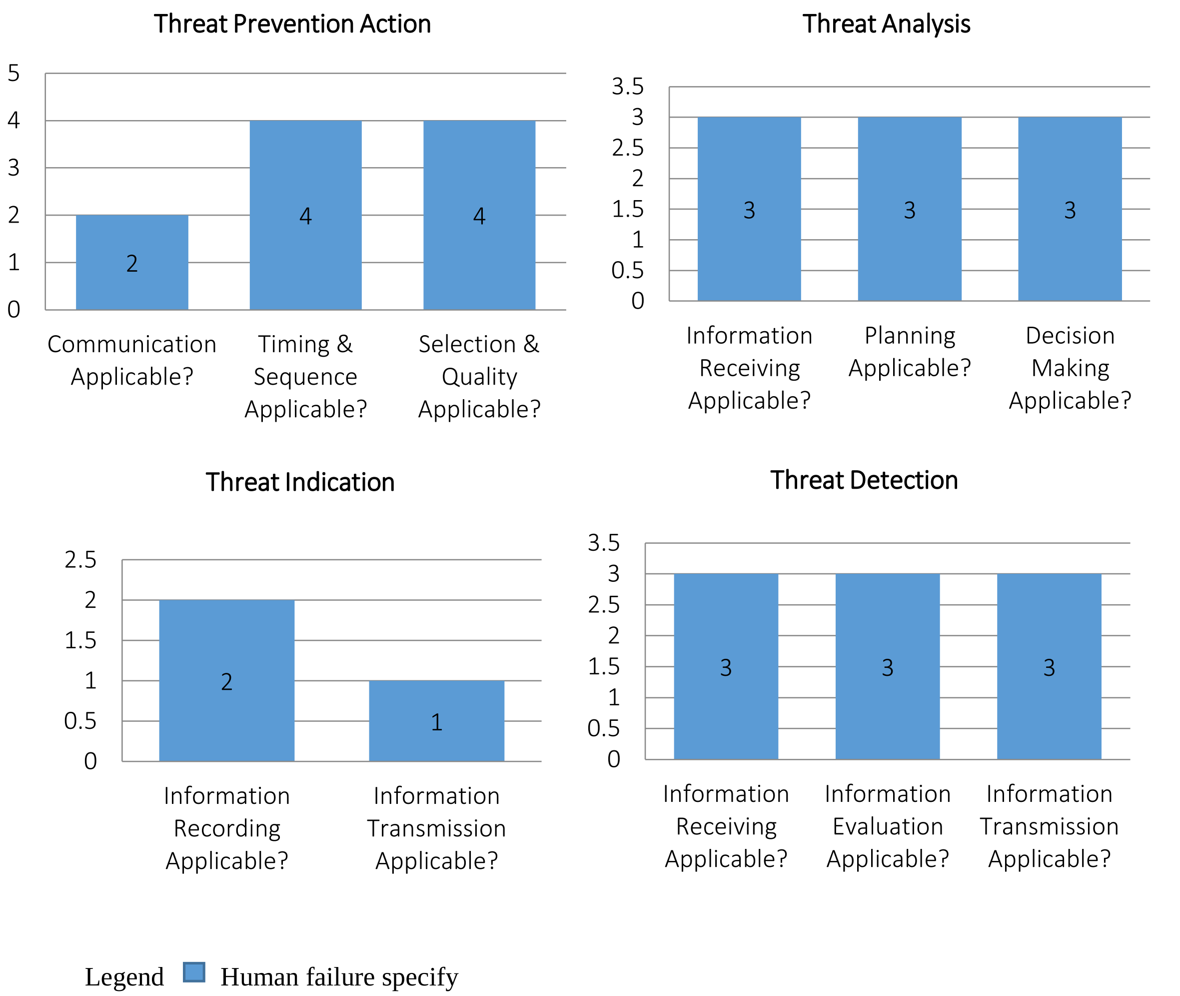


Legend
Applicable & Successful
Applicable & Unsuccessful
Not applicable

A threat not detected and analysed in time, does not have a corresponding mitigation action but the threat of an incident does not diminish. This level helps to study the applicable aspect and whether it was successful or not. Applicable aspects were successful 29 times and unsuccessful 31 times.

Level 4-5 of SEMOMAP taxonomy specifies human or equipment failure. Figure 26, depicts Level 4-5. This depicts the further breakdown of the 'orange' legend – 'applicable & unsuccessful' of figure 25.

Figure 26: Grounding 'phase 1' overview (L4-5); **Source:** Student based on taxonomy



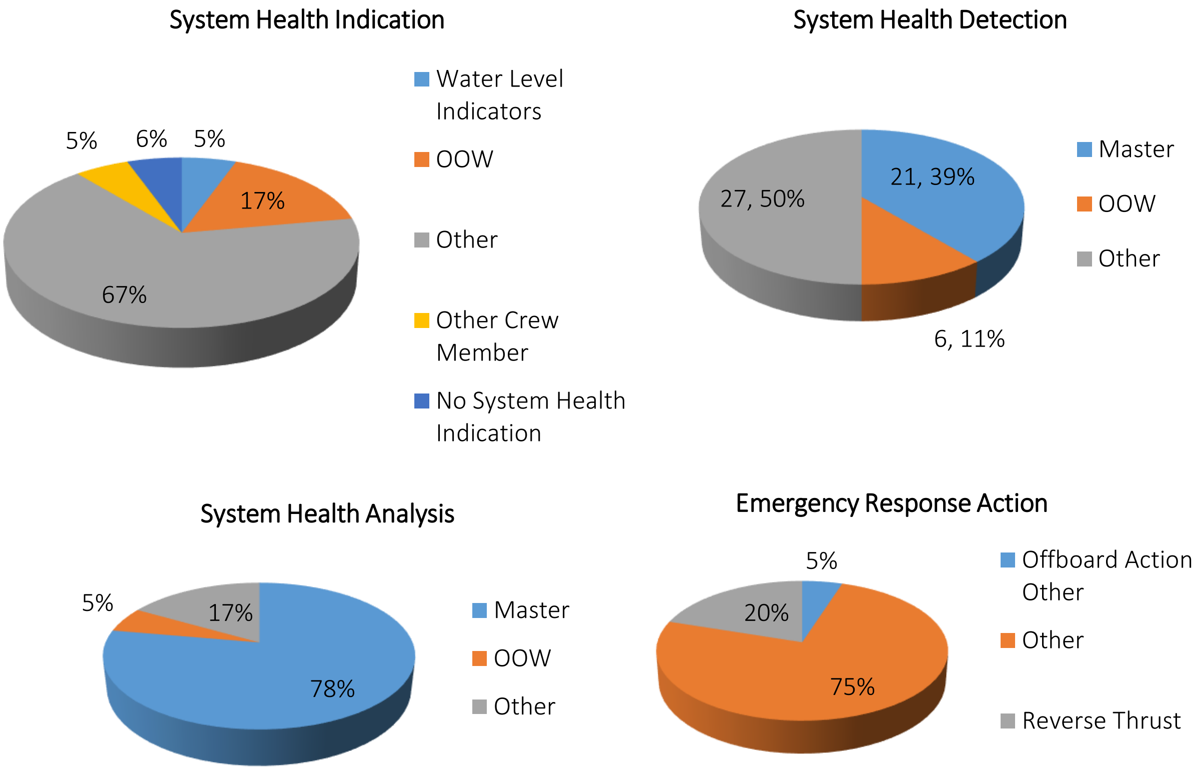
There is no equipment failure in phase 1 (L4-5), human failure has been noted in all 31 instances at this level. The situation further exacerbates and moves into 'Phase 2'.

4.2.2.3 GROUNDING CATEGORY 'PHASE 2' OVERVIEW

The accident takes place in this phase and the threat indication changes into the indication of system health, after the accident.

Figure 27: Grounding 'phase 2' overview (L1-2)

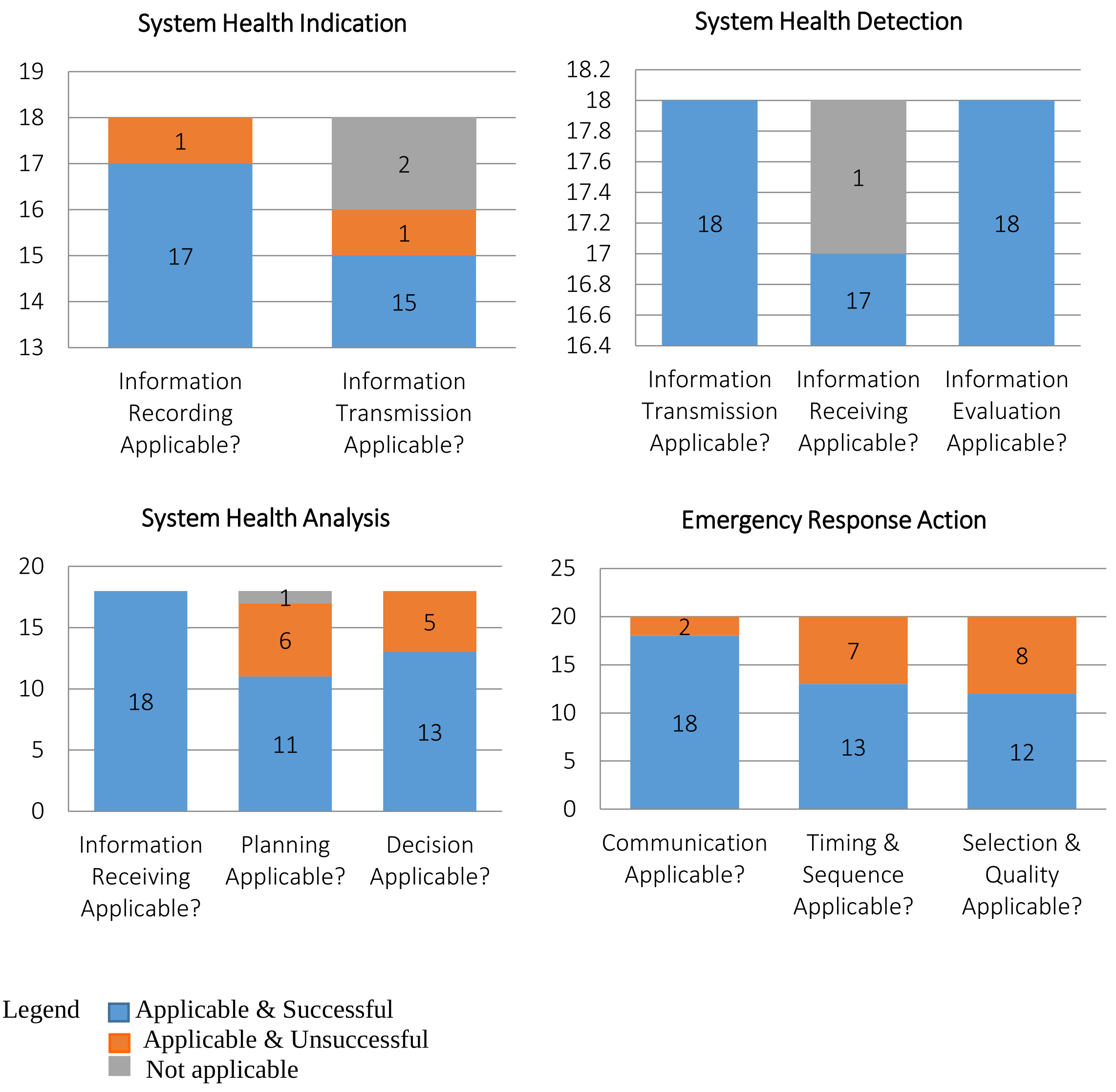
Source: Student, based on taxonomy



System health is indicated by the equipment such as the water level indicators and crew members such as the OOW. System health is detected largely by the Master and the OOW. System health analysis is largely carried out by the Master and emergency response actions include off board action by shore based tenders to evacuate passengers, doing the reverse thrust and deliberately grounding the vessel (*Monarch of the Seas*) among other actions.

Figure 28: Grounding 'phase 2' overview (L3-4)

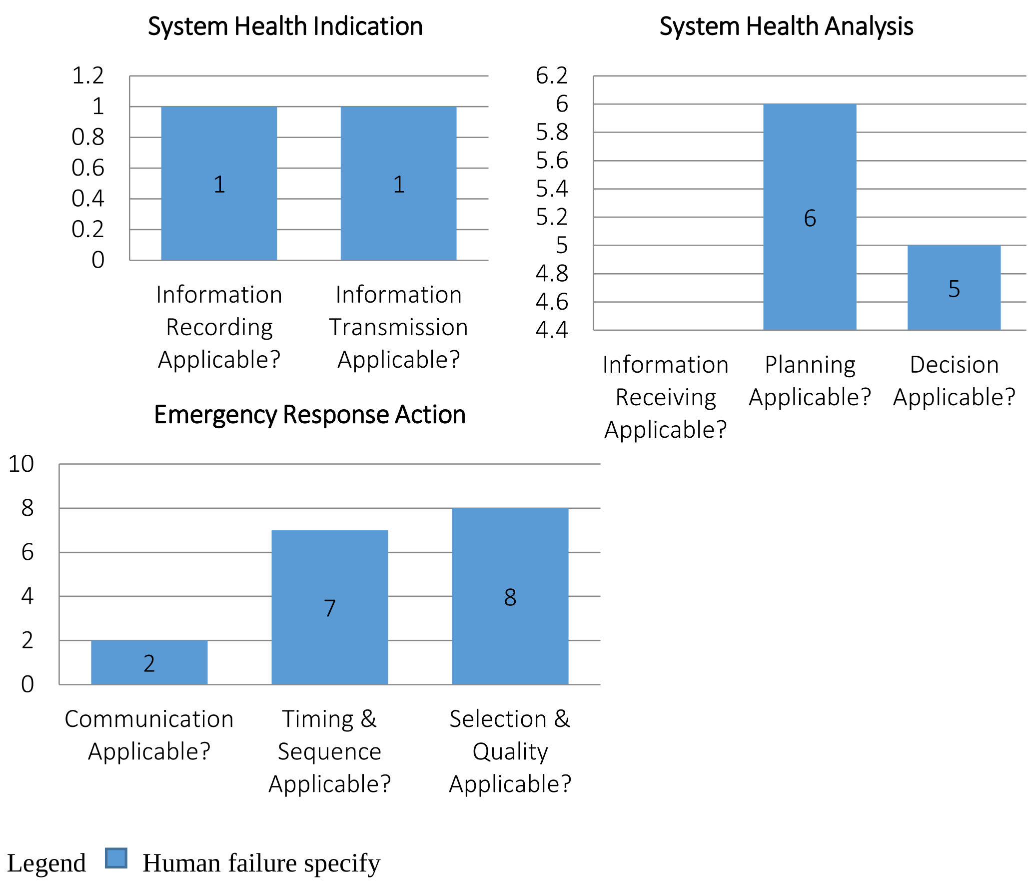
Source: Student, based on taxonomy



Level L3-4 of phase two of the taxonomy helps identify which aspects of system health indication, detection, analysis and emergency action were applicable and whether they succeeded or not. In phase two of the grounding accident, at this level, there have been instances in system health indication, analysis and emergency response action where there have been failures. Aspects were applicable and successful 170 times and applicable but unsuccessful 30 times.

Figure 29: Grounding 'phase 2' overview (L4-5)

Source: Student, based on taxonomy



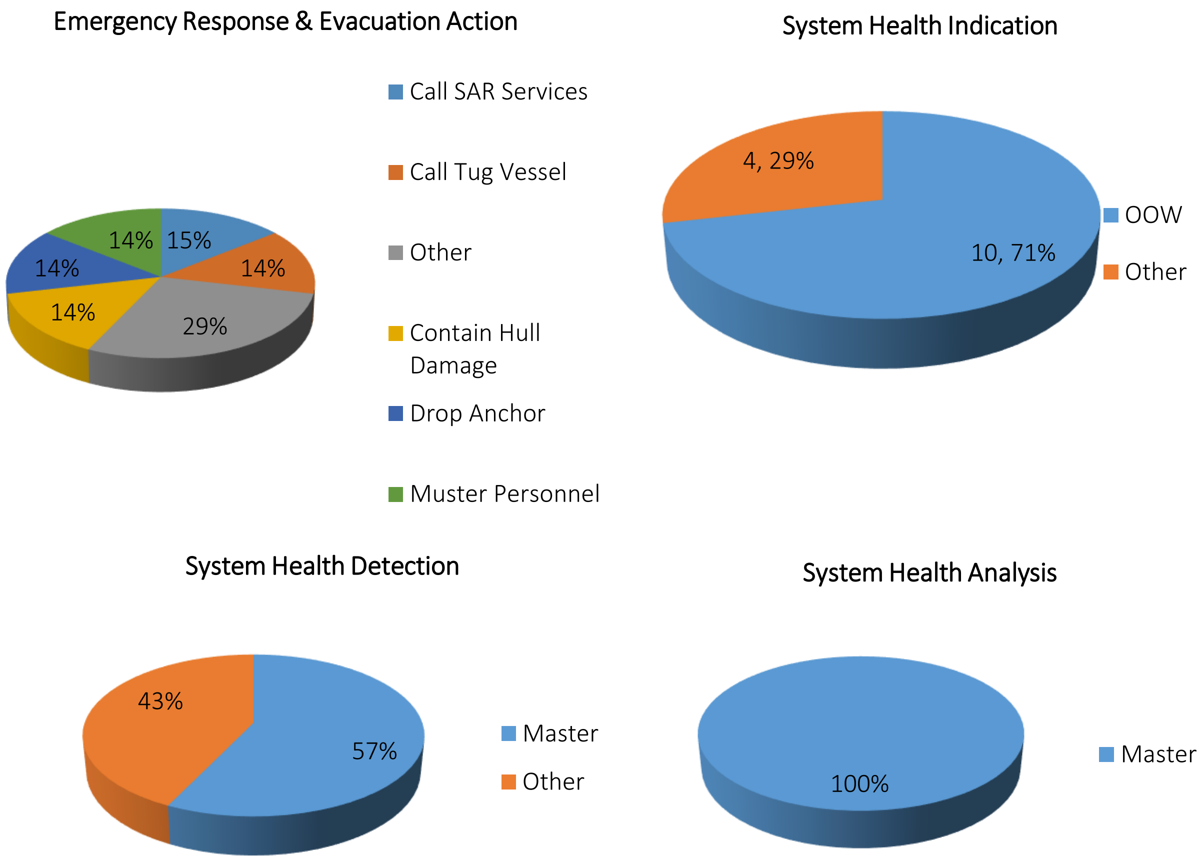
In level 4-5 of phase 2 taxonomy, the failure can be attributable to the human or equipment and in each of the 30 cases of failure specification in grounding, it pertained to the human operator as depicted in figure 29 above. An accident moves into the final evacuation phase to protect lives and grounding is the only accident category that has led to evacuations. Accident categories of fire and flooding have not entered this phase.

4.2.2.4 GROUNDING CATEGORY 'PHASE 3' OVERVIEW

The final 'phase 3' pertains to evacuation in an accident situation. In phase 1 and 2 system health is required to be evaluated to initiate appropriate emergency actions. However, in phase 3, emergency response and actions take precedence over the evaluation of system health

Figure 30: Grounding 'phase 3' overview (L1-2)

Source: Student, based on taxonomy

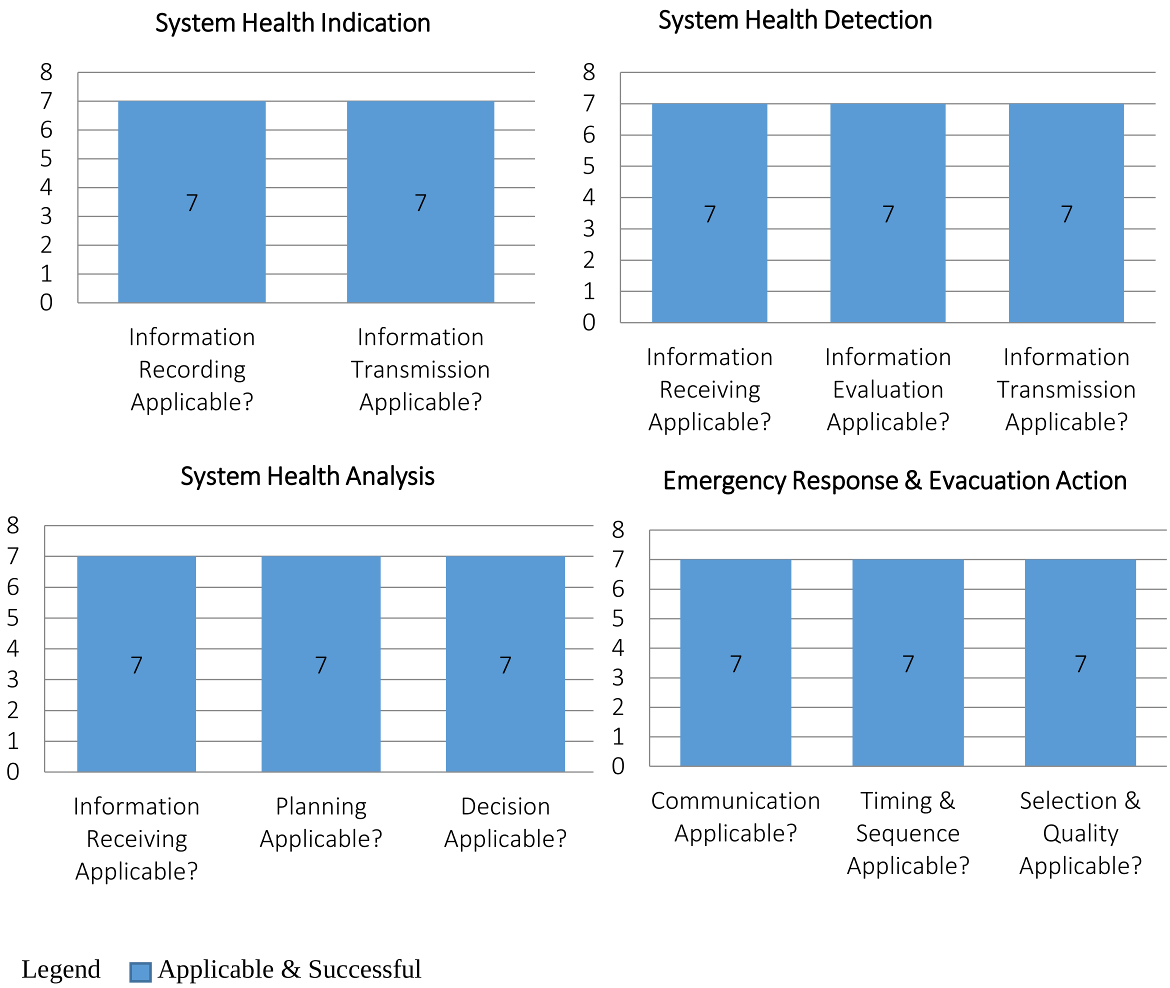


In an emergency situation arising out of grounding, several measures can be initiated like mustering personnel, calling SAR services, tugs, attempting to contain hull damage, dropping anchor etc. System health is usually indicated by the personnel on the scene like the OOW. It is brought to the attention of senior personnel, the Master and in all the grounding cases system analysis is carried out by the Master.

