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**WORLD MARITIME UNIVERSITY**

Malmö, Sweden

**A STUDY ON MARINE ACCIDENT CAUSATION MODELS EMPLOYED  
BY MARINE CASUALTY INVESTIGATORS**

By

**FATOUMATTA CASSAMA**

**The Gambia**

A dissertation to be submitted to the World Maritime University in partial  
Fulfilment of the requirements for the award of the degree of

**MASTER OF SCIENCE**

**in**

**MARITIME AFFAIRS**

**MARITIME SAFETY AND ENVIRONMENTAL ADMINISTRATION**

2015

## **DECLARATION**

I certify that all the material in this dissertation that is not my own work has been identified, 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):** ..Fatoumatta Cassama.....

**(Date):** ..21 Sep 2015.....

**Supervised by:** Jens-Uwe Schröder-Hinrichs

**World Maritime University**

**Assessor: \***

**Institution/organization:**

**Co-assessor: \***

**Institution/organization:**

## **ACKNOWLEDGEMENTS**

This study is a product of the joint effort by World Maritime University's (WMU) Maritime Safety and Environmental Administration Department headed by Professor Jens-Uwe Schröder-Hinrichs, my supervisor. I therefore extend my deep gratitude to Professor Schröder-Hinrichs for his expert guidance and tremendous support through the completion of this study. I would also like to express my sincere thanks to his research team; Raza Mehdi, Dr Gesa Praetorius and Aditi Kataria for their valuable support throughout this project.

The pursuance of the Master's program would not have been a possibility for me without the support of the International Transport Workers Federation's (ITF) Seafarers' Trust. My sincere appreciation therefore goes to ITF's Seafarers Trust and all the Seafarers in the world. At this juncture, I also extend my deep appreciation to Susan Jackson, WMU's Registrar, for her priceless input in opening the doors that motivated me to apply for ITF's fellowship. Special mention should go to my dear husband Paul E. Carman for his constant and constructive guidance throughout the study and also to my father Malamin F. Cassama who participated greatly in building a strong academic foundation that reflects the great abilities in me.

Finally, to all those who participated in responding to my research questionnaire, interviews, and others who gave their support namely; WMU's Administration & Web Manager Erik Ponnert, WMU's Librarians Chris Hoebeke and Anna Volkova, WMU's Henrik Smith Residence's staff Ursula Hoebeke and Kylie Campbell Lundqvist & their team for providing my husband & I a comfortable environment throughout our stay in Malmo, I say a very sincere thank you.

## ABSTRACT

Title of Dissertation: **A study on marine accident causation models employed by marine casualty investigators**

Degree: **MSc**

This research highlights relevant issues related to marine casualties and presents an overview on casualty investigation, a review of marine accidents, the regulatory framework on marine casualty investigations, a brief discussion on system's design complexity and coupling characteristics, accident causation models used in casualty analysis and the marine accident investigation organizations.

The principal objective of the study was to identify and evaluate marine casualty investigators' endeavors of determining causes of a marine accident with the help of accident causation models or investigation procedures involving accident causation models. The study therefore focuses on the marine accident causation models one could utilize for conducting investigation into marine accidents. States establish an accident investigation regime to determine why an accident happened and to learn lessons that prevent similar accidents from happening in the future.

The overall approach towards the research methodology was to employ mixed methods to complement the data as well as to obtain increased response from the target group. In pursuance of this goal, a mixed methods approach comprising questionnaires and structured interviews was adopted towards data collection for the study.

The models applied by practitioners ranged from none to a plethora of models. The SHELL and Reason's Swiss cheese model were common to the questionnaire respondents and interview participants while the other models mentioned were the ATSB, IMO-MAIIF, HTO, FRAM, AcciMap, MTO, ISIM and Heinrich's Domino model. The utilization of event and causal factors diagrams was also mentioned along with path dependency. This highlights the diversity in the available models. The reasons the participants gave for the utilization of models largely depended upon the ability of the model to capture maritime accidents including complex accidents and the level of training required in the application of the model. The ability of the model to address organizational aspects rather than mechanical failures was highlighted. Also highlighted was the juxtaposition of models – that is utilizing a model to identify the technical aspects of the accident and another to explore how it was managed. Another reason highlighted was the requirement by organizations which mandated a particular model to be used. Various reasons have been stipulated by these marine accident investigators for their preferences of using particular models or none at all. The reduction of marine accidents in the maritime industry as a result of the use of models or not, is in conclusive.