In levels 3-4 of phase 3 taxonomy, aspects are checked for their applicability and success.

Figure 31: Grounding ‘phase 3’ overview (L3-4)

Source: Student, based on taxonomy



In level 3-4 of phase 3 taxonomy in grounding, in each of the 77 times, the applicable aspect has been successful, pointing towards success in post-accident observable aspects and actions. As no aspect has been applicable and unsuccessful, the coding stops at this point. At this stage, no equipment or human failure is noted and phase 3 of grounding accidents have led to successful evacuations with no loss of lives.

4.2.3 FIRE CATEGORY OVERVIEW

In this sub-section the findings related to the fire accident category are presented. A total of 8 accident investigation reports were coded under this category, of which 7 resulted in a mitigated loss and 1 resulted in a severe loss of the vessel. None of the fire accidents entered phase 3 – evacuation phase of the accident. Major accidents in this category are due to engine room fires, especially auxiliary engine or main engine fires. Most of the fires were caused by fuel oil leaks due to loose connections or equipment failure. Personnel immediately concerned with fire accidents were the OOW and the engineer officer on duty and motorman, among others. The accidents have largely occurred due to a failure to comply with standard good engineering practice and a failure to comply with equipment/manufacturer's guidelines.

4.2.3.1 FIRE CATEGORY 'PHASE 0' OVERVIEW

The HFACS coding for both human operators and equipment (tables 17 and 18) is provided on pages 64 and 65 for this category.

Figure 32: Fire 'phase 0' HFACS operator overview; **Source:** Student

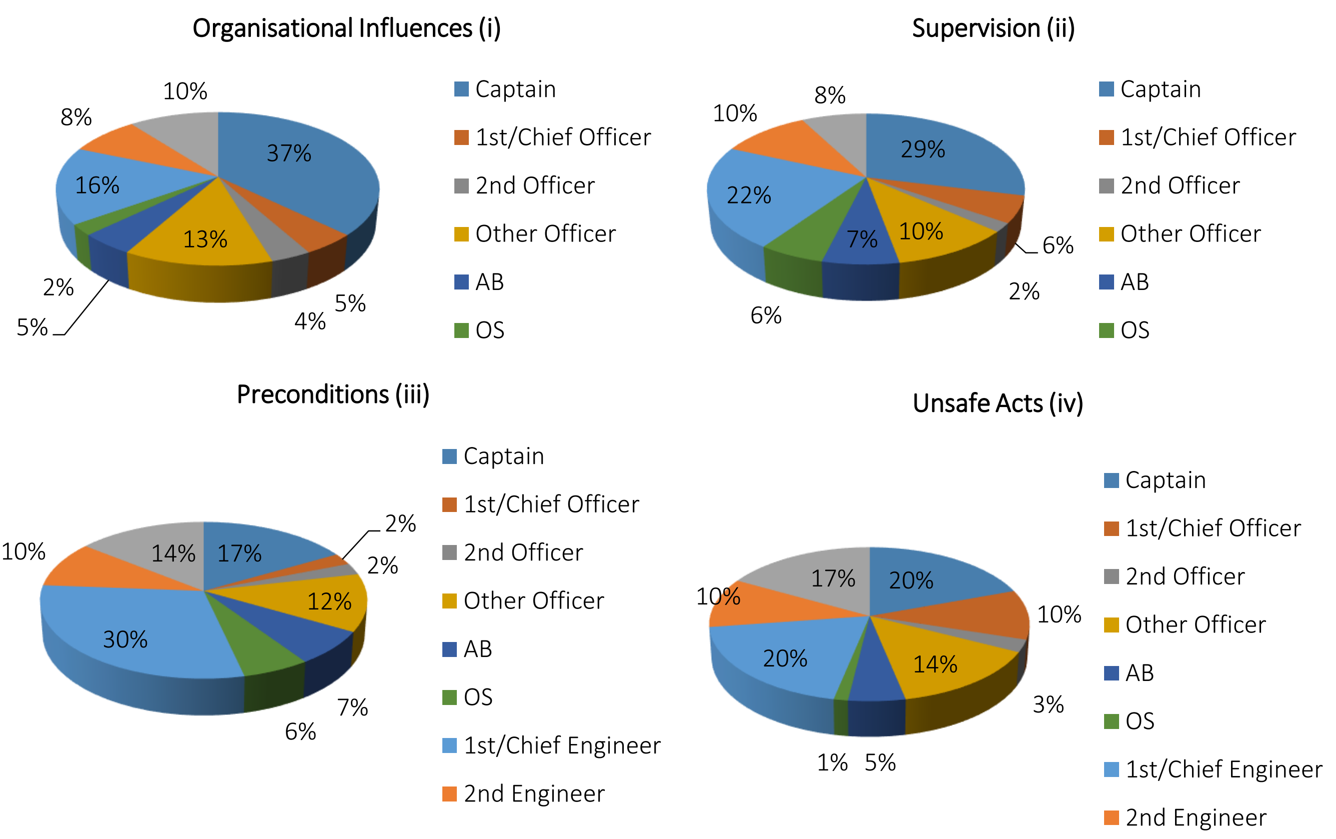
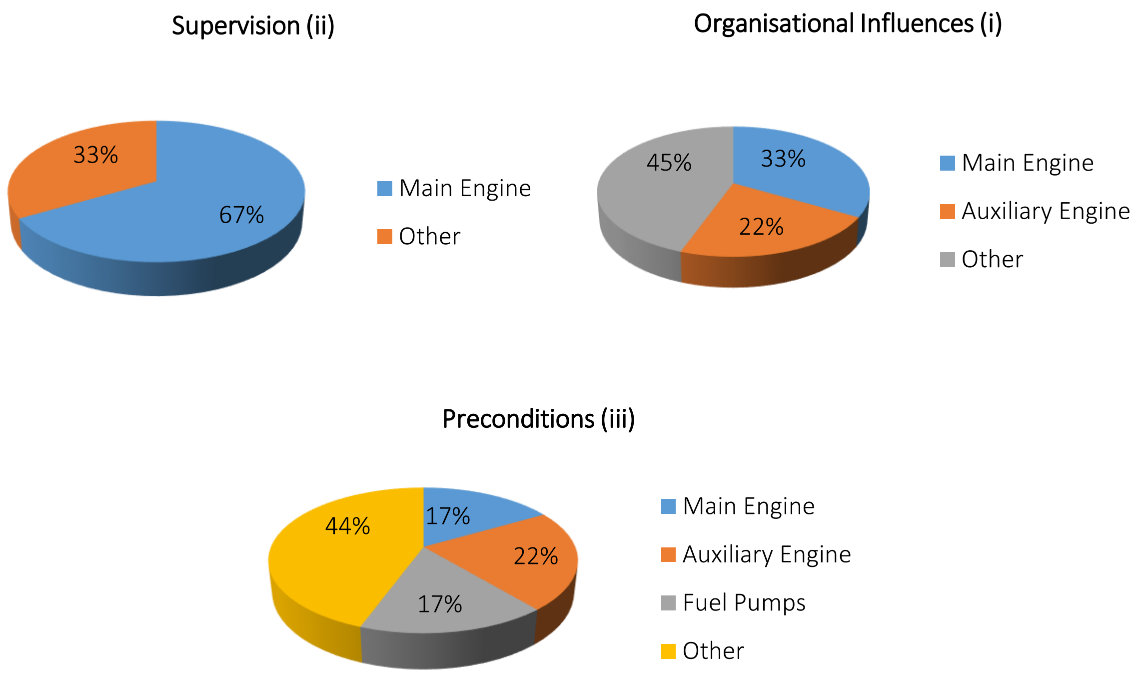


Figure 33: Fire 'phase 0' HFACS equipment overview; **Source:** Student



Figures 32 and 33 above, depict the HFACS categories for operators and equipment respectively. Noteworthy in figure 32 is that the HFACS categories of 'organisational influences' and 'supervision' impact the captain most, however in 'preconditions', the captain is preceded by the chief engineer, who is in-charge of the engine room. Under 'unsafe acts', the captain and chief engineer are equally identified.

The auxiliary engines and the main engine are critical equipment and they are impacted along with fuel pumps by the HFACS categories of 'supervision', 'organisational influences' and 'preconditions'.

Table 17: Fire accident category 'phase 0' HFACS operator overview; **Source:** Student according to taxonomy

L1	Sub-Category L2	Sub-Sub-Category L3	Operator Break Down									**Total**
			C	CO	2O	OO	AB	OS	CE	2E	OE	
Organisational Influences (i)	Resource Management	Lack of Human Resources	4	1	1	4	2	1	5	4	4	26
		Poor Equipment/Facility Resources	2	0	0	0	0	0	1	0	0	3
	Organisational Climate	Disorganised Structure	0	0	0	0	0	0	1	0	0	1
		Inadequate Policies	2	0	0	0	0	0	1	0	0	3
		Poor Work Culture	9	2	2	4	2	1	4	3	4	31
	Organisational Process	Inappropriate Procedures	4	0	0	2	0	0	2	0	1	9
		Lack of Oversight	5	1	0	1	0	0	0	0	0	7
	Statutory Factors	Poor International/National Standards	1	0	0	0	0	0	0	0	0	1
		Inadequate Flag State Implementation	5	0	0	0	0	0	0	0	0	5
											Category Total	86
Supervision (ii)	Inadequate Supervision	Poor Shipborne and Shore Supervision	8	0	1	1	3	2	9	3	1	28
	Planned Inappropriate Operations	Poor Shipborne Operations	7	2	0	4	1	2	6	3	3	28
	Failed to Correct Known Problems	Shipborne Related Shortcomings	9	3	0	3	1	1	6	2	1	26
	Supervisory Violations	Shipborne Violations	6	1	1	3	2	1	2	3	3	22
											Category Total	104

Preconditions (iii)	Environmental Factors	Poor Physical Environment	0	0	0	0	0	0	4	0	1	5
		Poor Technological Environment	3	0	0	2	1	1	4	1	1	13
	Crew Condition	Negative Cognitive Factors	4	1	1	2	3	2	7	3	5	28
	Personnel Factors	Poor Crew Interaction	3	0	0	3	0	0	5	0	1	12
		Poor Personal Readiness	4	1	1	3	2	2	5	4	4	26
											Category Total	74
Unsafe Acts (iv)	Errors	Skill-based errors	4	2	0	3	1	0	4	2	5	21
		Decision and judgement errors	5	2	1	2	1	1	4	2	5	23
		Perceptual errors	0	0	0	0	0	0	1	0	0	1
	Violations	Routine	6	4	1	6	2	0	6	4	3	32
											Category Total	77
		Total	91	20	9	43	21	14	77	34	42	351
Operator: C-Captain; CO-Chief Officer; 2O-2nd Officer; OO-Other Officer; AB-Able Seaman; OS-Ordinary Seaman; CE-Chief Engineer; 2E-2nd Engineer; OE-Other Engineer												

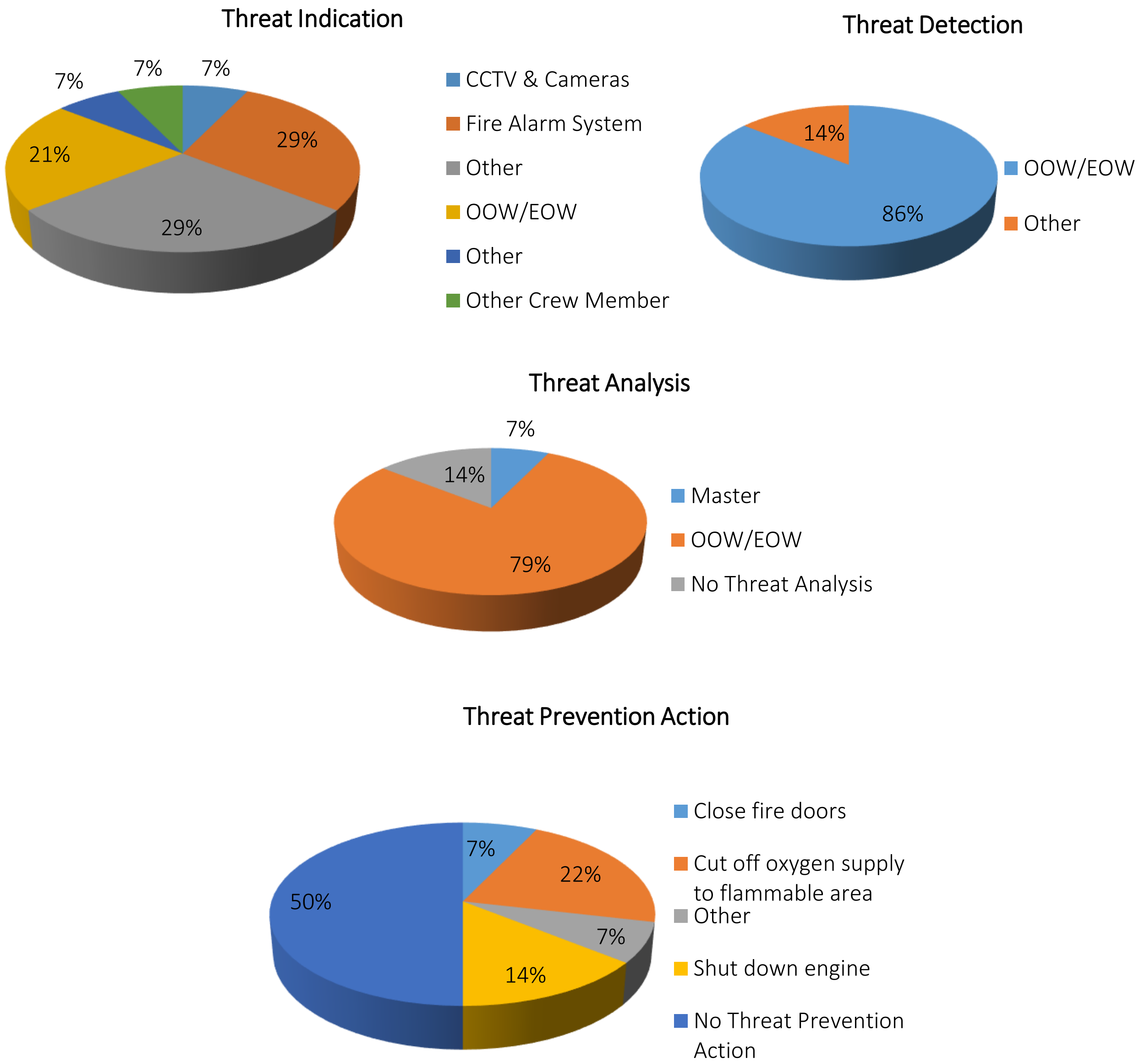
Schröder-Hinrichs et al. (2010) analysed engine room space fires for reporting deficiencies pertaining to organisational factors. The researchers found organisational factors were underrepresented, which could in part be due to the investigator applying the stopping rule early or there could be a difficulty in understanding and applying IMO guidelines on casualty investigation. In their research, unsafe supervision accounted for 3.8% of the coded items (p. 1190), while in this dissertation, supervision accounts for 30% (104/351) in fire accident category and organisational influences account for 24.5% as against their 3.8%.

Table 18: Fire accident category 'phase 0' HFACS equipment overview; **Source:** Student according to taxonomy							
L1	Sub-Category L2	Sub-Sub-Category L3	Equipment Breakdown				Total
			ME	AE	FO PUMP	Other	
Organisational Influences	Resource Management	Poor Equipment/Facility Resources	2	3	0	4	9
	Organisational Climate	Poor Work Culture	1	0	0	2	3
	Organisational Process	Inappropriate Procedures	2	1	0	0	3
		Lack of Oversight	1	0	0	0	1
	Statutory Factors	Poor International/National Standards	0	0	0	1	1
	Statutory Factors	Inadequate Flag State Implementation	0	0	0	1	1
Supervision	Inadequate Supervision	Poor Shipborne and Shore Supervision	1	0	0	0	1
	Planned Inappropriate Operations	Poor Shipborne Operations	1	0	0	0	1
	Failed to Correct Known Problems	Shipborne Related Shortcomings	0	0	0	1	1
Preconditions	Environmental Factors	Poor Physical Environment	0	2	0	0	2
		Poor Technological Environment	3	2	3	6	14
	Crew Condition	Negative Cognitive Factors	0	0	0	1	1
	Personnel Factors	Poor Personal Readiness	0	0	0	1	1
		Total	11	8	3	17	39
Equipment: ME-Main Engine; AE-Auxiliary Engine; FO Pump-Fuel Oil Pump							

4.2.3.2 FIRE CATEGORY 'PHASE 1' OVERVIEW

In 'phase 1' of the fire, the indication of the threat is given by the equipment (CCTV, alarms etc.) and human operators. The threat is largely detected by personnel on watch keeping duty, who also analyse the threat and initiate threat mitigation action.

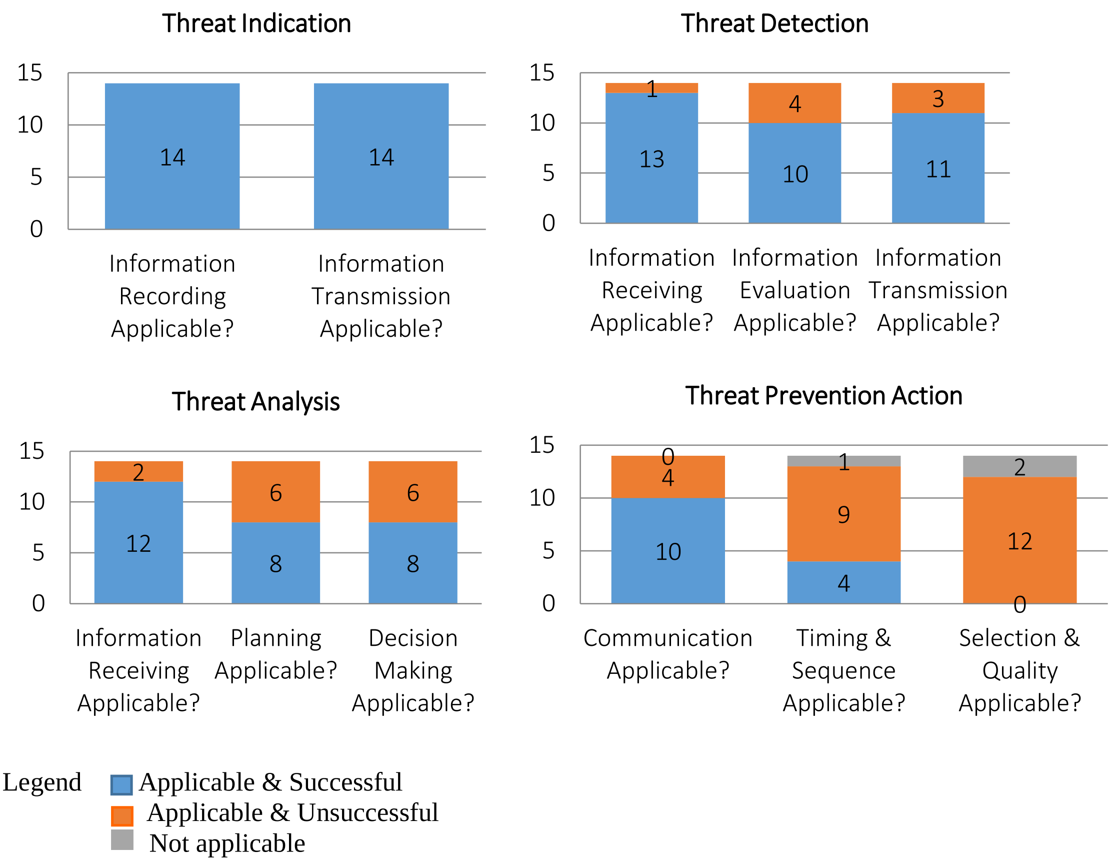
Figure 34: Fire 'phase 1' overview (L1-2); **Source:** Student, based on taxonomy



Threat mitigation actions in this phase usually include closing fire doors, cutting oxygen supply to the area and shutting down engines among others.