**Keywords:** Accident, Casualty, Investigation, Marine, Model, Complexity, Coupling

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## LIST OF ABBREVIATIONS

Australian Maritime Safety Authority.....	(AMSA), 48
Australian Transport Safety Bureau.....	(ATSB), 47
Bridge Reliability and Error Analysis Method.....	(BREAM), 31
Cognitive Reliability and Error Assessment Method.....	(CREAM), 21
Comprehensive Environmental Response, Compensation and Liability Act of 1980.....	(CERCLA), 12
Cruise Lines International Association's.....	(CLIA), 14
Driver Reliability and Error Analysis Method.....	(DREAM), 31
European Commission.....	(EC), 44
European Union.....	(EU), 13
Functional Resonance Accident Model.....	(FRAM), 21
Global Integrated Shipping Information System.....	(GISIS), 19
Man Technology Organisation.....	(MTO/HTO), 37
Human Element.....	(HE), 4
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Implementation of IMO Instruments Code.....	(III), 17
Integrated Safety Investigation Methodology.....	(ISIM), 66
International Convention for the Prevention of Pollution from Ships... (MARPOL), 12	
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International Maritime Organization.....	(IMO), 3
International Safety Management.....	(ISM), 12
Management Oversight and Risk Tree.....	(MORT), 36
Marine Accident Investigation Branch.....	(MAIB), 13
Marine Accident Investigators International Forum.....	(MAIIF), 45
Marine Accidents Investigators Forum Asia.....	(MAIFA), 45
Maritime Safety Administration.....	(MSA), 45
Merchant Vessel.....	(MV), 10
Oil Pollution Act of 1990.....	(OPA 90), 13
Royal Australian Air Force.....	(RAAF), 38
Safety of Life at Sea.....	(SOLAS), 11
SEquential MOdel of the Maritime Accident Process.....	(SEMOMAP), 40
Sequential Timed Event Plotting.....	(STEP), 74
SHEL.....	(Software, Hardware , Environment and Liveware ) , 3
Simple Model of Cognition.....	(SMOC), 44
Standards of Training Certification and Watchkeeping.....	(STCW), 16
System Theoretical Model of Accidents.....	(STAMP), 21
Transport Safety Investigation Act 2003.....	(TSI Act), 47
Transportation Safety Board of Canada.....	(TSB), 46
United Kingdom.....	(UK), 13
United Nations.....	(UN), 6
United Nations Convention on the Law of the Sea.....	(UNCLOS), 15

United States.....	(US), 12
Very Large Crude Carrier.....	(VLCC), 12
Voyage Data Recorder.....	(VDR), 18
What-You-Find-Is-What-You-Fix.....	(WYFIWYF), 24
What-You-Look-For-Is-What-You-Find.....	(WYLFIWYF), 24

# **A STUDY ON MARINE ACCIDENT CAUSATION MODELS EMPLOYED BY MARINE CASUALTY INVESTIGATORS**

## **1. INTRODUCTION**

The principal objective of this dissertation is to identify and evaluate marine casualty investigators' endeavors of determining causes of a marine accident with the help of accident causation models or investigation procedures involving accident causation models.

The shipping industry, similar to aviation, nuclear and chemical industry, is regarded as a very high risk industry. This risky nature results in great losses and therefore makes it very necessary and essential for accident investigation to serve its purpose. It is widely recognized that there is need for accident investigation since it provides an avenue to learn lessons from and prevent future occurrences. It is the moral responsibility of an Administration towards its citizens to conduct investigations into accidents. When an accident occurs, some tools investigators use to analyze an accident are accident causation models, investigation methods and taxonomies (Singh, 2014).