Figure 35: Fire 'phase 1' overview (L3-4)

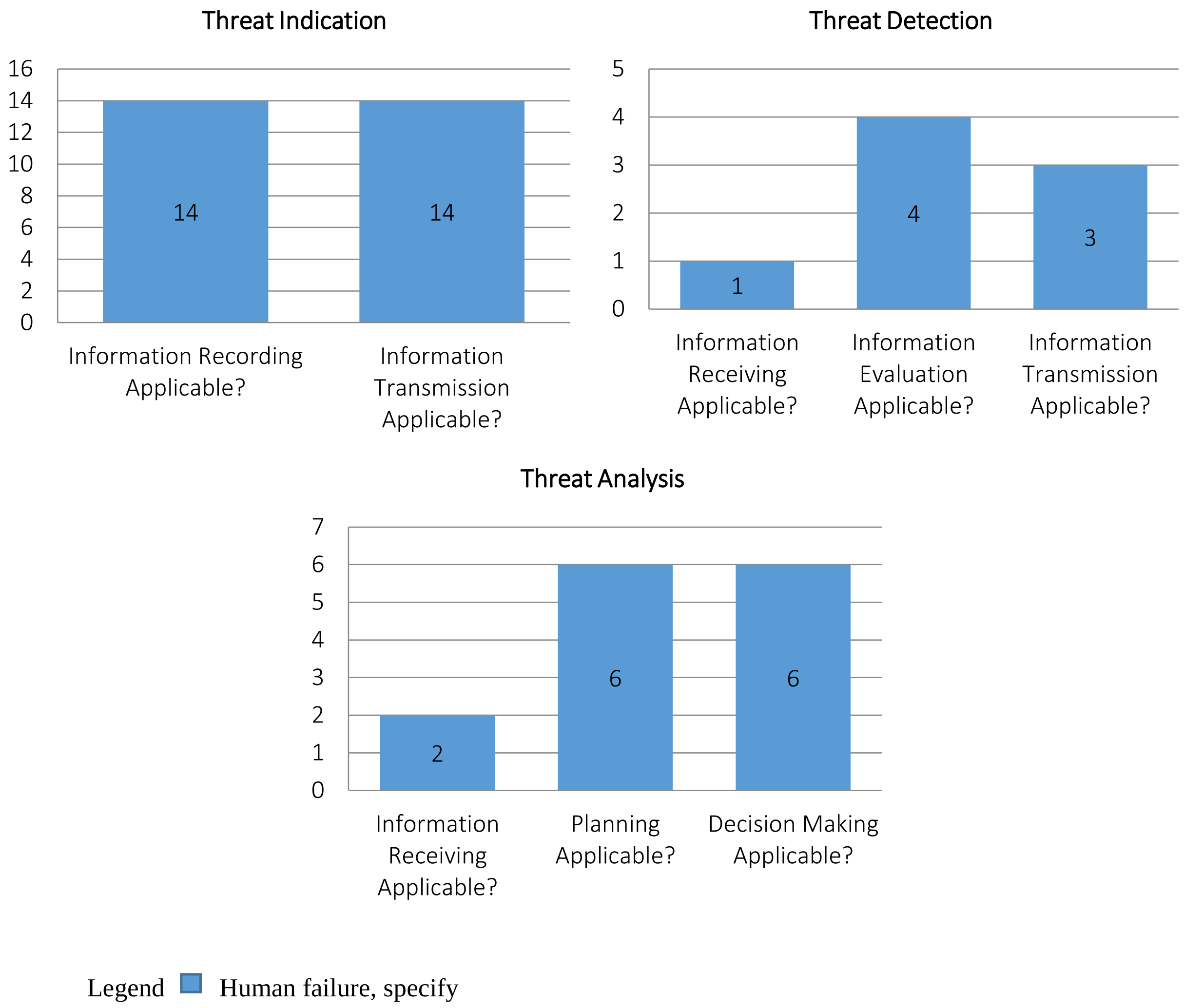
Source: Student, based on taxonomy



'Phase 1' level 3-4, codes information related aspects, planning, decision making and action and identifies if they were successful or not. According to the analysis, 104 times an aspect was applicable and successful while 47 times an applicable aspect was unsuccessful. 'Phase 1' level attributes the failure to human or equipment (see figure 36 on page 69).

Figure 36: Fire 'phase 1' overview (L4-5)

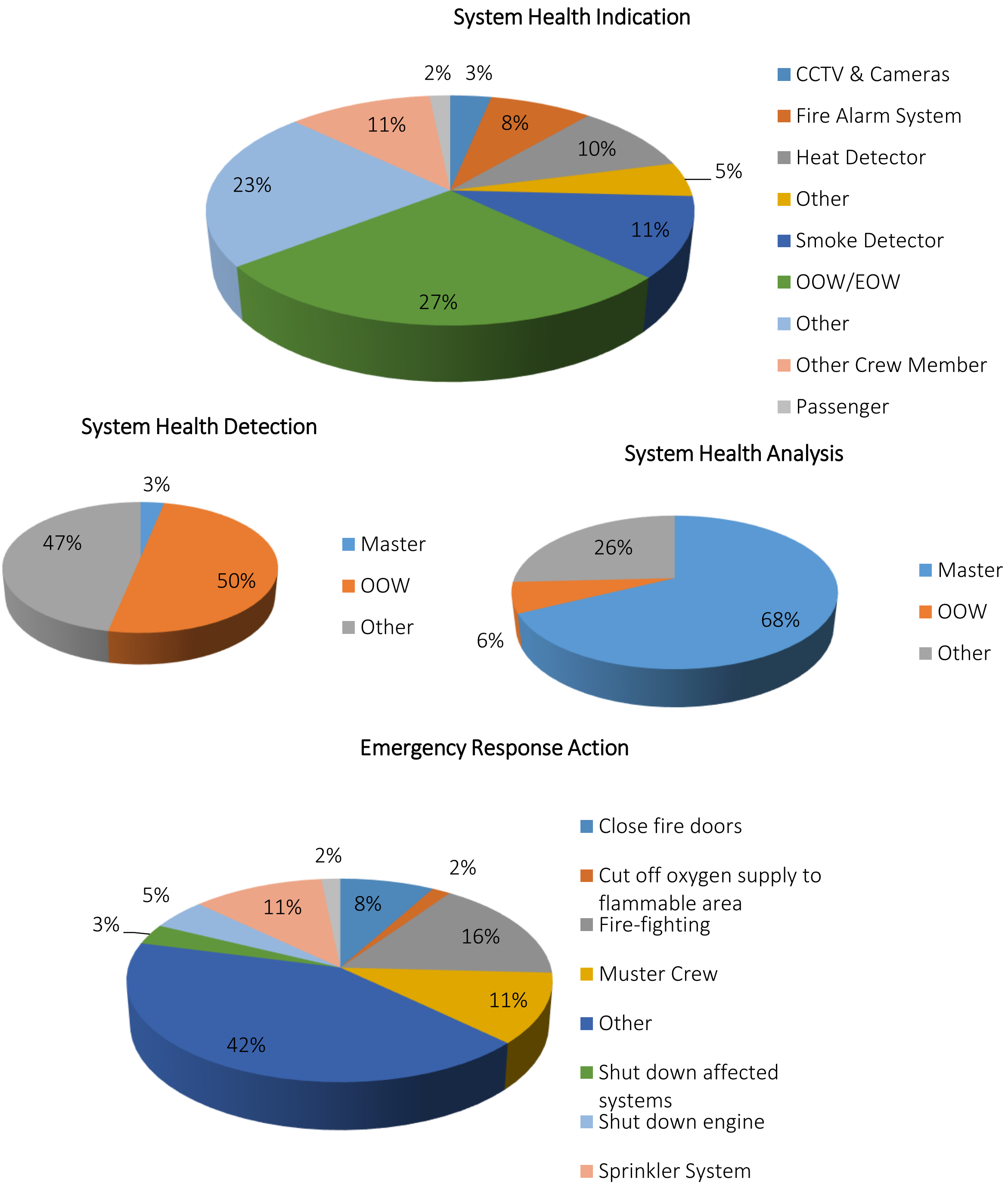
Source: Student, based on taxonomy



In phase 1, in each of the 47 instances, the failure was attributable to human operators. Lack of success in phase 1, moves an accident into the next accident phase in which the system health has to be evaluated after the accident has taken place.

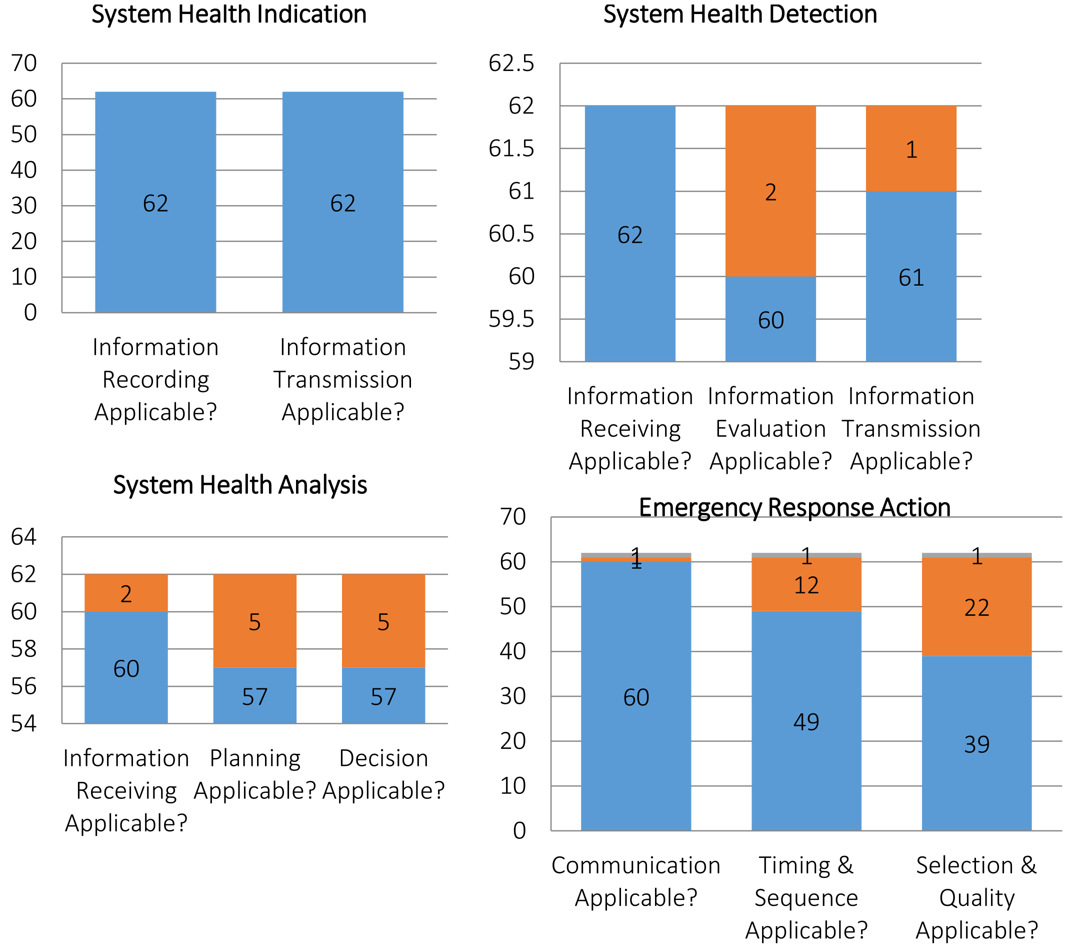
4.2.3.3 FIRE CATEGORY 'PHASE 2' OVERVIEW

Figure 37: Fire 'phase 2' overview (L1-2); **Source:** Student, based on taxonomy



In phase 2 (L1-2), once the fire has taken place, the system health is detected by various on-board equipment like the fire alarms, heat detector, smoke detector, CCTV and cameras. However it is noteworthy that the system health indication is largely attributed to the human operators on duty, which are the officer of the watch and the engineer officer on watch, who also detect system health. Unlike phase 1 which is the beginning phase of the accident, in phase 2 the incident has progressed. While in phase 1, the threat analysis was largely conducted by the officers on site, in phase 2 the threat analysis is predominantly carried out by the master and a host of emergency response actions are carried out. Level 3-4 analyse the applicability and success and failure of aspects of information (recording, transmission, receiving, and evaluation), planning and decision and emergency response action.

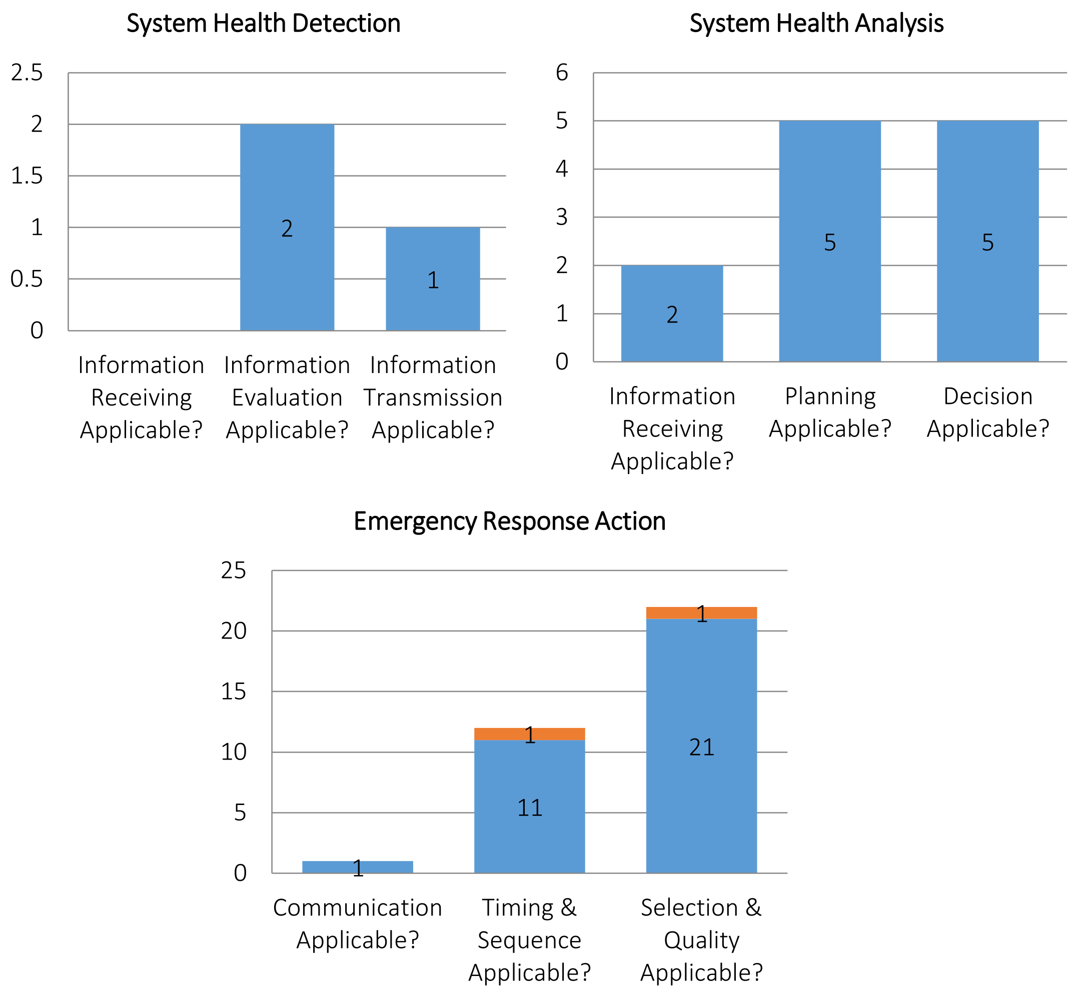
Figure 38: Fire 'phase 2' overview (L3-4); **Source:** Student, based on taxonomy



Legend: Applicable & Successful; Applicable & Unsuccessful; Not applicable

Figure 38 shows that in 50 instances an aspect was applicable and unsuccessful and there were a total of 629 instances when an aspect was applicable and successful.

Figure 39: Fire 'phase 2' overview (L4-5); **Source:** Student, based on taxonomy



Legend
- Human error, specify
- Equipment error, specify

In level 4-5 of 'phase 2' of the fire accident category, the failures of the preceding level are specified to equipment or the human operator. In this phase of the fire accident out of a total of 50 failures, 2 are attributable to equipment failure and 48 to human operators.

Although all of the vessels in the fire accident category were in compliance with SOLAS equipment and certification requirements, however a number of times these certificates have been issued without adequate verification and by cutting the corners with respect to the safety checks. For e.g. *Queen Mary 2*, Harmonic Filters were not tested during Continuous Survey of Machinery (CSM) surveys as required and failure of this impacted the accident after almost two months (MAIB, 2011, p. 32). In the case of *M.V. Calypso*, CO_2 system was not tested as required and CO_2 failed to release during engine room fire. On investigation it was found that even the procedure posted on-board were incorrect. Majority of the fire accidents on-board were due to the fuel oil leakage in Auxiliary engines or Main engine. Which was largely due to the failure to comply with standard good engineering practices during routine and non-routine maintenance work. An aspect was the failure to comply with equipment / manufacturers guidelines when overhauling or replacing / refitting the damaged parts or leaking pipes. This also highlights inadequate training trends for engineers who failed to refer to equipment manual during inspection and investigation of leaks or failed to consult senior engineers in case of doubt, for e.g. *M.V. Azamara Quest* (MSI, 2013, p. 14, p. 22). Inadequate Formal Safety Assessment (FSA) also impacted the accident, for e.g. *Queen Mary 2*, in which the Hi Fog system was fitted in compartments containing the high voltage system.

All of the fire accidents finished in stage two due to good response from duty engineers, officers of the watch as well as due to modern automatic firefighting equipment on some ships which contributed positively. However at times due to lack of training or a failure to understand the equipment / system limitations have resulted in failure to contain the fire, for e.g. *M.V. Carnival Splendor* accident report (USCG, 2013, p. 6), where OOW performed a general reset on the fire detection system and by doing so, the Hi-Fog system failed to activate automatically as it was designed to avoid time delay. This initial mitigation measure could have contained the fire from spreading, provided the OOW was aware of the system limitation.

4.3 OVERVIEW OF THE RESULTS OF ALL 3 CATEGORIES – FLOODING, GROUNDING AND FIRE

This section combines the results obtained from all three accident categories and provides an overview of the findings.

Table 19: All accident categories 'phase 0' (HFACS) operator overview; Source: Student based on taxonomy

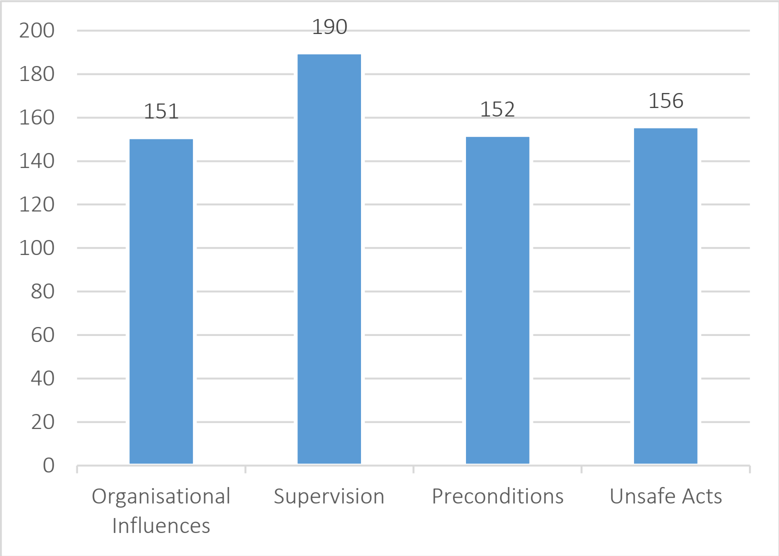
L1	Sub-Category L2	Sub-Sub-Category L3	Total Operator Break Down											Total
			C	CO	2O	OO	AB	OS	H	P	CE	2E	OE	
Organisational Influences (i)	Resource Management	Lack of Human Resources	11	5	2	5	2	1	0	1	5	4	4	40
		Poor Technological Resources	2											2
		Poor Equipment / Facility Resources	2	0	0	0	0	0			1	0	0	3
	Organisational Climate	Disorganised Structure	2	1	0	0	0	0			1	0	0	4
		Inadequate Policies	3	0	0	0	0	0			1	0	0	4
		Poor Work Culture	18	7	4	7	2	1	1	3	4	3	4	54
	Organisational Process	Poorly Designed Operation	9		1									10
		Inappropriate Procedure	7											7
		Inappropriate Procedures	4	0	0	2	0	0			2	0	1	9
		Lack of Oversight	6	1	0	1	0	0			0	0	0	8
	Statutory Factors	Poor International/National Standards	4	0	0	0	0	0			0	0	0	4
		Inadequate Flag State Implementation	6	0	0	0	0	0			0	0	0	6
													Category Total	151

Supervision (ii)	Inadequate Supervision	Poor Shipborne and Shore Supervision	18	3	3	3	3	2			9	3	1	45
	Planned Inappropriate Operations	Poor Shipborne Operations	21	9	3	7	1	2		3	6	3	4	59
	Failed to Correct Known Problems	Shipborne Related Shortcomings	17	7	2	3	1	1		2	6	2	1	42
	Supervisory Violations	Shipborne Violations	19	5	3	6	2	1			2	3	3	44
													Category Total	**190**
Preconditions (iii)	Environmental Factors	Poor Physical Environment	1	0	0	0	0	0			4	0	1	6
		Poor Technological Environment	8	0	3	3	1	1		1	4	1	1	23
	Crew Condition	Negative Cognitive Factors	15	3	4	7	3	2		1	7	3	6	51
		Poor Physiological State	3											3
	Personnel Factors	Poor Crew Interaction	9	4	1	4	0	0	2	2	5	0	1	28
		Poor Personal Readiness	12	4	2	4	2	2	2		5	4	4	41
													Category Total	**152**
Unsafe Acts (iv)	Errors	Skill-based errors	21	5	2	7	1	0	1	3	4	2	5	51
		Decision and judgement errors	16	3	2	2	1	1			4	2	5	36
		Perceptual errors	0	0	0	0	0	0			1	0	0	1
	Violations	Routine	20	9	5	10	2	0	1	1	6	4	3	61
		Exceptional	4	1	1					1				7
													Category Total	**156**
		Total	258	67	38	71	21	14	7	18	77	34	44	**649**

Operator: C-Captain; 2O-2nd Officer; OO-Other Officer; AB-Able Seaman; OS-Ordinary Seaman; H-Helmsman; P-Pilot; CE-Chief Engineer; 2E-2nd Engineer; OE-Other Engineer

Table 19 on the preceding page provides an overview of all the 15 passenger ship accidents coded for the dissertation under the 'phase 0' HFACS adapted taxonomy. A total of 649 items were coded, of which a third were coded under the supervision category (190, 30%), followed by unsafe acts (156, 24%), preconditions (152, 23%) and organisational influences (151, 23%).

Figure 40: All accident categories 'phase 0' HFACS category overview
Source: Student



All the subcategories under *supervision* – *inadequate supervision, planned inappropriate operations, failed to correct known problems and supervisory violations* were coded highly. Under *organisational influences,* the category of *poor work culture* was coded 54 times, which is a cause for concern. Under the category of *preconditions*, *negative cognitive factors* were coded 51 times and under the category of *unsafe acts*, *skill based errors* were coded 51 times and *routine violations* 61 times. Poor work culture will be discussed further in chapter 6.

The captain was coded 258 times out of 649 (40%), followed by the chief engineer (12%), other officer (11%) and chief officer (10%).

Table 20: All accident categories 'phase 0' (HFACS) equipment overview
Source: Student based on taxonomy

1	Sub-Category L2	Sub-Sub-Category L3	Total Equipment Breakdown						
			ME	AE	FO PUMP	Other	Navigation Aids (AIS, ECDIS, Radar, GPS, etc.)	Steering Equipment	Total
Organisational Influences (i)	Resource Management	Poor Technology Resource				2	1		3
		Poor Equipment/Facility Resources	2	3	0	4		1	10
	Organisational Climate	Disorganized Structure				1		1	2
		Inadequate Policies							
		Poor Work Culture	1	0	0	4	1		6
	Organisational Process	Poorly Designed Operation				1			1
		Inappropriate Procedures	2	1	0	2			5
		Lack of Oversight	1	0	0	0			1
	Statutory Factors	Poor International / National Standards	0	0	0	1			1
	Statutory Factors	Inadequate Flag State Implementation	0	0	0	1			1
									Organisational Influences Category Total: 30
Supervision (ii)	Inadequate Supervision	Poor Shipborne and Shore Supervision	1	0	0	0			1
	Planned Inappropriate Operations	Poor Shipborne Operations	1	0	0	0		1	2
	Supervisory Violations	Shipborne Violations						1	1
	Failed to Correct Known Problems	Shipborne Related Shortcomings	0	0	0	1			1
									Supervision Category Total: 5

Preconditions (iii)	Environmental Factors	Poor Physical Environment	0	2	0	1		1	4
		Poor Technological Environment	3	2	3	8	1	1	18
	Crew Condition	Negative Cognitive Factors	0	0	0	2			2
	Personnel Factors	Poor Personal Readiness	0	0	0	1			1
Preconditions Category Total: 25									
Total			11	8	3	29	3	6	60

A total of 60 items were coded in the ‘phase 0’ HFACS coding for technical subjects (equipment). *Organisational influences* were coded the highest (30, 50%), followed by *preconditions* (25, 41%) and *supervision* (5, 9%). Under *organisational influences*, attention needs to be paid to the subcategory of *poor equipment/facility resources* which was coded 10 times (17%). Under *preconditions*, sub-sub category of *poor technological environment* received a high coding of 18 (30%) which would further need to be evaluated.

Among the equipment, the main engine (11, 18%) and the auxiliary engines (8, 13%) received a high coding. A high 50% of equipment coded available under the ‘other’ equipment category. The raw data pertaining to the other equipment would be used to expand the SEMOMAP taxonomy.

Table 21 on the following page provides an overview of all three accident categories in all the three phases for taxonomy level 3-4 and 4-5 evaluation. The table shows that the fire accident category went into two phases and the bulk of the effort is concentrated in ‘phase 2’. The table also shows that the flooding accident finished within ‘phase 1’ itself.

Table 21: All accident categories, all phases, level 3-4 and 4-5 evaluation; **Source:** Student

No	Nature of Accident	Phase	Stages	Number of Subjects	Number of events	process fail/safe status			Failure source	
						Safe	Fail	Not Applicable	Human Failure	Equipment Failure
1	Fire	Phase-1	Threat Indication	6	28	28	0	0	0	0
			Threat Detection	2	42	34	8	0	8	0
			Threat Analysis	3	42	28	14	0	14	0
			Threat Prevention Action	5	42	14	25	3	25	0
		Phase-2	System Health Indication	9	124	124	0	0	0	0
			System Health Detection	3	186	183	3	0	3	0
			System Health Analysis	3	186	174	12	0	12	0
			Emergency Response Action	9	186	148	35	3	33	2
		Phase-3	Emergency Response & Evacuation Action		0					
			System Health Indication		0					
			System Health Detection		0					
			System Health Analysis		0					
2	Flooding	Phase-1	Threat Indication	1	2	2	0	0	0	0
			Threat Detection	1	3	3	0	0	0	0
			Threat Analysis	1	3	3	0	0	0	0
			Threat Prevention Action	1	3	3	0	0	0	0
		Phase-2	System Health Indication		0					
			System Health Detection		0					
			System Health Analysis		0					
			Emergency Response Action		0					
		Phase-3	Emergency Response & Evacuation Action		0					
			System Health Indication		0					
			System Health Detection		0					
			System Health Analysis		0					

3	Grounding	Phase-1	Threat Indication	6	20	11	3	6	3	0
			Threat Detection	3	30	9	9	12	9	0
			Threat Analysis	2	30	4	9	17	9	0
			Threat Prevention Action	2	33	5	10	18	10	0
		Phase-2	System Health Indication	5	36	32	2	2	2	0
			System Health Detection	3	54	53	0	1	0	0
			System Health Analysis	3	54	42	11	1	11	0
			Emergency Response Action	3	60	43	17	0	17	0
		Phase-3	Emergency Response & Evacuation Action	6	21	21	0	0	0	0
			System Health Indication	2	14	14	0	0	0	0
			System Health Detection	2	21	21	0	0	0	0
			System Health Analysis	1	21	21	0	0	0	0

The grounding accident category in table 21 above shows that the accident entered into the third phase of evacuation and the bulk of efforts were concentrated in ‘phase 2’.

Table 22 on the following page presents an overview of each time a human operator was applicable and successful or unsuccessful and each time an equipment was applicable and successful or unsuccessful.

Table 22: All accident categories, all phases, level 3-4 and 4-5 evaluation

Source: Student

Category	Phase	Human operator		Equipment		Total
		Applicable		Applicable		
		Successful	Unsuccessful	Successful	Unsuccessful	
Flooding	Phase 1	11				**11**
Fire	Phase 1	104	47			**151**
	Phase 2	629	48		2	**679**
Grounding	Phase 1	29	31			**60**
	Phase 2	170	30			**200**
	Phase 3	77				**77**
Total		**1020**	**156**		**2**	**1178**

Table 22 shows that the equipment only failed 2 times when applicable and the human operator failed 156 times (13%) and succeeded 1020 times (87%). Timing is crucial in on-board accident situations. The success of the human operators in phase 1 of the flooding incident averted a more serious accident and the successes of the human operators in 'phase 2' of the fire accident category prevented the fire accidents from going further into the next evacuation accident phase. Failure in a phase leads the accident to progress to the next subsequent phase, however the analysis shows that the recovery from accidents is creditable to the successes of human operators (Reason, 2008).

Table 23: Timelines: all accident categories across all phases

Source: Student

Category	Vessel Name	Phase 1	Phase 2	Phase 3
Flooding	M.V. Saga Sapphire	00H 02M 00S	--	--
	Total	**2 Min**		
Fire	M.V. Azamara Quest	00H 03M 00S	00H 01M 29S	--
	M.V. Carnival Spirit	--	--	--
	M.V. Carnival Splendor	00H 02M 00S	09H 13M 00S	--
	RMS Queen Mary 2	00H 36M 00S	00H 24M 00S	--
	M.V. Royal Princess	00H 00M 45S	04H 32M 00S	--
	M.V. Star Princess	00H 19M 00S	01H 27M 00S	--
	M.V. The Calypso	NA	00H 38M 00S	--
	M.V. Zenith	00H 20 M 00S	01H 28M 00S	--
	Total	**80 Min 45 Sec**	**17 Hr 43 Min**	
	Average time	**13 Min**	**2 Hr 31 Min**	
Grounding	M.V. Lauren L	01H 17M 00S	Not mentioned	Not mentioned
	M.V. Clipper Adventure	00H 32 M 00S	Not mentioned	Not mentioned
	M.V. Deutschland	00H 06M 15S	00H 08M 37S	--
	M.V. Van Gogh	00H 02M 00S	00H 03M 00S	--
	M.V. Astor	00H 04M 00S	00H 03M 00S	--
	M.V. Monarch of the Seas	00H 03M 00S	01 H 05 M 00S	02H 55M
	Total	**2 H 4 M 15 S**	**1 H 19 M 37 S**	**2 H 53 M**
	Average time	**20 Min**	**20 Min**	**2 H 53 M**

Table 23 depicts the timelines applicable to all phases across all accidents. It can be seen that the time in phase 1 for the flooding accident category was only two minutes and the accident did not progress further. In the fire accident category, the bulk of the efforts were concentrated in phase 2 with an average of 2 hours and 31 minutes and the accident not progress to the evacuation phase. In the grounding accident category, phase 1 and 2 took an average of 20 minutes each. It is noteworthy that the average of the grounding accident category for phase 2 is distorted as one vessel, *M.V. Monarch of the Seas* had a high phase 2 timeline of one hour and five minutes which affected the average. Going by the other three vessels that have provided timelines for grounding (*M.V. Deutschland, M.V. Van Gogh and M.V. Astor*), the phase 2 timeline in grounding accidents is between 3 and 8 minutes. *M.V. Monarch of the Seas* moved into phase 3 of evacuation and therefore spend considerable time in both phases 2 and 3. The other two vessels that evacuated passengers (*M.V. Lauren L and M.V. Clipped Adventurer*), did not mention timelines for phases 2 and 3 and therefore the timeline analysis is incomplete. It is to be noted that the timeline analysis is not robust as all of the accident investigation reports had not mentioned clear timelines. This analysis is indicative of the insights one can gain if standardised reporting procedures include timelines in the reports.

4.4 SUMMARY

This chapter has presented the findings of the dissertation across all accident categories, phases and taxonomy levels according to the SEMOMAP accident investigation model and its complementary taxonomy. The following chapter reflects on the findings.

5 DISSERTATION REFLECTIONS

This chapter reflects upon the findings of the dissertation and discusses how the research questions have been answered in the dissertation.

5.1 REFLECTION ON SEMOMAP

SEMOMAP as a maritime accident investigation model has tremendous potential. It is extremely useful to consider the accident process to reveal insights that could help us ultimately to learn from accidents and prevent them from recurring in the future. SEMOMAP is a robust model that incorporates both HFACS and TRACEr taxonomies, allowing for the identification of factors impinging on the accident situation removed in time. However, worthwhile to note here is that the analysis utilising SEMOMAP is largely dependent on the quality of the accident investigation report, which will be discussed further in this chapter

The SEMOMAP taxonomy can be further expanded to be more comprehensive and specific. It could include other ranks on-board to make it more specific. In case of passenger ships they have other staff which is not reflected in the taxonomy (e.g. Staff Captain, Customer service, Safety officer, Staff Chief Engineer, Hotel Staff, etc.). In the electronic database platform created in MaRiSa, WMU to facilitate SEMOMAP coding, 'other' additional human operators are not included in the category as it accepts the first entry. This can be resolved to be more specific about the 'other' human operators involved.

Muster passengers and muster crew should be depicted separately in the taxonomy as these are two different actions most of the times and occur at different time intervals. Under communication, the urgency message / distress message can be included in the taxonomy. The critical equipment list can be expanded to be more exclusive as most of the time these are involved in the accident (quick closing valves, harmonic filters, etc.).

The taxonomy could consider including MAIB, NTSB, USCG etc. under the investigating authorities. Analysis of the report depends upon the quality of the investigation report as well as the investigator and assessor, as many reports may be investigated by a technical expert who has none or limited in depth training on Human element or factors. So he/she is likely to miss out key human element or human factors issues which may have contributed to the accident or incident. Therefore it is imperative to follow a uniform standard for accident investigation where all aspects are covered / approached with equal importance. It is worth noting that investigation reports conducted by USCG and ATSB are much more comprehensive than other reports which were conducted by some flag states. When analysing these reports one gets a much broader and clearer picture about the various contributory factors. A research on various investigating bodies and a comparison of their findings itself will be highly valuable and can contribute positively in drawing future guidelines for accident investigation of the IMO.

The NTSB is an independent governmental agency charged with determining the probable cause of transportation accidents and promoting transportation safety in the United States, whereas in some other states it may not be the same and they might not be in a position to conduct similar independent investigations due to lack of freedom.

For further validation of SEMOMAP, professional researchers from different spectrum of the industry must be considered (operational, academics, inspectors etc.). They should be given similar case studies for the analysis and the outcome must be compared for further improvement and amendment. This will help in making the model more robust to meet diverse complex requirements.

5.2 REFLECTION ON RESULTS AND RESEARCH QUESTIONS

All the research questions, the student had identified in the beginning of the dissertation have been adequately answered in the preceding chapters. This section provides a reflection on them.

- **Is the maritime industry specific SEMOMAP suitable to explore maritime accidents?**

  This research question has been answered adequately in chapter 4 on the analysis of accident investigation reports. The model has undergone comprehensive testing and evaluation in the analysis of 15 accident investigation reports and has served the student well by not being generic but rather specific to the maritime domain with a nuanced understanding of its language, personnel, operations, equipment and shipboard and shore based dimensions.

- **What is it about the unique unfolding of the accident process on board and the shipboard behaviours and barriers, if any, that can lead to different accident outcomes for different accidents.**

  The time of reaction to a developing dangerous situation and corresponding evaluation of applicable and successful/unsuccessful aspects leads to different outcomes for different vessels. The majority of the fire accidents were the result of inadequate investigation of the underlying causes by the responsible engineers and failure to comply with standard procedures. This occurred despite frequent break down and parameter alarms (e.g. *M.V. Carnival Splendor* (USCG, 2013)) where auxiliary engine frequently tripped due to overload and torsional vibration alarm from the equipment. In another case of *M.V. Azamara Quest* (MSI, 2013), the auxiliary engine was made to run on load directly after the repair was performed for fuel oil leakage and without conducting any test run as necessary to ensure that the repair was successful.

Accident investigation with a focus on the involved processes and actions reveals unique insights into on-board work culture. The case of *M.V. Azamara Quest*, highlights that the accident could have been completely averted in 'phase 1' itself if the motor man who had detected the fuel oil leak had the authority to tackle it locally. He reported the risk to the second engineer on the VHF who came down to confirm the source of the leak and assess the situation and then decided to stop the generator remotely from the control room instead of locally taking care of the risk. This costly time delay resulted in a full-fledged fire incident which resulted in a severe loss to the vessel. This aspect highlights among others, the lack of authority of the lower ranked motor man to deal with issues locally; the complacency of the second engineer which resulted in loss of time and poor decision of the second engineer to remotely turn off the generator. This is especially more important when given the fact that most of the fire accidents were caused due to fuel oil leakage. Any leakage from critical equipment with hot surfaces around, should be dealt with, without any time delay. However, in some cases where vigilant crew responded swiftly, they managed to contain the fire and loss was mitigated. This highlights that good practices and additional barriers on-board can certainly help in mitigating loss.

- **What are the common processes in emergency situations on-board in case of fire, grounding and flooding?**

  In majority of the cases they followed the routine SMS procedures for the particular emergency, however at times failed to comply with the same which could be due to lack of training and/or complacency, among other factors. In case of flooding no claims can be made about common processes as only one accident was analysed under the category. In fire it is noteworthy that in all accidents the first phase is relatively short and if the threat is not detected and mitigated swiftly, it develops quickly into an accident and enters 'phase 2'. It is noteworthy that in most firefighting accidents, 'phase 2' is long as the bulk of the firefighting efforts are concentrated in this phase. In the grounding accident category, most of the accidents have a short phase 1 and a short phase 2. It can be safely assumed that they would then have a longer phase 3 as that would involve evacuation.

- **How much time is available to recover from an emergency situation during the different phases of the accident?**

The majority of the accident investigation reports do not provide a very good time line and therefore it is difficult to make claims related to time analysis. However this is a potential aspect that SEMOMAP allows to be evaluated.

- **How realistic is the time limit of 30 minutes required for abandoning ship, post breach of threshold.**

All three vessels that conducted evacuations only did it for the passengers and no timelines are provided for crew transfer. *M.V. Monarch of the Seas* had 2557 passengers and 831 Crew members, *M.V. Clipper Adventurer* 128 passengers and 69 Crew members on-board and *M.V. Lauren L* had only 38 passengers and the number of crew member was not mentioned in the report. They remained on-board for further duration.

- **M.V. Clipper Adventurer**

The grounding incident occurred on 27th Aug at 1832 Lt and all passengers were mustered at 1910 Lt, which is almost after 38 minutes delay and since the vessel was firmly aground; after assessing the situation, passengers were asked to stand down at approximately 2030 Lt. The total number of passengers on-board at the time of the incident was 128 and 69 crew. The passengers were transferred to another vessel on the 29th August at 1000 Lt.

Although the passengers were transferred safely from all ships however the time taken to transfer them was not clearly defined and certainly it was much more than the 30 minutes time window as required by the IMO.

One of the observations made during this analysis is that during most of these emergencies, the passengers were not updated and mustered immediately after the accident. This can lead to a dangerous situation as it is difficult to hide an impact or blackout on-board. Waiting till the last minute, keeping the passengers uninformed can cause panic and uncertainty. Therefore, it is recommended that whenever there is an accident on-board, it is imperative to muster the crew and passengers without delay, and continue system assessments as appropriate. In case the situation is not so serious the passengers and crew can be stood down later on.

- **M.V. Monarch of the Seas**

The grounding incident occurred on 15th December at 0130 Lt and all the passengers were mustered at 0148 Lt. The portside lifeboats were lowered at 0210 and STBD side at 0215. However after assessing the damage the master decided to ground the vessel intentionally at 0235 Lt this was done to minimise the chances of flooding and foundering. Since vessel was close to the port the master decided to use tenders for transferring passengers from the ship to shore. At 0245 first tender came alongside and at 0519 they completed the passenger disembarkation operation. The operation took around 02h 34m which is much more than the IMO’s limit of 30 minutes and this is when the vessel was resting on the reef. The total number of passengers on-board at the time of incident was 2557 and 831 crew members.

- **M.V. Lauren L**

M.V. Lauren L had only 38 passengers and the number of crew members number was not mentioned in the report. They remained on-board for further duration. The timeline for the transfer operation is also not mentioned in the report.

With a limited number of evacuation incidents, it is difficult to confirm the validity of the IMO's time requirement, however, in the above accidents it certainly took much more time to evacuate the passengers as compared to the 30 minute time limit. Delay in mustering the passengers is a major cause for concern and this approach highlights the lack of training and standardised procedures in such an emergency. This needs to be highlighted further to create mandatory procedures to ensure that passengers are informed and mustered without delay in case of an incident or accident on-board.

5.3 SUMMARY

Reports from NTSB, USCG, MAIB and BSU covered the investigation in depth whereas some other administration and investigating agency reports were shallow without adequate timeline or further information. A majority of the accidents were attributed to human error and SEMOMAP has the strength to investigate how humans mitigate accidents on-board. Accident investigation reports should include the positive human contribution and support SEMOMAP in studying this aspect. In some cases the reports have highlighted the need of further training etc., but unfortunately these accidents were found to be recurring on ships supposedly manned by well-trained officers and crew. The question is, are we looking in the right direction? If so, why are we unable to minimize these accidents? And what needs to be improved so that we can get positive results on a global level?

SEMOMAP is a step in the right direction with respect to maritime accident investigation and should be utilised to study accident cases to reveal comprehensive insights into accident processes and what action we might recommend at which stage to stop the situation from escalating further.

6 CONCLUSIONS

The SEMOMAP model and its accompanying taxonomy are robust for the purpose of maritime accident investigation. Most of the accidents analysed in this dissertation highlight a lack of inadequate risk assessment and non-compliance with SMS in line with the ISM code. The results revealed among other issues, a poor work culture on-board and negative cognitive attitudes. It is important to sensitise the shipping industry and academic community to HFACS aspects in connection with on-board accident processes which can be analysed with SEMOMAP. This can help us to understand recovery from accident situations and help us to learn in detail about accident processes, in addition to the other factors impacting the accidents.

Given the dissertation findings, effective implementation of rules and regulations like the ISM code is essential for increasing overall safety and reducing risk on-board ships[2]. The theme for the 2014 World Maritime day is the effective implementation of IMO conventions (IMO, 2014b). Mandatory compliance is required with the ISM with the introduction of chapter IX into SOLAS - *"Management for the Safe Operation of Ships"*. The ISM code links the flag, the owner and the vessel and requires a customized SMS tailored to suit the company needs to improve on-board safety (Baldwin and Cave, 1999).

Regarding the ISM code, Bhattacharya (2012a, p. 528) found *'a wide gap between its intended purpose and practice'*. The researcher found a *lack of seafarers' participation* and the *underlying causal factors* were located in *poor employment conditions* and *low trust relationships*.

[2] A previous version on the implementation of the ISM code has been submitted by the student for MSEA 253, Maritime Human Element assignment.

Learning from incidents on board is essential to enhance shipboard safety. The self-regulatory nature of the ISM code requires for shipboard incidents to be *reported, investigated and analyzed* (Bhattacharya, 2012b, p. 4). Batalden & Sydnes (2014) found that the main challenges pertained to four sections *of the ISM code*: Section 5 – Master's responsibility; Section 6 – resources and personnel; Section 7 – development of plans for shipboard operation and Section 12 – company, verification, review and evaluation. The findings of the HFACS coding of this dissertation are in a similar direction and need to be addressed to contribute to the on-board safety culture.

The ISM code has contributed to safety (Heijari and Tapaninen, 2010) and should be effectively implemented to reap the benefits. There is a link between the *organizational safety climate* and *employee safety compliance* which leads to *increased employee participation and reduction in accidents* (Clarke, 2006). Management of shipboard safety requires building and sustaining a safety culture on board (Havold, 2010, Ek et al., 2014). Company and on-board implementation of the ISM code should address the safety of shipping by taking into account the human element (Hetherington et al., 2006).