According to Hollnagel (1998) it is within an accident model's framework resulting in taxonomy and method supporting the analysis of an accident that every casualty investigation should be conducted (Schröder, 2003). Accident causation models are therefore different from accident investigation methods because the methods help gather data in conjunction with the models' philosophy (Singh, 2014).

Thoughts of people about accidents and accident models have changed overtime. In the 1920s, basic investigation techniques and accident models were meant for lost-time accidents in factories involving events where an operator loses

his thumbs in mechanical saws. In this contemporary era, complex systems such as rail roads and nuclear power plants require more sophisticated accident models to deal with accidents in such systems. How accidents in linear and loosely coupled systems are different from accidents in complex and tightly coupled systems is described by Perrow (1999). However, accidents in tightly coupled and complex systems should be considered as normal occurrences rather than abnormal. New kinds of accidents have developed in addition to those that were the focus of early accident investigations. As a result of this, new accident models and investigation methods have been developed by the scientific community (Lundberg et al., 2009, p. 1297). Safeguards, barriers and defenses developed by modern technologies have decreased the occurrences of major accidents. Nevertheless, these accidents continue to occur and consistently lead to catastrophically unacceptable loss of lives and property (Reason, 1997). Perrow (1999) argued about the increasing complexity of high risk systems to a large extent because of the defenses developed by designers to reduce an accident's likelihood to happen. Some safety barriers may increase the systems' interactive complexity and tractability. The system's interactive complexity together with its tight coupling processes (i.e. the sequential processes occurring in a strict manner and in specific time frames responding to actions or events, makes the operators actions' outcome obscured from the operators themselves (University of Glasgow, Scotland, 2002). One of the main challenges encountered is the development of more effective ways to better comprehend and mitigate these accidents (Reason, 1997).

Furthermore, it is very important that an appropriate accident investigation method is selected for a particular system and situation because the need to investigate an accident is essential (Hollnagel & Speziali, 2008). Currently, there is limited guidance to help accident investigators in choosing the best model and methodology for their inquiries. Accident investigators often encounter serious challenges with the investigative methods and concepts. Congressmen, the scientific community members and many other individuals have criticized accident investigators (Benner, 1985).

Organizational accidents which are events that occur in complex modern socio technical systems like marine and rail transport, petrochemical industry, nuclear power plants and commercial aviation etc., are challenging events to understand and control. Nonetheless, however challenging they are, finding a solution to understand how these accidents develop will actually help mitigate their occurrence (Reason, 1997). The International Maritime Organization (IMO) was addressing the issue of accident causation by providing guidance in its Resolution A.884(21) (Appendix 1). The guidance included a methodology to collect data and two models (SHEL - Software, Hardware , Environment and Liveware and Reason's Swiss Cheese) to be used in the human factor investigation process. When the new IMO Casualty Investigation Code was introduced in 2010 (Res. MSC.255 (84)), no such guidance was included. IMO Res. 1075(28), which dealt with areas of the previous IMO casualty investigation regulations not covered by the new Code, did not include such guidance. Member states could not see benefits in recommending specific guidance related to accident causation. As such, the current Casualty Investigation Code may be considered one step back. A fundamental question is how uniform accident investigation results in an organization can be achieved if no method or model is suggested.

This thesis therefore addresses the issue: if and how accident investigators see merits in using accident causation models. Since there are wide variety of methods that can be used in an accident investigation, the criteria applied by investigators when they make decisions about the usefulness of accident causation models will be considered.