Appendix 1: Detail list of accident investigation reports

No	Ship Name	IMO No	Flag	Classification	Nature of accident	Narrative and report Source
1	M.V. Zenith	8918136	Malta	Germanischer Lloyds	Fire	On 25 June 2013, at 0335, the fire alarm sounded in the engine-room of the Maltese registered passenger ship Zenith. Upon investigation, a fire was noticed on the starboard father main engine. The seat of the fire was between the turbocharger and cylinder head no. 1. Immediate actions were taken by the crew members to contain the fire and ensure the safety of all persons on board. The safety investigation identified that the immediate cause of the fire was the fracture of a low carbon steel pipe on a fuel damping cylinder assembly on the starboard father main engine. This fracture led to the release of gas oil, at a pressure of about 6 bars, which sprayed on an exposed high temperature area of the main engine exhaust gas manifold. The MSIU has issued one recommendation to the Company intended to enhance the vessels maintenance regime vis-à-vis all the critical equipment installed in the machinery spaces. https://mti.gov.mt/en/Pages/MSIU/Safety-Investigations-2014.aspx
2	M.V. Azamara Quest	9210218	Malta	Lloyds' Register	Fire	On 30 March 2012, *Azamara Quest* departed Manila, Philippines for Sandakan, Malaysia as her next planned call on her cruise itinerary. There were 1001 persons on board, *i.e.* 590 passengers and 411 crew members. At around 2000, a fire broke out on diesel generator no. 4 whilst it was being tested following repairs on a leaking fuel oil return pipe. The prime mover was shut down, and the low pressure water mist firefighting system automatically activated. The fuel oil quick closing valves were closed and the ventilation to the engine-room stopped. Thereafter, at 2006, the vessel suffered a complete blackout as all the other generator engines stopped working. The crew and passengers were mustered and the crew fire parties entered the main engine-room to assess the fire. At about 2043, the staff chief engineer reported that the fire had been extinguished and thereafter, some fire doors and shell doors were subsequently opened to ventilate the heavy smoke out of the affected area. Power to *Azamara Quest's* engines was restored in the evening of 31 March and the vessel resumed her passage at slow speed. She entered Sandakan Harbour on 01 April with one crew member in a critical condition as a result of smoke inhalation. https://mti.gov.mt/en/Pages/MSIU/Safety-Investigations-2012.aspx

3	M.V. Carnival Spirit	9188647	Malta	Lloyds' Register	Fire	At 1818 (LT) on 30 December 2012, a fire broke out in the women sauna room of the passenger vessel Carnival Spirit, whilst en route from Mystery Island, Vanuatu to Sydney Australia. Automatic fire/heat detection devices activated and alerted the crew. Although the fire was contained inside the sauna room, the fixed water dry sprinkler system did not activate and the fire was extinguished manually. The safety investigation has concluded that the fire was caused by the placement of the women's sauna wooden cedar floor grate on top of the frame work surrounding the sauna's heating element/hot stones. An examination of the dry sprinkler pipe and check valve revealed that the latter was blocked in the closed position and did not open due to corrosion/oxidation of the valve seat. The safety investigation has also found that there were no specific maintenance records for the fixed dry sprinkler system in the sauna. In view of the safety actions taken by the ship managers, no recommendations have been made. https://mti.gov.mt/en/Pages/MSIU/Safety-Investigations-2012.aspx
4	M.V. Carnival Splendor	9333163	Panama	Lloyds' Register	Fire	On November 8, 2010 at 0600 (Local Time), the Carnival Splendor was underway off the coast of Mexico when the vessel suffered a major mechanical failure in the number five diesel generator. As a result, engine components, lube oil and fuel were ejected through the engine casing and caused a fire at the deck plate level between generators five and six in the aft engine room which eventually ignited the cable runs overhead. The fire in the cable runs was relatively small, but produced a significant volume of smoke which hampered efforts to locate and extinguish it. In addition, the fire caused extensive damage to the cables in the aft engine room, which contributed to the loss of power. Post casualty analysis of the event revealed that the installed Hi-Fog system for local protection was activated 15 minutes after the initial fire started. This delay was the result of a bridge watch stander resetting the fire alarm panel on the bridge. This was a critical error which allowed the fire to spread to the overhead cables and eventually caused the loss of power. While the fire was eventually self-extinguished, the failure of the installed CO2 system and the poor execution of the firefighting plan contributed to the ineffectiveness of the crew's firefighting effort. https://homeport.uscg.mil/mycg/portal/ep/contentView.do?channelId=-18374&contentId=460088&programId=21431&programPage=%2Fep%2Fprogram%2Feditorial.jsp&pageTypeId=13489&contentType=EDITORIAL

5	RMS Queen Mary 2	9241061	United Kingdom	Lloyds' Register	Fire	At 0425 on 23 September 2010, as RMS Queen Mary 2 (QM2) was approaching Barcelona, an explosion occurred in the vessel's aft main switchboard room. Within a few seconds, all four propulsion motors shut down, and the vessel blacked out shortly afterwards. Fortunately, the vessel was clear of navigational hazards and drifted in open sea. The emergency generator started automatically and provided essential supplies to the vessel, and it was quickly established that the explosion had taken place in the aft harmonic filter (HF) room, situated within the aft main switchboard. The aft main switchboard was isolated, main generators were restarted and the ship was able to resume passage at 0523, subsequently berthing in Barcelona at about 0900. No one was injured. The accident caused extensive damage to the aft HF and surrounding structure. Two water-mist fire suppression spray heads were activated, one in the aft harmonic filter room and the other in the aft main switchboard room. The explosion was triggered by deterioration in the capacitors in the aft HF. Internal arcing between the capacitor plates developed, which vaporised the dielectric medium causing the internal pressure to increase, until it caused the capacitor casing to rupture. Dielectric fluid vapour sprayed out, igniting and creating the likely conditions for an arc-flash to occur between the 11000 volt bus bars that fed power to the aft HF. A current imbalance detection system, which was the only means to warn against capacitor deterioration, was found to be inoperable, and it was evident that it had not worked for several years. http://www.maib.gov.uk/cms_resources.cfm?file=/QM2Report.pdf
6	M.V. Royal Princess	9210220	Bermuda	NA	Fire	In the evening of 18th of June 2009, a few minutes before 20:00 hours Royal Princess departed from Port Said, Egypt having spent the day alongside there as a planned call on her cruise itinerary. On board were 733 passengers and a crew of 393 giving total number of persons on board of 1126. As the vessel passed between the breakwaters leaving Port Said a fire broke out on diesel generator No4. This unit and unit No. 2 were both in operation providing power for the ship. A number of alarm conditions alerted the automation system of a pending loss of power from No.4 and diesel generator No.1 started automatically and took up the electrical load in conjunction with No. 2. Propulsion was maintained and the Captain made for the first available anchorage. Crew fire parties were mustered and an attempt was made to enter the engine room but the team were beaten back by smoke and heat. Passengers were called to muster stations and looked after there by the passenger services teams. A decision to tackle the fire with the CO2 total flooding system was quickly made and as soon as the vessel was in a position

						to anchor the engine room was sealed, machinery stopped and CO2 injected. Boundary cooling was maintained where necessary and temperatures were seen to reduce quite quickly after the CO2 injection. Passengers were held at muster stations until just after midnight when they were allowed more freedom to access open decks in view of the heat in muster stations in June in Egypt with no air conditioning and limited ventilation. At about 0041 hours an entry was made to the engine room which confirmed that the fire was extinguished and shortly afterwards passengers were allowed to return to their cabins to rest. http://www.bermudashipping.bm
7	M.V. Star Princess	9192363	Bermuda	RINA	Fire	At 0309 (UTC+5) on 23 March 2006, a fire was detected on board the cruise ship Star Princess. The ship was on passage from Grand Cayman to Montego Bay, Jamaica, with 2690 passengers and 1123 crew on board. The fire was investigated by the Marine Accident Investigation Branch (MAIB) on behalf of the Bermuda Maritime Administration, in co-operation with the United States Coast Guard (USCG), and the United States' National Transportation Safety Board (NTSB). The fire started on an external stateroom balcony sited on deck 10 in the centre of main vertical zone 3, on the vessel's port side. It was probably caused by a discarded cigarette end heating combustible materials on a balcony, which smoldered for about 20 minutes before flames developed. Once established, the fire spread rapidly along adjacent balconies and, assisted by a strong wind over the deck, it spread up to decks 11 &12 and onto stateroom balconies in fire zones 3 and 4 within 6 minutes. After a further 24 minutes, it had spread to zone 5. The fire also spread into the staterooms as the heat of the fire shattered the glass in stateroom balcony doors, but was contained by each stateroom's fixed fire-smothering system, the restricted combustibility of their contents, and their thermal boundaries. As the fire progressed, large amounts of dense black smoke were generated from the combustible materials on the balconies, and the balcony partitions. This smoke entered the adjacent staterooms and alleyways, and hampered the evacuation of the passengers, particularly on deck 12. One passenger died as a result of smoke inhalation, and 13 others were treated for the effects of the smoke. http://www.maib.gov.uk/cms_resources.cfm?file=/star%20princess.pdf
8	M.V. The Calypso	NA	Cyprus	Lloyds' Register	Fire	At 0330 ship's time on 6 May 2006, the Cypriot registered cruise ship The Calypso suffered an engine room fire while on passage from Tilbury to St.

						Peter Port, Guernsey, with 708 passengers and crew on board. Initial action by the watch keeping engineer officer was effective in eventually extinguishing the fire although the vessel lost all but emergency electrical power and was left drifting in the south-west lane of the Dover Straits Traffic Separation Scheme (TSS), 16 miles south of Beachy Head. The vessel's starboard main engine had been very seriously damaged and she was towed to the port of Southampton by the Maritime and Coastguard Agency's (MCA) emergency towing vessel Anglian Monarch. http://www.maib.gov.uk/publications/investigation_reports/2007/calypso.cfm?view=print&
9	M.V. Saga Sapphire	7822457	Malta	Germanischer Lloyds	Flooding	On 06 January 2013, at 0050 (UTC), Saga Sapphire experienced a flooding in a number of forward compartments during a ballast operation, while in the English Channel on passage from El Ferrol to Southampton. The flooding effected deck no. 6 forward (Hotel Store Compartment), deck no. 5 forward (Hotel Carpenters' Workshop Area) and the bow thruster space. The flooding, which reduced the vessel's GM height by 34 cm, was discovered at 0038 (UTC) during a fire patrol. The ingress of water also damaged the bow thruster motor. There were no reported injuries or pollution. The direct cause of the flooding was a crack, which developed in the vent / overflow pipe during the ballasting of deep tank no. 1, which was being conducted without adequate supervision. The safety investigation also found less than adequate watch handover procedures. Moreover, the rubber seal of the watertight cover to the bow thruster flat was damaged. As a result of the safety investigation, the MSIU has issued one recommendation aimed to enhance the vessel's safe ballast operations. https://mti.gov.mt/en/Pages/MSIU/Safety-Investigations-2014.aspx
10	M.V. Lauren L	9246827	Malta	Germanischer Lloyds	Grounding	On 01 April 2012, at 1318 (LT), the passenger vessel Lauren L sailed from La Digue to Praslin in Seychelles. The intention was to seek a sheltered anchorage on the north-west side of Praslin, where it would have been possible to land the passengers with the vessel's tenders onto an appropriate beach. After transiting the Baie Curieuse Channel, Lauren L headed west past the northern coast of Praslin. Approaching the planned anchoring position on a roughly south westerly heading, the vessel ran aground at 1435 on a rock pinnacle charted as an isolated danger at a depth of 1.7 m. Lauren L was refloated at 1820. An inspection revealed that the damage was confined to the bow thruster compartment and in way of the grey water tank. The safety investigation concluded that bridge navigational equipment, in particular the

						ECDIS, was not utilised to its full potential. There were also shortcomings in the bridge team composition. MSIU has issued three recommendations to the company designed to address the navigational procedures and practices on board and the use of VDR data. https://mti.gov.mt/en/Pages/MSIU/Safety-Investigations-2013.aspx
11	M.V. Clipper Adventure	NA	Bahamas	NA	Grounding	Upon departure from Port Epworth, the Clipper Adventurer followed the planned course along a single line of soundings at 13.9 knots. The chief officer who was in charge of the watch monitored the vessel's progress using parallel indexing on the starboard radar and monitored the water depth on the echo-sounder. The master monitored the portside radar when on the bridge. Once clear of Port Epworth and on course 300°gyro, the vessel was placed on autopilot and proceeded at 13.9 12F12F 13 knots. The quartermaster remained on the bridge, to take over the steering when required. Shortly after departing Port Epworth, the chief officer marked a depth of 66 m on the chart in an area near where the chart indicated a depth of 40 m. At 1832, the vessel ran aground on a shoal in position 67°58.2' N and 112°40.3' W and listed 5 ° to port. The vessel grounded on hard rock shelf from approximately the forepeak to amidships. This was a previously reported shoal not marked on the chart in use. http://www.tsb.gc.ca/eng/rapports-reports/marine/2010/m10h0006/m10h0006.asp
12	M.V. Deutschland	9141807	Germany	Germanischer Lloyds	Grounding	The passenger ship DEUTSCHLAND was on a cruise through the group of islands off southern Chile and reached the Italia Glacier in the northern arm of the Beagle Channel on Sunday 15 January 2012 at about 2300. The master, an officer on watch, a helmsman and a pilot were on the bridge. A few minutes before reaching the glacier, the ship's command asked the pilot if it would be acceptable to sail closer to the glacier than planned so as to provide passengers with the best possible view of this area. The pilot responded with a decision to reduce the speed and sail much closer to the glacier. The DEUTSCHLAND grounded on her starboard side as she was turning back towards the middle of the fjord two cables away from the coastline. The engine was stopped immediately and instructions to establish the damage to the ship were given. It was possible to move the ship back in the direction of the middle of the fjord by means of various engine and helm manoeuvres a short time later and continue the voyage to the next port. Damage to the ship or environment was not found.

						http://www.bsu-bund.de
13	M.V. Van Gogh	7359400	Marshall Island	Det Norske Veritas	Grounding	At about 1817 on 23 February 2008, the Marshall Islands registered passenger ship Van Gogh grounded briefly on the western shore of the Mersey River during a departure from Devonport, Tasmania. The ship was under the conduct of a harbour pilot who had taken over the conduct from the master about five minutes before, after the master had manoeuvred the ship off the berth. As the ship left the berth, it began to be set towards the bulk carrier Goliath berthed ahead. Van Gogh was under the influence of the ebb tide and fresh water that was flowing from the Mersey River's catchment following heavy rain in the area in the previous 24 hours. Van Gogh was difficult to manoeuvre at low speed because of its twin propellers and single rudder configuration. This, combined with the strong ebb tide and fresh water outflow in the river at the time of departure, resulted in there being insufficient water flow over its rudder to enable the pilot to manoeuvre the ship as he intended. In addition, the master did not inform the pilot that the crew would be using the ship's engines independently during turns in the river. This resulted in the pilot being concerned that his orders were being countermanded because he saw that the engine telegraph levers were not as he had ordered. Following the grounding, the pilot successfully manoeuvred the ship back into the channel and the ship departed the port without further incident. There was no damage to the ship and no pollution resulted. The report identifies a number of safety issues and acknowledges the safety actions which have been taken by Club Cruise International and the Tasmanian Ports Corporation to address them. http://www.atsb.gov.au/publications/investigation_reports/2008/mair/pdf/mair252_001.pdf
14	M.V. Astor	8506373	Bahamas	Germanischer Lloyds	Grounding	At 1900 on 26 February 2004, the Bahamas registered passenger ship Astor let go its mooring lines and departed the Queensland port of Townsville. The ship, equipped with twin rudders, controllable pitch main propellers and a single bow thruster, did not require a tug for the departure. The master, as is common practice on passenger ships, manoeuvred the ship clear of the berth and then, even though this was his first visit to Townsville, kept the conduct of the ship without consulting the harbour pilot. The pilot adopted an advisory role. As the ship was turning from the harbour into Platypus Channel, part of the approach channel to the port, it grounded on its port side. The ship heeled three degrees to starboard and, after about three minutes, slid clear of the bank without assistance and continued out of the channel.

						http://www.atsb.gov.au/publications/investigation_reports/2004/mair/mair200.aspx
15	M.V. Monarch of the Seas	8819500	Norway	Det Norske Veritas	Grounding	At approximately 0030 hours on the night of 15 December 1998, the passenger vessel MONARCH OF THE SEAS arrived outside of Great Bay, St. Maarten in order to evacuate a sick passenger to a shore side medical facility. At 0125 the vessel's crew completed the passenger evacuation evolution and the MONARCH OF THE SEAS departed St. Maarten, taking a South-Southeasterly departure route with the intention of safely passing to the east of the Proselyte reef obstruction. At approximately 0130 hours the MONARCH OF THE SEAS raked the Proselyte Reef at an approximate speed of about 12 knots without becoming permanently stranded. Almost immediately emergency and abandon ship signals were sounded and the crew and passengers were mustered at their abandon ship stations. At 0235 the vessel was intentionally grounded on a sandbar in Great Bay, St. Maarten. By 0515 hours all 2,557 passengers were safely evacuated ashore by shore based tender vessels. http://marinecasualty.com/documents/monarch.pdf

Appendix 2: SEMOMAP code book

SEMOMAP Draft Codebook

1. Overview of SEMOMAP

SEMOMAP is a primarily sequential accident investigation model developed for the maritime industry. The original framework, developed by Schröder (2003) as a part of his PhD thesis, is shown below:

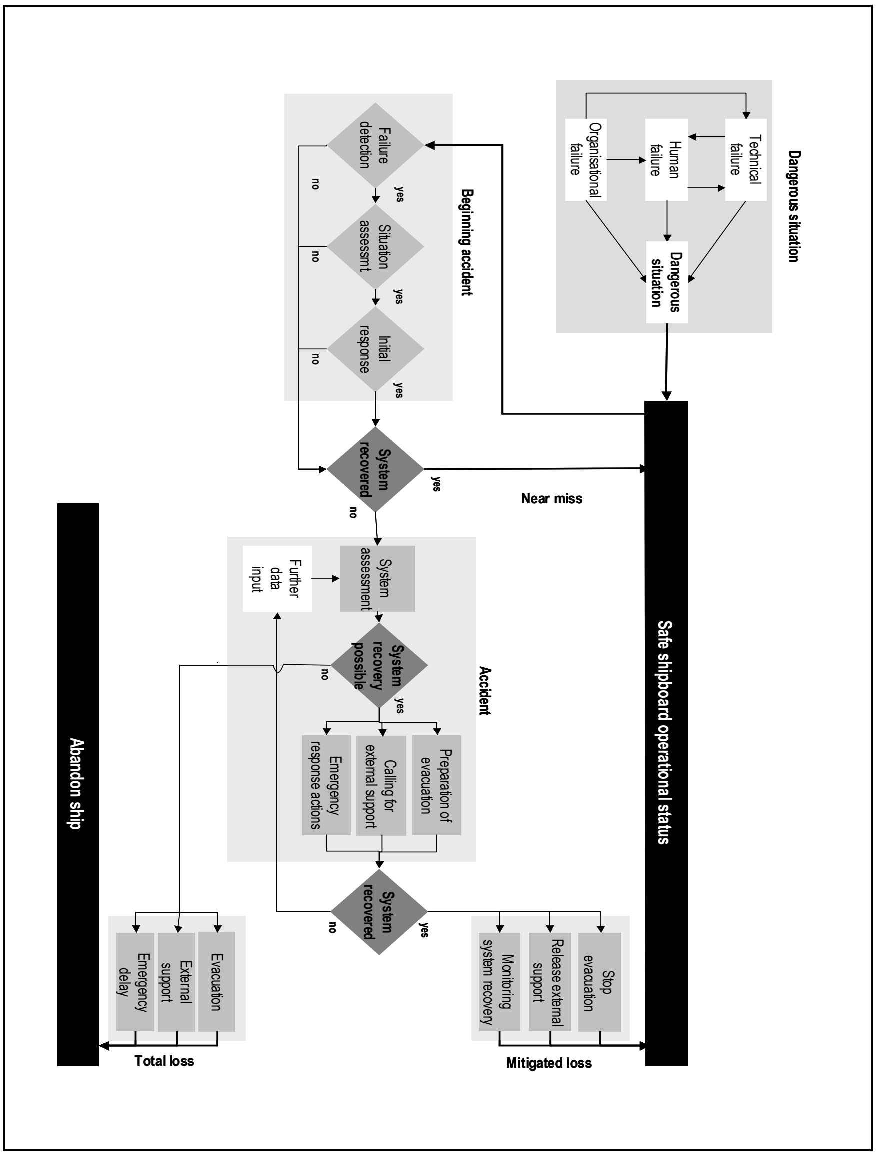
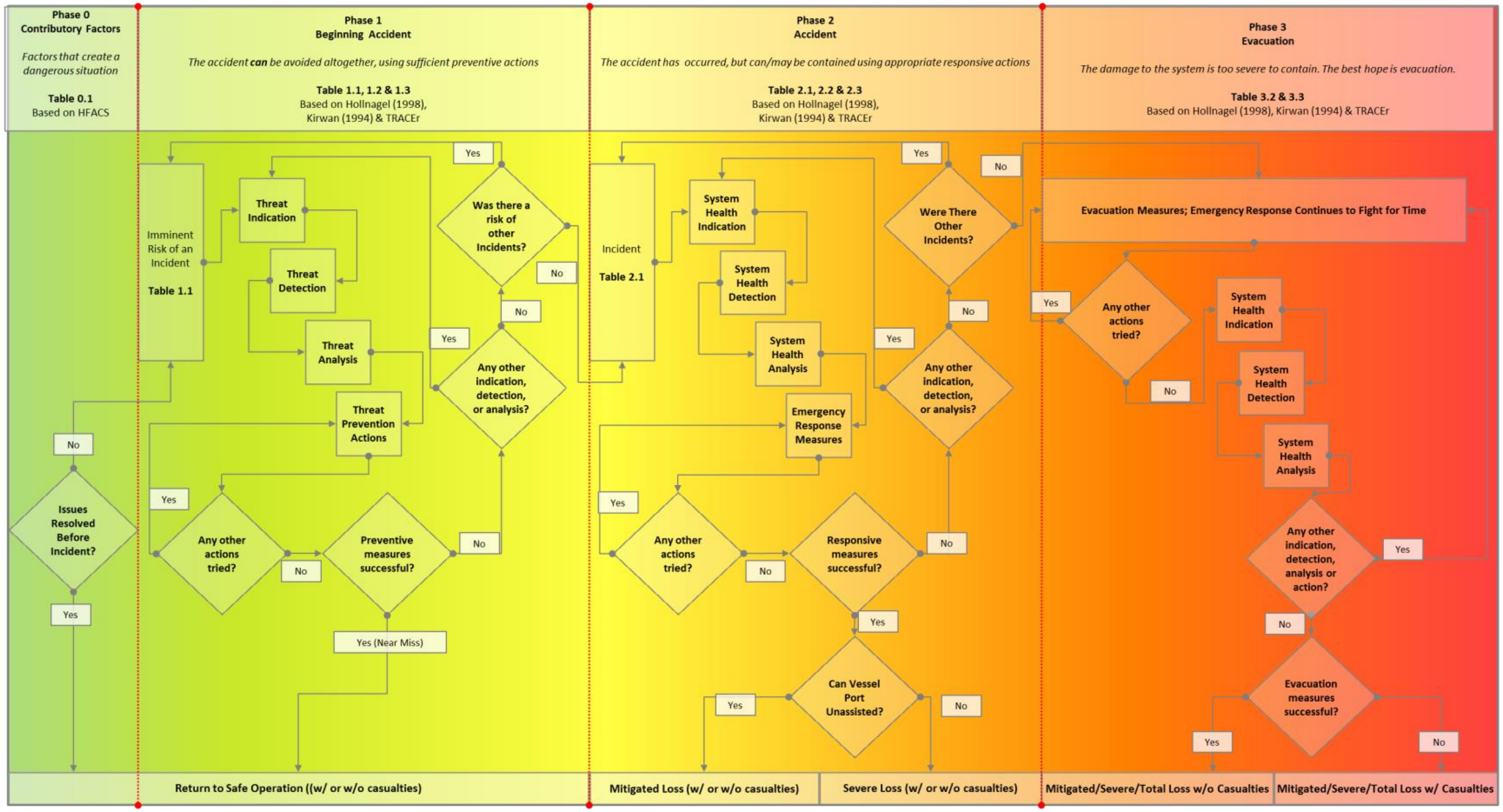


Fig. 1 – The 'Original' SEMOMAP model

The idea behind this original model was that an accident can be depicted via a series of sequential steps and crucial phases. Building on this idea, a revamped SEMOMAP model – SEMOMAP v2 – was developed, as shown in Fig. 2 on the following page.



Phase 0
Contributory Factors
Factors that create a dangerous situation
Table 0.1
Based on HFACS
Phase 1
Beginning Accident
The accident can be avoided altogether, using sufficient preventive actions
Table 1.1, 1.2 & 1.3
Based on Hollnagel (1998), Kirwan (1994) & TRACEr
Phase 2
Accident
The accident has occurred, but can/may be contained using appropriate responsive actions
Table 2.1, 2.2 & 2.3
Based on Hollnagel (1998), Kirwan (1994) & TRACEr
Phase 3
Evacuation
The damage to the system is too severe to contain. The best hope is evacuation.
Table 3.2 & 3.3
Based on Hollnagel (1998), Kirwan (1994) & TRACEr
Issues Resolved Before Incident?
Yes
No
Imminent Risk of an Incident
Table 1.1
Threat Indication
Threat Detection
Threat Analysis
Threat Prevention Actions
Any other actions tried?
Yes
No
Preventive measures successful?
No
Yes (Near Miss)
Any other indication, detection, or analysis?
Yes
No
Was there a risk of other incidents?
Yes
No
Incident
Table 2.1
System Health Indication
System Health Detection
System Health Analysis
Emergency Response Measures
Any other actions tried?
Yes
No
Responsive measures successful?
No
Yes
Can Vessel Port Unassisted?
Yes
No
Any other indication, detection, or analysis?
Yes
No
Were There Other Incidents?
Yes
No
Evacuation Measures; Emergency Response Continues to Fight for Time
Any other actions tried?
Yes
No
System Health Indication
System Health Detection
System Health Analysis
Any other indication, detection, analysis or action?
Yes
No
Evacuation measures successful?
Yes
No
Return to Safe Operation ((w/ or w/o casualties)
Mitigated Loss (w/ or w/o casualties)
Severe Loss (w/ or w/o casualties)
Mitigated/Severe/Total Loss w/o Casualties
Mitigated/Severe/Total Loss w/ Casualties

Fig. 2 – The revamped SEMOMAP model – SEMOMAP v2

Before beginning the analysis of an accident through SEMOMAP, some general data needs to be collated. The taxonomy of the information that needs to be gathered is provided in section 2; it consists of fields such as the ship name, IMO Number, and type and severity of incident. The information collected via this taxonomy can allow users to compare how accidents differ (if at all), based on factors such as type of ship, type of incident, and ship size. If the right data and information is available, users can also do further analyses – such a comparing the safety records of ships classified by different class societies or that of ships having different flag states.

Having collected some basic background information, one can then use the SEMOMAP model. The 'new' SEMOMAP v2 consists of 4 different phases. The 'first' phase is called 'Phase 0'. This phase identifies all the 'Contributory Factors' that contributed indirectly in a way that led to a risk of an accident happening – but did not contribute to the accident itself. In other words, the factors described in this phase led to the creation of a dangerous situation, but did not *directly* cause any consequences per se. The taxonomy for 'Phase 0' is adapted from HFACS – the Human Factors Analysis & Classification System, and was originally used for a paper published by Schröder-Hinrichs, et al. (2011) titled *'Accident investigation reporting deficiencies related to organizational factors in machinery space fires and explosions'*. The taxonomy for phase 0 is presented in section 3 of this codebook. A person using SEMOMAP identifies various subjects (human and technical) from the accident report, and then using the HFACS taxonomy, describes factors that influenced that subject and contributed to the creation of a dangerous situation.

If the factors mentioned in 'Phase 0' are resolved in time, the vessel can return to normal operation; if this is not the case however, the accident progresses to the next 3 phases of SEMOMAP. The second, third, and fourth phases of SEMOMAP are called 'Phase 1', 'Phase 2', and 'Phase 3' respectively.

'Phase 1' is the 'Beginning Accident' phase. At this point, the subjects in the system – and by extension, the system itself – have been affected by the factors identified in 'Phase 0'. This means that the system is facing an imminent risk of an incident, but still, the accident itself has not come to pass. 'Phase 1' could indicate, for example, a vessel turning on to collision or grounding route due to some factors as identified in 'Phase 0' – but would not cover the collision or grounding itself. At this stage then, there is still a possibility to avoid the accident through correct threat indication, detection, analysis, and correct threat prevention action. If the correct steps are followed, the vessel can return to safe operations, with the incident classed as a 'near-miss'.

If however, the situation remains unchanged, the timeline moves into 'Phase 2' – i.e. – 'The Accident' phase. As the name implies, this phase starts the moment the vessel experiences an accident. At this stage, there is a possibility to prevent the accident from escalating any further, through appropriate system health indication, detection, analysis, and appropriate emergency response measures. If the appropriate measures are undertaken, depending on the severity, the vessel can either suffer a 'mitigated loss' or a 'severe loss'. Mitigated loss would indicate that the vessel has suffered damage, but can port unassisted; a severe loss indicates a large enough damage that the ship cannot port unassisted.

If, by the end of Phase 2, the damage is not contained, it is possible that the situation escalates further into the very last, critical phase – 'Phase 3' – a.k.a. – 'Evacuation'. In this phase, as the name implies, the best course of action is to evacuate and abandon the vessel. However, emergency response measures may also continue to fight for increased evacuation time. In this phase the priority is on the emergency and evacuations actions; system health indication, detection and analysis may also continue to monitor the developments.

All 3 latter phases – Phases 1, 2, and 3 – have 4 types of steps: an 'indication' step, a 'detection' step, an 'analysis' step, and an 'action' step. These steps and their 'common' taxonomies are discussed further in section 4. Each step has multiple 'levels' of information that can be filled in, to provide more details that describe the accident. The taxonomies of these 'levels' are also discussed in section 4.

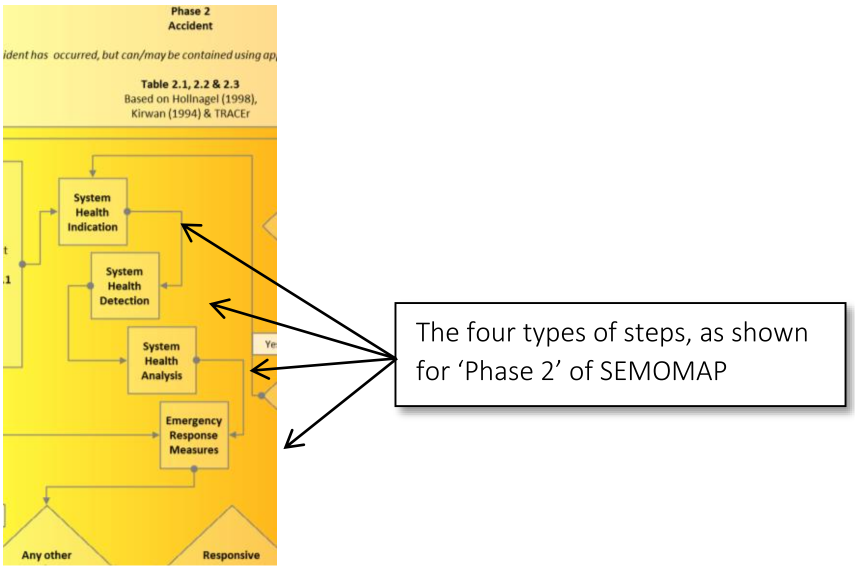


Fig. 3 – The steps of SEMOMAP

The reader may also note that it is possible to 'loop around' or have 'iterations', as shown in Fig. 2. In *each* 'loop' or 'iteration' there can only be one (or none) 'indication', 'detection', and 'analysis' – but more than one 'action' is possible. Each phase, can of course, have multiple iterations. It is also possible for an iteration to change the actual type of accident, or risk of accident that a vessel faces.

This is because maritime accidents can be very complex, and a risk or an accident of one type can quickly evolve into another type. In fact, according to Vassalos (2009), the following possible links are possible between different types of accidents:

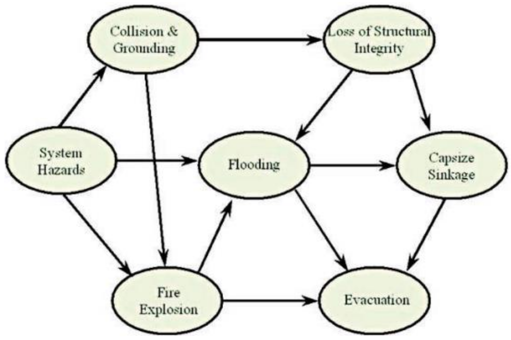


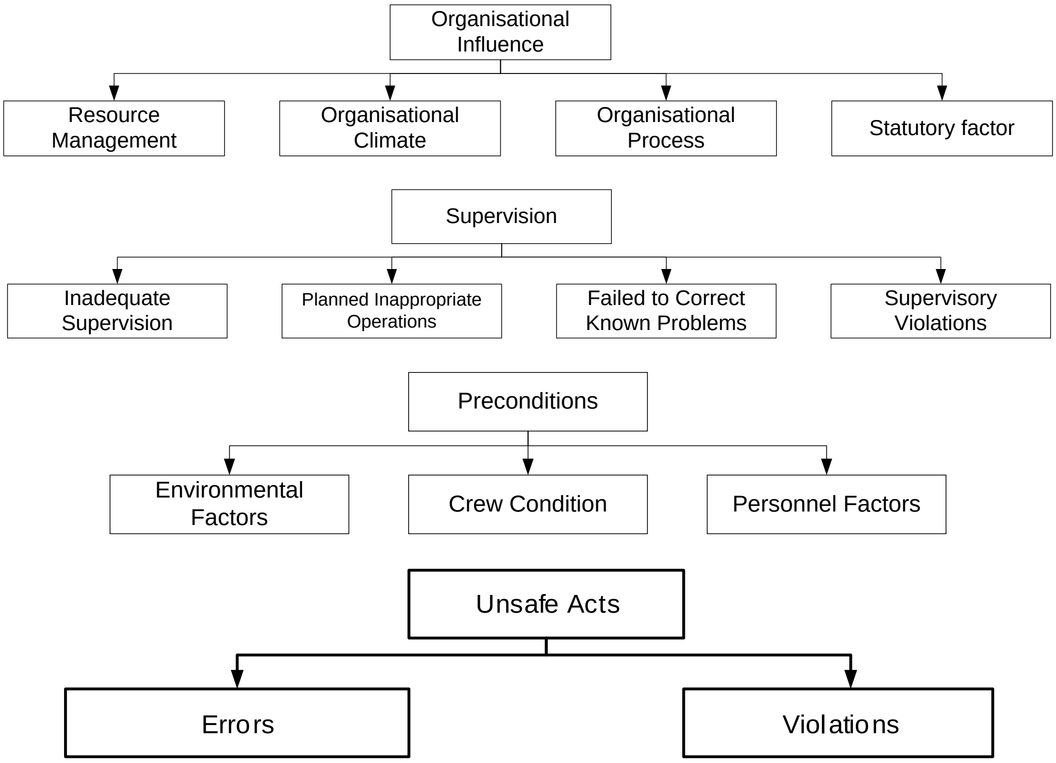
Fig. 4 – Possible accident evolutions. Source: Vassalos (2009)

2. Taxonomy for General Information

Taxonomy Category	Description
IMO Number	State the IMO number of the ship
Vessel Name	State ship name and its previous name
Vessel type	Classify the type of ship by its functionality to carry its cargo: GC, Container, Bulk Carrier, Tanker, Passenger, Ro-Ro, Others
Vessel Flag State	State ship flag at the time of the accident
Classification Society	State the class society the ship was classified under at the time of the accident
Keel Laid Year	State the keel laid year as indicated in ship certificate
Built at	State the location (shipyard, country) the ship built
Deadweight Ton (DWT)	DWT of the ship
Ship Length Over All (m)	Overall length of the ship
Ship Beam (m)	State ship breadth
Ship Loaded Draft (m)	State the ship draft at the time of the occurrence
Ship Height (m)	state the vertical measure of ship bottom to the upmost deck
Date of Occurrence	State date of occurrence
Time of Occurrence	State time of occurrence by Local time and GMT
Geographical Occurrence Location	State the location of the occurrence by its fix gps position and other geographical reference
Type of Occurrence	Classify nature of accident with following event: Collision, Grounding, Contact, Fire/explosion, Hull failure, Loss of control, Ship/equipment damage, Capsize/listing, Flooding/foundering, Ship Missing, Occupational accident, Others, Unknown
Number of Fatalities / Injuries	State number of the fatalities as a result of the accident at the point and subsequent fatality,
Consequence to the Ship	Provide sufficient information of the end consequences to the ship due to accident,
Narratives	Brief overview of the occurrence

3. Taxonomy for Phase 0

As mentioned earlier, the taxonomy for Phase 0 was adapted from HFACS. This section breaks down the HFACS taxonomy, and provides descriptions of what each option. The taxonomy used for SEMOMAP consists of 4 levels; for brevity, however, the taxonomy definitions provided in the codebook are only for levels 1, 2 and 3.

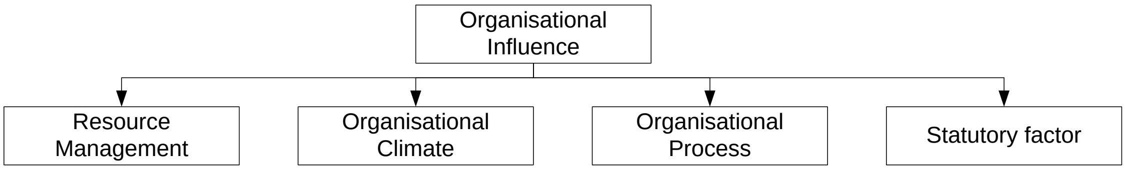


Level-1 Taxonomy

Terminology	Definition
Organisational Influence	factors in a mishap if the communications, actions, omissions or policies of upper-level management directly or indirectly affect supervisory practices, conditions or actions of the operator(s) and result in system failure, human error or an unsafe situation
Supervision	a mishap event can often be traced back to the supervisory chain of command.
Pre-Condition	factors in a mishap if active and/or latent preconditions such as conditions of the operators, environmental or personnel factors affect practices, conditions or actions of individuals and result in human error or an unsafe situation
Unsafe Acts	

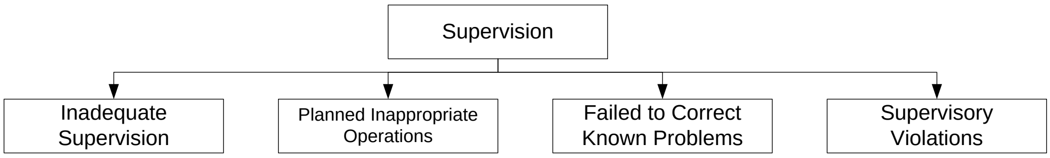
Level-2 Taxonomy

Taxonomy under Organisational influence



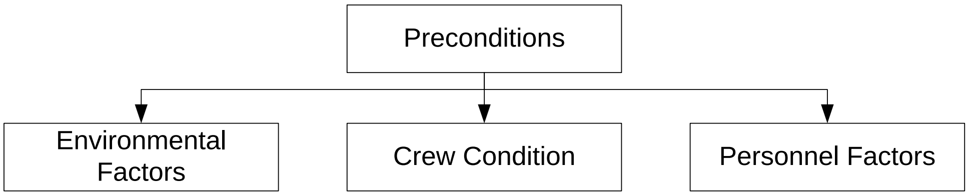
Parent Level	L-2 Terminology	Definition
Organisational Influence	Resource Management	factor in a mishap if resource management and/or acquisition processes or policies, directly or indirectly, influence system safety and results in poor error management or creates an unsafe situation
	Organisational Climate	Factor in a mishap if organizational variables including environment, structure, policies, and culture influence individual actions and results in human error or an unsafe situation.
	Organisational Process	Factor in a mishap if organizational processes such as operations, procedures, operational risk management and oversight negatively influence individual, supervisory, and/or organizational performance and results in unrecognized hazards and/or uncontrolled risk and leads to human error or an unsafe situation
	Statutory factors	Considered as external factor that mostly on the policy and regulatory side

Taxonomy under supervision



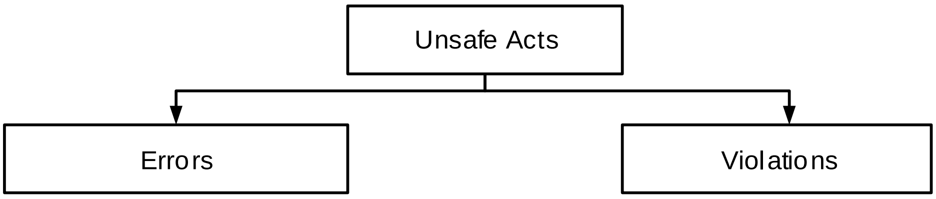
Parent Level	L-2 Terminology	Definition
Supervision	Inadequate supervision	factor in a mishap when supervision proves inappropriate or improper and fails to identify a hazard, recognize and control risk, provide guidance, training and/or oversight and results in human error or an unsafe situation
	Planned inappropriate operation	factor in a mishap when supervision fails to adequately assess the hazards associated with an operation and allows for unnecessary risk. It is also a factor when supervision allows non-proficient or inexperienced personnel to attempt missions beyond their capability or when crew or flight makeup is inappropriate for the task or mission.
	Failure in correct known problem	factor in a mishap when supervision fails to correct known deficiencies in documents, processes or procedures, or fails to correct inappropriate or unsafe actions of individuals, and this lack of supervisory action creates an unsafe situation.
	Supervisory violation	factor in a mishap when supervision, while managing organizational assets, wilfully disregards instructions, guidance, rules, or operating instructions and this lack of supervisory responsibility creates an unsafe situation.

Taxonomy under Precondition



Parent Level	Terminology	Definition
Pre Condition	Condition of Individual	Factors in a mishap if cognitive, psycho-behavioural, adverse physical state, or physical/mental limitations affect practices, conditions or actions of individuals and result in human error or an unsafe situation.
	Environmental Factor	factors in a mishap if physical or technological factors affect practices, conditions and actions of individual and result in human error or an unsafe situation
	Personal Factor	factors in a mishap if self-imposed stressors or crew resource management affects practices, conditions or actions of individuals, and result in human error or an unsafe situation

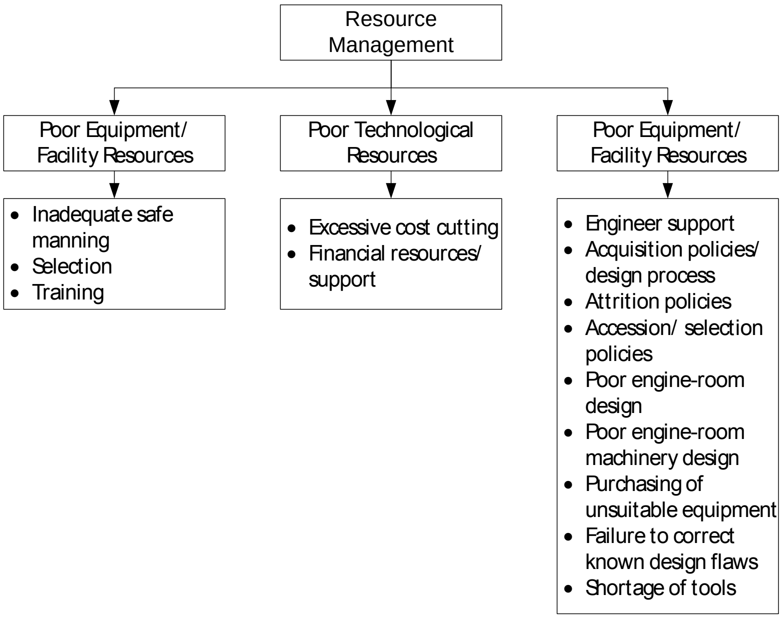
Taxonomy under Unsafe Acts



Parent Level	Terminology	Definition
Unsafe Acts	Errors	Factors in a mishap when mental or physical activities of the operator fail to achieve their intended outcome as a result of skill-based, perceptual, or judgment and decision making errors, leading to an unsafe situation
	Violations	Factors in a mishap when the actions of the operator represent wilful disregard for rules and instructions and lead to an unsafe situation. Unlike errors, violations are deliberate.

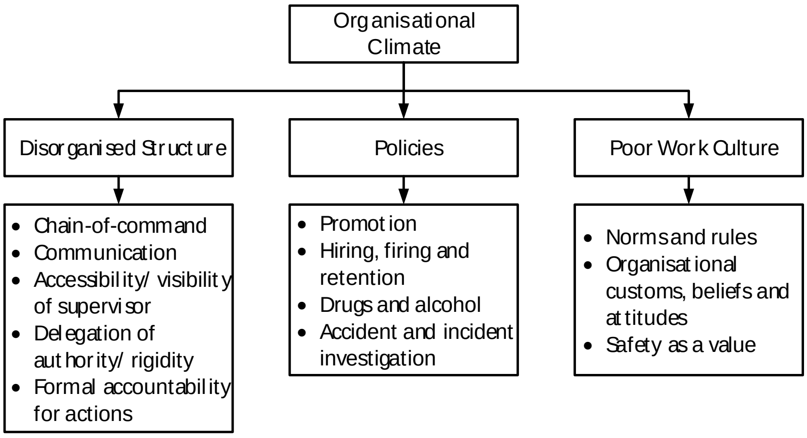
Level-3 Taxonomy

Taxonomy under Resource Management (under Organisational Influence)



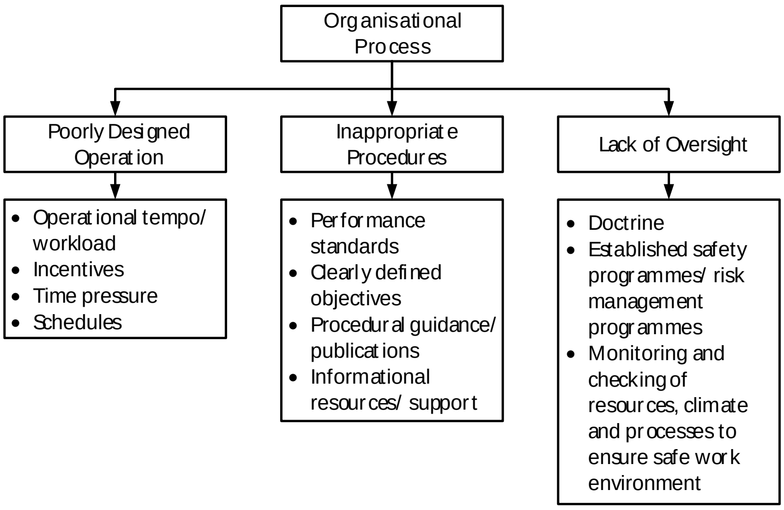
Parent Level	Terminology	Definition
Resource Management	Lack of human resource	Issues that directly influence safety include selection (including background checks), training, and staffing/manning
	Poor technological resources	Are factors in a mishap when ship design factors or automation affect the actions of individuals and result in human error or an unsafe situation
	Poor equipment/facility	issues related to equipment design, including the purchasing of unsuitable equipment, inadequate design of workspaces, and failures to correct known design flaws

Taxonomy under Organisational Climate (under Organisational Influence)



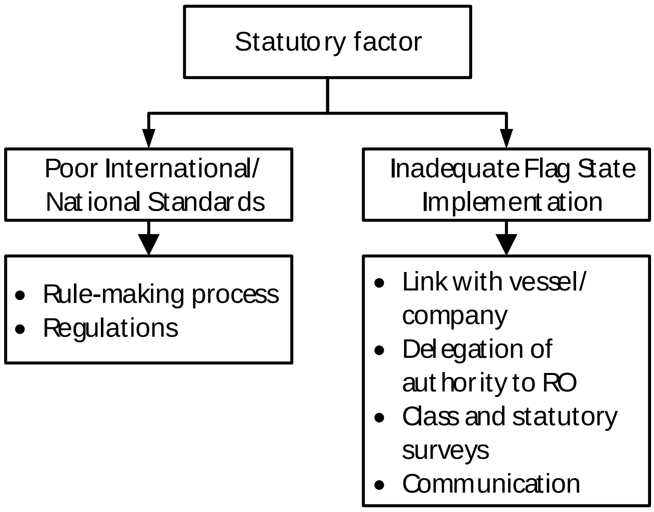
Parent Level	L-3: Terminology	Definition
organizational climate	Disorganised Structure	a factor when the chain of command of an individual or structure of an organization is confusing, non-standard or inadequate and this creates an unsafe situation
	Inadequate Policies	A course or method of action that guides present and future decisions. Policies may refer to hiring and firing, promotion, retention, raises, sick leave, drugs and alcohol, overtime, accident investigations, use of safety, equipment, etc. When these policies are ill-defined, adversarial, or conflicting, safety may be reduced
	Poor Work Culture	a factor when explicit/implicit actions, statements or attitudes of unit leadership set unit/organizational values (culture) that allow an environment where unsafe mission demands or pressures exist

Taxonomy under Organisational Process (under Organisational Influence)



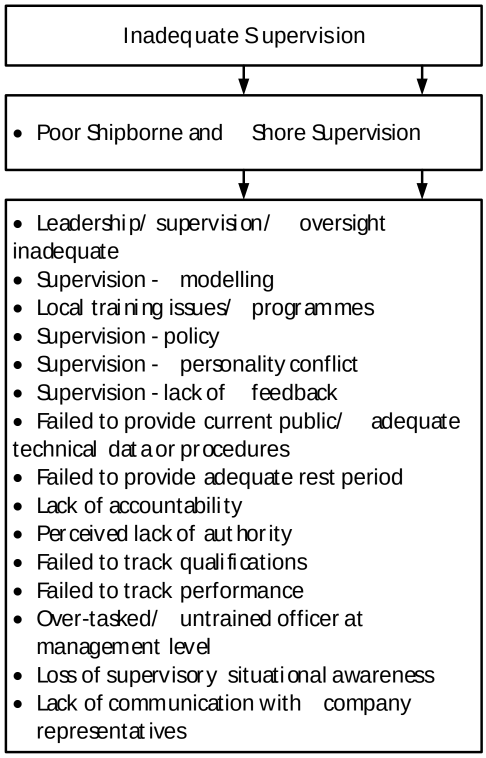
Parent Level	L-3: Terminology	Definition
Organisational Process	Poorly designed operation	a factor when the potential risks of a large program, operation, acquisition or process are not adequately assessed and this inadequacy leads to an unsafe situation.
	Inappropriate procedures	a factor when written direction, checklists, graphic depictions, tables, charts or other published guidance is inadequate, misleading or inappropriate and this creates an unsafe situation
	Lack of oversight	a factor when programs are implemented without sufficient support, oversight or planning and this leads to an unsafe situation

Taxonomy under Statutory Factor (under Organisational Influence)



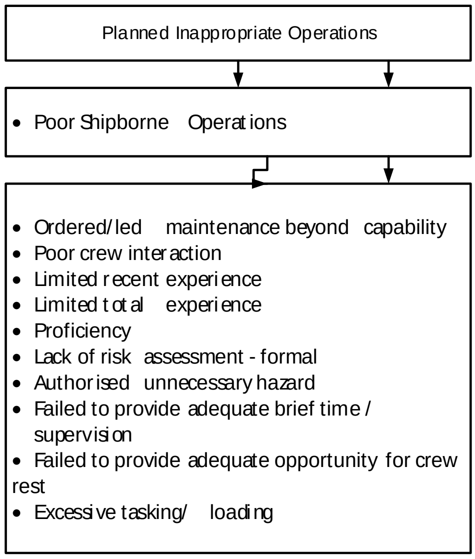
Parent Level	L-3: Terminology	Definition
Statutory factor	Poor international/national standards	national or international standards that led to poor conditions and a dangerous situation
	Inadequate flag state implementation	the flag state procedures were inadequate and led to a dangerous situation

Taxonomy under Inadequate Supervision (under Supervision)



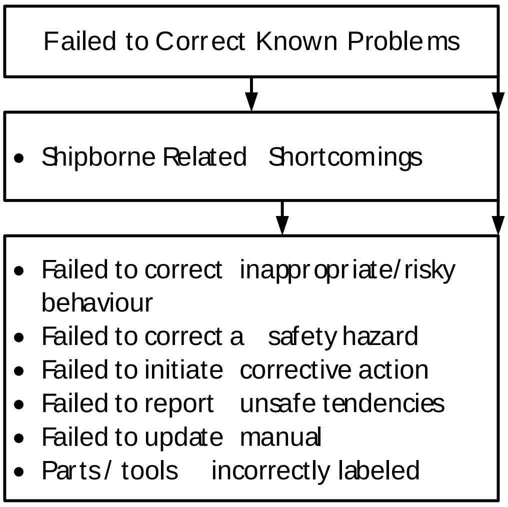
Parent Level	L-3: Terminology	Definition
Inadequate supervision	Poor shipborne and shore supervision	a factor when the availability, competency, quality or timeliness of leadership, supervision or oversight does not meet task demands and creates an unsafe situation

Taxonomy under Planned Inappropriate Operations (under Supervision)



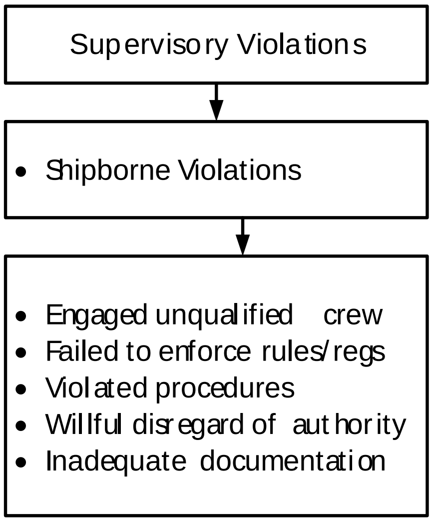
Parent Level	L-3: Terminology	Definition
Planned inappropriate operations	Poor shipborne operations	a factor in a mishap when supervision fails to adequately assess the hazards associated with an operation and allows for unnecessary risk

Taxonomy under Failed to Correct Problems (under Supervision)



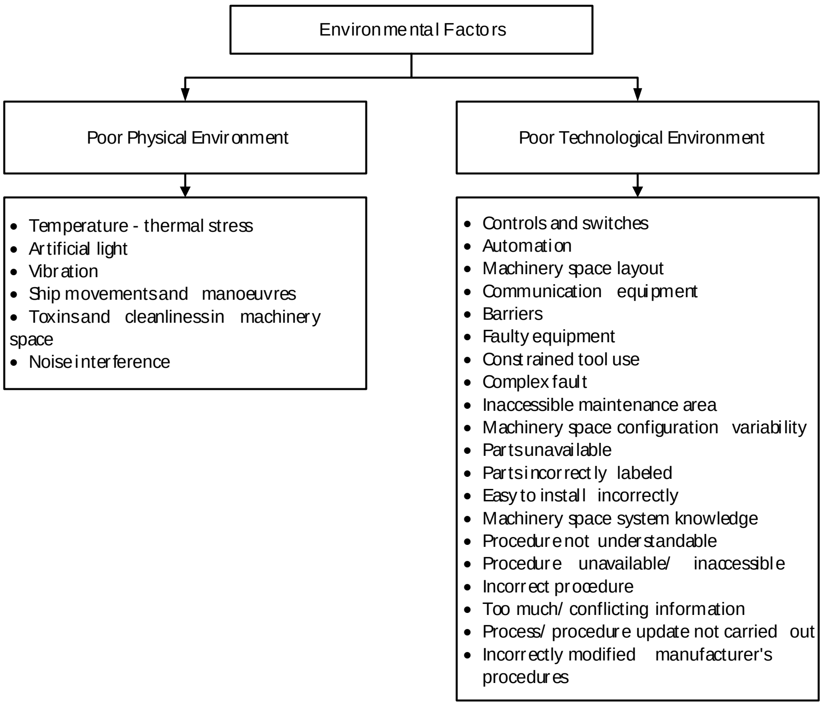
Parent Level	L-3: Terminology	Definition
Failed to correct known problems	Shipborne related shortcomings	a factor when the supervisor selects an individual who's experience for either a specific manoeuvre, event or scenario is not sufficiently current to permit safe mission execution.

Taxonomy under Supervisory Violations (under Supervision)



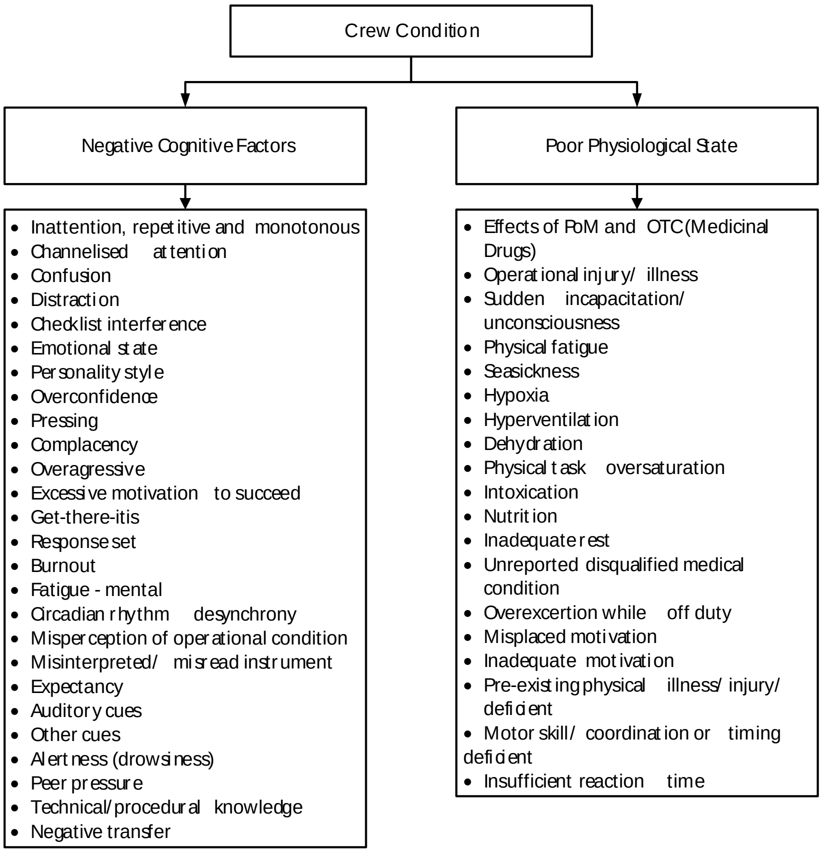
Parent Level	L-3: Terminology	Definition
Supervisory violations	Shipborne violations	Violations on board the ship that led to the creation of a dangerous situation

Taxonomy under Environmental Factors (under Preconditions)



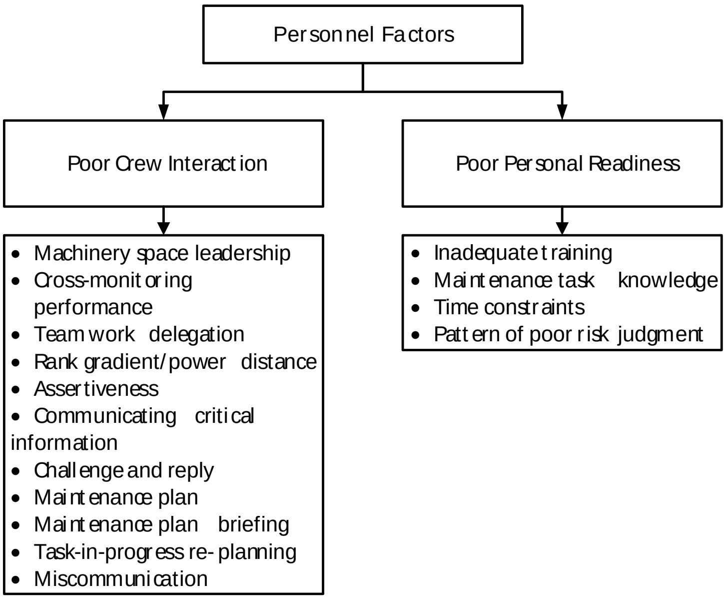
Parent Level	L-3: Terminology	Definition
Environmental factors	Poor physical environmental	Physical environment are factors in a mishap if environmental phenomena such as weather, climate, white-out or dust-out conditions affect the actions of individuals and result in human error or an unsafe situation
	Poor technological environment	Technological environment are factors in a mishap when cockpit/vehicle/workspace design factors or automation affect the actions of individuals and result in human error or an unsafe situation

Taxonomy under Crew Condition (under Preconditions)



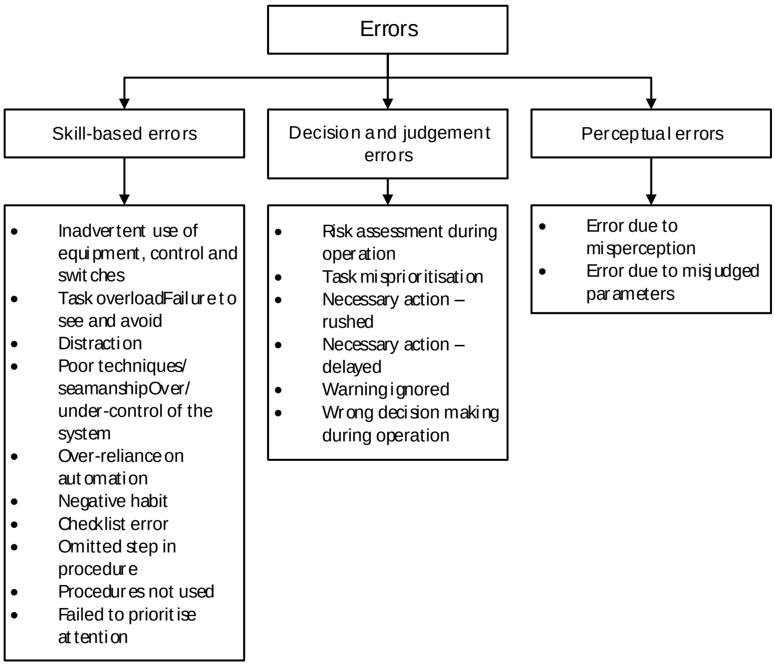
Parent Level	L-3: Terminology	Definition
Crew condition	Negative cognitive factors	Are factors in a mishap if cognitive or attention management conditions affect the perception or performance of individuals and result inhuman error or an unsafe situation
	Poor physiological state	Are factors when an individual's personality traits, psychosocial problems, psychological disorders or inappropriate motivation creates an unsafe situation

Taxonomy under Personnel Factors (under Preconditions)



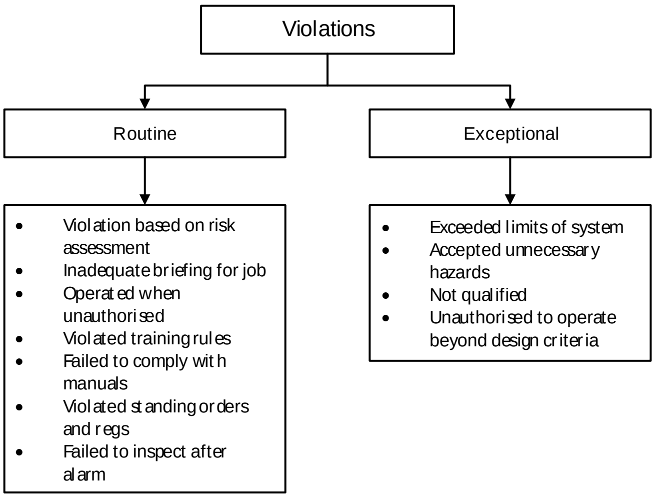
Parent Level	L-3: Terminology	Definition
Personnel factors	Poor crew interaction	Refer to interactions among individuals, crews, and teams involved with the preparation and execution of a mission that resulted in human error or an unsafe situation
	Poor personal readiness	factors in a mishap if the operator demonstrates disregard for rules and instructions that govern the individuals readiness to perform, or exhibits poor judgment when it comes to readiness and results in human error or an unsafe situation

Taxonomy under Errors (under Unsafe Acts)



Parent Level	L-3: Terminology	Definition
Errors	Skilled based errors	Are factors in a mishap when errors occur in the operator's execution of a routine, highly practiced task relating to procedure, training or proficiency and result in an unsafe a situation
	Decision and judgement errors	Are factors in a mishap when behaviour or actions of the individual proceed as intended yet the chosen plan proves inadequate to achieve the desired end-state and results in an unsafe situation
	Perceptual errors	Are factors in a mishap when misperception of an object, threat or situation, (such as visual, auditory, pro prioceptive, or vestibular illusions, cognitive or attention failures, etc), results in human error

Taxonomy under Violations (under Unsafe Acts)



Parent Level	L-3: Terminology	Definition
Violations	Routine	a factor when a procedure or policy violation is systemic in a unit/setting and not based on a risk assessment for a specific situation. It needlessly commits the individual, team, or crew to an unsafe course-of-action. These violations may have leadership sanction and may not routinely result in disciplinary/administrative action. Habitual violations of a single individual or small group of individuals within a unit can constitute a routine/widespread violation if the violation was not routinely disciplined or was condoned by supervisors
	Exceptional	a factor when an individual, crew or team intentionally violates procedures or policies without cause or need. These violations are unusual or isolated to specific individuals rather than larger groups. There is no evidence of these violations being condoned by leadership

‘**Taxonomy of Subjects Affected by Contributory Factors**

It was mentioned earlier that it is important to identify the subjects that are influenced by the contributory factors. Following is a tabulated list of subjects. Note that this list is by no means exhaustible. Each of the subjects is self-explanatory.

Category of Subject	Sub-Category	Subject
Human Subjects	Captain & Officers	Captain
		1st/Chief Officer
		2nd Officer
		3rd Officer
		Other Officer
	Navigators	Helmsman
		Pilot
	Other Crew	AB
		Bosun
		OS
	Engineers	1st/Chief Engineer
		2nd Engineer
		Other Engineer
Technical Subjects	Bridge & Deck	Steering Equipment
		Navigation Aids (AIS, ECDIS, Radar, GPS, etc…)
		Communication Equipment
		Alarm Panels & System
	Engine Room	Main Engine
		Auxiliary Engine
		Engine Control Panel
		Fuel Pumps
		Ballast Water Pumps
		Generators
		Boilers
	Ship Structure & Design	Hull
		Separators

4. Taxonomy for Phases 1 – 3

Phases 1, 2 and 3, as mentioned earlier, each consist of 4 types of steps. At each step, several levels of information can be filled in – in a given order. The section details the order in which information is filled in, and provides taxonomies for each of the 4 different steps.

Phase 1 - Beginning Accident (1)						
This phase covers how an accident could have been avoided altogether, despite the imminent risk of a dangerous situation						
L1	L2	L3A	L3B	L4A	L4B	L5
(2) Threat Indication	(3) Which specific threat indicator, based on the dangerous scenrio, did not functio	Information Recording Applicable?	(4) Information Recording Successful? If not:	(5) Equipment Failure - Specify	No Threat Information Recorded (6)	(7) Choose a problem based on chosen hardware - e.g. not installed, turned off, wrong settings, electric failure, poor maintenance record, out-of-date technology, loose connections, unreliable software
					Unclear Threat Information Recorded	
					Partial Threat Information Recorded	
					Wrong Threat Information Recorded	
					Delay in Threat Information Recorded	
					Unnecessary Threat Information Recorded	
				Human Failure - Specify	No Threat Information Recorded	Mis-hear, mis-see, mis-read threat; ignore threat; late detection of threat; forget to monitor for threat; forget to share information of threat; omitted action
					Unclear Threat Information Recorded	
					Partial Threat Information Recorded	
					Wrong Threat Information Recorded	
					Delay in Threat Information Recorded	
					Unnecessary Threat Information Recorded	
		Information Transmission Applicable?	Information Transmission Successful? If not:	Equipment Failure - Specify	No Threat Information Transmitted	Choose a problem based on chosen Auto. System - e.g. not installed, turned off, wrong settings, electric failure, poor maintenance record, out-of-date technology, loose connections, unreliable software
					Unclear Threat Information Transmitted	
					Partial Threat Information Transmitted	
					Wrong Threat Information Transmitted	
					Delay in Threat Information Transmitted	
					Unnecessary Threat Information Transmitted	
				Human Failure - Specify	No Threat Information Transmitted	Mis-hear, mis-see, mis-read threat; ignore threat; late detection of threat; forget to monitor for threat; forget to share information of threat; omitted action
					Unclear Threat Information Transmitted	
					Partial Threat Information Transmitted	
					Wrong Threat Information Transmitted	
					Delay in Threat Information Transmitted	
					Unnecessary Threat Information Transmitted	

As shown in the figure on the previous page, filling in a SEMOMAP step during any phase consists of up to 7 stages (shown in black circles, numbered 1 to 7).

1. Determine the Phase

The phases have been discussed previously in Section 1. It is possible to be in Phase 0, 1, 2 or 3. This section deals exclusively with Phases 1, 2 and 3.

2. Determine the Step (Indication, Detection, Analysis or Action) – Level 1

If they are in Phase 1, the steps will be [Threat] Indication, [Threat] Detection, [Threat] Analysis, and [Threat Prevention] Action

In Phase 2, the steps will be [System Health] Indication, [System Health] Detection, [System Health] Analysis, and [Emergency Response] Action

In Phase 3, the steps will be [Emergency Response & Evacuation] Action, [System Health] Indication, [System Health] Detection, and [System Health] Analysis

The steps are self-explanatory. An 'Indication' step is one where something may be indicated by someone or something. A 'detection' step is where the indication from an indicator may be detected by someone or something. In the 'analysis' step, someone or something may performs an analysis on what is detected in the previous step. In the 'action' step, an action may be taken based on the 'analysis' step. It is important to note that any of these steps, it is possible that nothing is done at all.

3. Choose a Subject – Level 2

Depending on stages 1 and 2, as well as the type of risk, or type of accident that the vessel faces, the users must choose a subject at this stage that was used for a particular step in a particular phase, for a particular type of accident. The type of accident (navigation, on-board, entire-vessel constitutes 'Level 2A').

The tables on the following pages show the possible subjects for the various phases, steps, and types of incidents.

Possible subjects for Phase 1 under navigational incidents (collision, contact, grounding)

L2B	L2C	L2D	L2E
Threat Indication	Onboard	Equipment	Radar
			Echo Sounder
			AIS
			ECDIS
			Sea Charts
			GPS
			Other
		Human	Lookout
			OOW
			Other Crew Member
			Passenger
			Other
	Ashore	Equipment	Foghorn
			Lighthouse
			Bouy/Navigational Aid
			Other
		Human	VTS
			Coastguard
			Other

L2B	L2C	L2D	L2E
Threat Detection	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Human	VTS
			Other

<table>
<tr><th>L2B</th><th>L2C</th><th>L2D</th><th>L2E</th></tr>
<tr><td rowspan="7">Threat Analysis</td><td rowspan="5">Onboard</td><td rowspan="2">Equipment</td><td>Decision Support System</td></tr>
<tr><td>Other</td></tr>
<tr><td rowspan="3">Human</td><td>Master</td></tr>
<tr><td>OOW</td></tr>
<tr><td>Other</td></tr>
<tr><td rowspan="2">Ashore</td><td rowspan="2">Human</td><td>VTS</td></tr>
<tr><td>Other</td></tr>
</table>

<table>
<tr><th>L2B</th><th>L2C</th><th>L2D</th><th>L2E</th></tr>
<tr><td rowspan="8">Threat Prevention Action</td><td rowspan="5">Onboard</td><td rowspan="5">Action</td><td>Steering & Manouvering</td></tr>
<tr><td>Altering Speed</td></tr>
<tr><td>Dropping Anchor</td></tr>
<tr><td>Reverse Thrust</td></tr>
<tr><td>Other</td></tr>
<tr><td rowspan="3">Offboard</td><td rowspan="3">Action</td><td>Other Vessel Alters Course</td></tr>
<tr><td>Other Vessel Alters Speed</td></tr>
<tr><td>Other</td></tr>
</table>

Possible subjects for Phase 1 under on-board incidents (fire, explosion, structural failure, engine failure, loss of control, equipment damage)

L2B	L2C	L2D	L2E
Threat Indication	Onboard	Equipment	Fire Alarm System
			Heat Detector
			Smoke Detector
			CCTV & Cameras
			Other
		Human	Lookout
			OOW/EOW
			Other Crew Member
			Passenger
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
Threat Detection	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW/EOW
			Other
	Ashore	Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
Threat Analysis	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
Threat Prevention Action	Onboard	Action	Cut off oxygen supply to flammable area
			Close fire doors
			Move flammable goods to safe place
			Reduce heat
			Shut down engine
			Shut down affected systems
			Other

Possible subjects for Phase 1 under entire-vessel incidents (Capsize, Listing, Flooding, Foundering)

L2B	L2C	L2D	L2E
Threat Indication	Onboard	Equipment	Alarms & Warning
			Stability Indicators
			Water Level Indicators
			CCTV & Cameras
			Other
		Human	Lookout
			OOW
			Other Crew Member
			Passenger
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
Threat Detection	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
Threat Analysis	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
Threat Prevention action	Onboard	Action	Altering Speed
			Stabilize & Secure Cargo
			Seal Hull Compartments
			Other

Possible Subjects for Phase 2 under navigational incidents (collision, contact, grounding)

L2B	L2C	L2D	L2E
System Health Indication	Onboard	Equipment	Hull Damage Sensors
			List Indicators
			Water Level Indicators
			Stability Indicators
			Other
		Human	OOW
			Other Crew Member
			Passenger
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
System Health Detection	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
System Health Analysis	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
Emergency Response Action	Onboard	Action	Contain Hull Damage
			Contain Equipment Damage
			Drop Anchor
			Reverse Thrust
			Other
	Offboard	Action	Tug Vessel
			Other

Possible subjects for Phase 2 under on-board incidents (fire, explosion, structural failure, engine failure, loss of control, equipment damage)

L2B	L2C	L2D	L2E
System Health Indication	Onboard	Equipment	Fire Alarm System
			Heat Detector
			Smoke Detector
			CCTV & Cameras
			Other
		Human	Lookout
			OOW/EOW
			Other Crew Member
			Passenger
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
System Health Detection	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
System Health Analysis	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
Emergency Response Action	Onboard	Action	Fire-fighting
			Sprinkler System
			Muster Crew
			Move flammable goods to safe place
			Cut off oxygen supply to flammable area
			Close fire doors
			Shut down engine
			Shut down affected systems
			Other
	Offboard	Action	Fire-fighting vessel
			Other

Possible subjects for Phase 2 under entire-vessel incidents (Capsize, Listing, Flooding, Foundering)

L2B	L2C	L2D	L2E
System Health Indication	Onboard	Equipment	Alarms & Warning
			Stability Indicators
			Water Level Indicators
			CCTV & Cameras
			Other
		Human	Lookout
			OOW
			Other Crew Member
			Passenger
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
System Health Detection	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
System Health Analysis	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
Emergency Response Action	Onboard	Action	Altering Speed
			Stabilize & Secure Cargo
			Seal Hull Compartments
			Seal Watertight Compartments
			Ballast Water Stabilisation
			Other
	Ashore	Action	Tug Vessel
			Other

Possible Subjects for Phase 3 under navigational incidents (collision, contact, grounding)

L2B	L2C	L2D	-L2E
Emergency Response & Evacuation	Onboard	Action	Contain Hull Damage
			Contain Equipment Damage
			Drop Anchor
			Reverse Thrust
			Lower Lifeboats
			Lower MES/Liferafts
			Muster Personnel
			Other Emergency Response Measure
			Other Evacuation Measure
	Offboard	Action	Call Tug Vessel
			Call SAR Services
			Other

L2B	L2C	L2D	L2E
System Health Indication	Onboard	Equipment	Hull Damage Sensors
			List Indicators
			Water Level Indicators
			Stability Indicators
			Other
		Human	OOW
			Other Crew Member
			Passenger
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
System Health Detection	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
System Health Analysis	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

Possible subjects for Phase 3 under on-board incidents (fire, explosion, structural failure, engine failure, loss of control, equipment damage)

L2B	L2C	L2D	L2E
Emergency Response & Evacuation	Onboard	Action	Fire-fighting
			Sprinkler System
			Muster Crew
			Move flammable goods to safe place
			Cut off oxygen supply to flammable area
			Close fire doors
			Shut down engine
			Shut down affected systems
			Lower Lifeboats
			Lower MES/Liferafts
			Muster Personnel
			Other Emergency Response Measure
			Other Evacuation Measure
	Offboard	Action	Call Fire-fighting vessel
			Call SAR Services
			Other

L2B	L2C	L2D	L2E
System Health Indication	Onboard	Equipment	Fire Alarm System
			Heat Detector
			Smoke Detector
			CCTV & Cameras
			Other
		Human	Lookout
			OOW/EOW
			Other Crew Member
			Passenger
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
System Health Detection	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
System Health Analysis	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

Possible subjects for Phase 3 under entire-vessel incidents (Capsize, Listing, Flooding, Foundering)

L2B	L2C	L2D	L2E
Emergency Response & Evacuation	Onboard	Action	Altering Speed
			Stabilize & Secure Cargo
			Seal Hull Compartments
			Seal Watertight Compartments
			Ballast Water Stabilisation
			Lower Lifeboats
			Lower MES/Liferafts
			Muster Personnel
			Other Emergency Response Measure
			Other Evacuation Measure
	Ashore	Action	Call Tug Vessel
			Call SAR Services
			Other

L2B	L2C	L2D	L2E
System Health Indication	Onboard	Equipment	Alarms & Warning
			Stability Indicators
			Water Level Indicators
			CCTV & Cameras
			Other
		Human	Lookout
			OOW
			Other Crew Member
			Passenger
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
System Health Detection	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

L2B	L2C	L2D	L2E
System Health Analysis	Onboard	Equipment	Decision Support System
			Other
		Human	Master
			OOW
			Other
	Ashore	Equipment	Fleet Monitoring System
			Other
		Human	Fleet Monitoring Centre
			Other

4. Specify whether the step was Applicable and Successful – Level 3A & 3B

This stage firstly breaks down each step into smaller 'sub-steps', as follows:

Step	Sub-Steps
Indication	Information Recording
	Information Transmission
Detection	Information Receiving
	Information Evaluation
	Information Transmission
Analysis	Information Receiving
	Planning
	Decision Making
Action	Communication
	Timing & Sequence
	Selection & Quality

Once again, these steps and sub-steps are self-explanatory.

At this stage, the user must determine whether each sub-step was applicable or not. If it was not applicable (for instance, if the threat indicator and detector are the same person and there is therefore no transmission or receiving or information; or if there was no threat detection) the user does not need to answer any more questions, and can move to the next sub-step or step. Alternatively, if a sub-step was applicable, and successful, in that case too, the user can move to the next sub-step without going into further stages of the sub-step.

If, however, a sub-step is applicable, and unsuccessful, the user must answer further questions, and moves to stage 5.

Note here that successful means success in the context of the sub-step – and not in the context of the entire accident or incident; a successful action might still be a *wrong* action in terms of the accident, but it was 'successful' because *in itself*, it was done correctly, but may, for example, have been based on wrong information from the previous step.

5. Specify whether Human or Equipment Failure – Level 4A

If a sub-step was unsuccessful, the user can select in this stage if it was due to human or equipment failure.

6. Specify *what* the Human or Equipment Failure Was – Level 4B

In this level, the user gets to specify what the exact human or equipment failure was. It depends on the sub-step, and the phase that the user is in. Tables on the following pages show the possible failures for each possible sub-step as defined in earlier on this page. This taxonomy is adapted from the TRACEr taxonomy of Kirwan and Shorrock (2002).

Possible Failures for Information Recording

No Information Recorded
Unclear Information Recorded
Partial Information Recorded
Wrong Information Recorded
Delay in Information Recorded
Unnecessary Information Recorded

Possible Failures for Information Transmission

No Information Transmitted
Unclear Information Transmitted
Partial Information Transmitted
Wrong Information Transmitted
Delay in Information Transmitted
Unnecessary Information Transmitted

Possible Failures for Information Receiving

No Information Received
Unclear Information Received
Partial Information Received
Wrong Information Received
Delay in Information Received
Unnecessary Information Received

Possible Failures for Information Evaluation

No Evaluation
Unclear Evaluation
Partial Evaluation
Incorrect Evaluation
Delayed Evaluation

Possible Failures for Planning

No Planning
Unclear Planning
Partial Planning
Wrong Planning
Delay in Planning
Unnecessary Planning

Possible Failures for Decision Making

No Decision
Unclear Decision
Partial Decision
Wrong Decision
Delay in Decision

Possible Failures for Communication

No Action Information Provided/Recorded
Unclear Action Information Provided/Recorded
Partial Action Information Provided/Recorded
Wrong Action Information Provided/Recorded
Delay in Action Information Provided/Recorded
Unnecessary Action Information Provided/Recorded

Possible Failures for Timing & Sequence

Action too long
Action too short
Action too early
Action too late
Action repeated
Action in wrong sequence

Possible Failures for Selection & Quality

Omission
Action too much
Action too little
Action in wrong direction
Wrong action on right object
Right action on wrong object
Wrong action on wrong object
Extraneous act

7. Specify *why* the failure occurred – Level 5

In this level, the user gets to specify why the human or equipment made an error or failed. It depends solely on whether a human or technical subject committed a failure, regardless of the phase or the step. The taxonomy for this stage too (at least for the human subjects) is adapted from TRACEr (Kirwan, Shorrock 2002).

The following tables show possible internal error modes for human subjects.

Perception: to acknowledge information, make a mental note of the information	
Mishear	The signal(s) of technical equipment were not heard accurately.
Mis-see	The signal of technical equipment was not seen properly. This aspect focusses on the ergonomic or physical part of human perception.
No detection (audio/visual)	The signal of technical equipment was not seen or heard.
Late detection	The signal of technical equipment was only detected when it was too late to correct the situation.
Repeat error	Repeating a mistake leading to a worsening of the situation.
Misread	The information from the technical equipment was misread.
Visual misperception	The visual signal was inaccurately perceived/ misperceived by the operator.
Memory: Remembering information	
Forget to monitor	The operator forgot to monitor the technical equipment.
Omitted or late action	The occurrence can be traced back to an operator who omitted to act or reacted late to a warning signal.
Forget temporary information	The occurrence can be traced back to a user who temporarily forgot relevant information.
Forget store information	The occurrence can be traced back to a failure in storing relevant information.
Mis-recall information/action	The user recalls inaccurate information and provides an inaccurate account of his actions post incident.
Prospective memory failure	Post-incident failure in recalling the event as it happened.
Forget to ask / share information	The operator suffered from a lack of information as he forgot to ask for relevant information/ share relevant information with other crew members.

Decision making	
Mis-projection	Faulty interpretation of information.
Poor decision/planning	A wrong decision taken that led to or could not prevent the occurrence.
Late decision/planning	The decision was taken too late to prevent the occurrence.
No decision/planning	No decision was taken to prevent the occurrence.
Action	
Information/data entry error	Wrong information was entered into the technical equipment
Selection error	Wrong technical equipment was selected for performing a certain task.
Unclear information	The information transferred to another party via technical equipment was not clear.
Incorrect information	The information transferred to another involved party via technical equipment was not correct.
Non-performed action	No action was taken in order to prevent the occurrence.
Timing error	The action taken was not faulty itself, but occurred at the wrong moment
Unclear information recorded	The information that was recorded was not clear.
Information not transmitted	Necessary information was not transmitted / transferred to the involved parties.
Violation	
Routine violations	On the vessel some informal work practise followed instead of complying with the formal rules. The formal rule was therefore routinely disobeyed.
Exceptional violation	The formal rule was not followed only in this one scenario which led to the incident.
Sabotage	The official rule was not followed with the intention to cause harm.

The following tables show the possible respective psychological error modes, also for human subjects.

Perception: to acknowledge information, make a mental note of the information	
Expectation	Information was not perceived properly as the operator was influenced by an expectation bias, i.e. the operator did only perceive the information that was expected and supported his view of the situation.
Confusion	The operator confused the perceived information with something else.
Discrimination failure	The operator perceived the information, but did not process it as he perceived it to be irrelevant
Tunnel vision	The operator focused on one single technical equipment or piece of information, ignoring all the others and not perceiving the relevant information.
Overloaded	The operator was overloaded with other information and therefore did not perceive the new information
Vigilance	The operator did not perceive the necessary information due to lack of vigilance
Distraction	The operator was distracted and therefore did not perceive the information
Memory: Remembering information	
Memory confusion	The operator got confused and used the wrong information for the given situation
Memory overloaded	The Operator's memory was overloaded as he was simultaneously processing other information.
Insufficient familiarisation	The operator was not familiar with the kind of information that he should process and therefore erred in processing it.
Mental block	Operator could not access the relevant information.
Distraction	The operator was processing other information and therefore did not realize the relevance of the new information and failed to process it.
Similarity interference	Due to the similarity of the character of the information the operator processed the information based on wrong assumptions.

Decision making	
Misinterpretation	The data were misinterpreted leading to a wrong decision.
Failure to consider side or long effects	The operator did not consider the long term or the side effects of the situation.
Mind set	The mind set and world view of the operator had an important influence on the decision making and eventually led to a wrong decision.
Knowledge/competency problems	The operator did not have the necessary competency or knowledge to make the right decision.
Decision freeze or overloaded	The operator was overloaded with information or tasks and was therefore unable to make a decision.
Risk cognition failure	The operator failed to recognize the risk in a given situation or the decision taken by him.
Action	
Manual Variability	The risky situation occurred due to a mistake in the manual handling of technical equipment.
Confusion	The operator got confused and used the wrong technical equipment for the action he wanted to perform.
Habit intrusion	Out of habit the operator handled the technical equipment in a certain way. However, this action led to a mistake in the given situation.
Distraction/preoccupation	The operator was distracted or preoccupied with something else and therefore did not perform the necessary action.
Other slip	Any other slip that occurred in the connection with the handling of technical equipment.
(intended) Violation	
Stress/pressure	Stress and pressure to perform lead to risky actions consciously violating existing rules.
Fatigue	Bodily and cognitive fatigue leading to risk taking behaviour/risky decisions taken consciously.
Intoxication	The operator is intoxicated due to alcohol, drugs or medicines and takes a risky decision consciously.
Lack of knowledge	The operator takes a risk knowing about the rules that are being violated, but not being aware of/not knowing the potential consequences.
Emotional condition	The operator is dissatisfied or emotional unstable leading him to willingly not follow the procedures and rules in place.

With regards to equipment failures, there is no 'taxonomy' per se. However, it is broadly been identified that an equipment may cause a failure if it is not installed, if it is turned off, is on the wrong settings, suffers from an electric failure, has a poor maintenance record, is out-dated technology, has loose connections or unreliable software. Some of these errors too can be traced back to human mistakes, but primarily may be considered 'equipment' failure causes.

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