## **1.1 Statement of the problem**

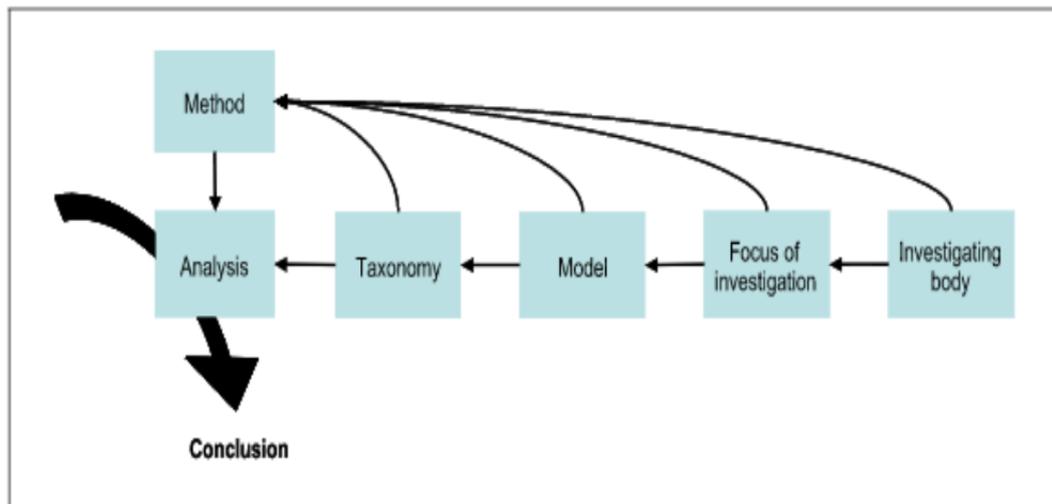
Dekker (2011) suggests that the great advancement of complexity in society has led to a diminished understanding of the operation and failure of complex systems including related processes and potential effects. These systems are built and have their properties modelled simply in isolation but when exposed to the competitive nominally regulated world, their complexity, interactions, connections or interdependencies proliferate. As a consequence, problems develop unexpectedly. The unavailability of well-developed framework to enhance understanding on how such complexities develop, encourage the application of simple linear componential ideas when such complexities fail. These ideas are believed to be a remedial measure (Dekker, 2011).

According to Sklet (2004), major accidents leading to huge number of fatalities still exist in some industries regardless of the great focus on risk management in our society today. As a result of the unacceptable circumstances of these accidents, thorough accident investigations should be conducted in order to learn from the occurrence and help avert future accidents. The accident investigation methods developed during the last decades each have various areas of application, various deficiencies and qualities. An accident requires a combination of various methods for a comprehensive investigation (Sklet, 2004, p. 29).

Furthermore, Schröder (2003) reiterates that- 80% of all marine casualties are still considered to be caused by the Human Element (HE). Particularly after major catastrophic events at the early 1990s, the policy makers through their regulatory regime shifted towards a more detailed approach of the HE issue rather than reacting to such accidents by pure technical measure stimulation. Nevertheless, by research in other transport modes, the progress made in the maritime field regarding HE is not very substantial. Specific accepted maritime definitions such as accident causation models and taxonomies are still missing (Schröder, 2003).

Additionally, many countries lack a solid database for marine casualties to help in risk assessment in the shipping industry (Schröder, 2003). However, policy makers tend to want to convince the public that the root cause of a particular accident

can be eliminated after the use of their ad-hoc measures. Rationally, only simple expert judgement could be utilized in the absence of marine casualty history data sources. Therefore, it is now a question of: what needs to be done in order to overcome the deficiencies of the marine accident investigation sector? (Schröder, 2003).



**Figure 1:** Framework for casualty investigation  
Source: (Schröder, 2003)

The figure above is a representation of Hollnagel’s (1998) statement regarding accident investigations being conducted within an accident causation model’s framework which will result in taxonomy and method that will support an accident investigation (Schröder, 2003). However, Schröder (2003) pointed out that it is the mandate of the investigation body that determines the focus of an investigation and as such the model to be used during the investigation.

The study therefore focuses on the marine accident causation models one could utilize for conducting investigation into marine accidents. States establish an accident investigation regime to determine why an accident happened and to learn lessons that prevent similar accidents from happening in the future. In order to achieve this, appropriate preventive measures need to be put in place with the objective to improve the overall reliability of maritime transport and to ensure safer

properties, crew and passengers as well as cleaner oceans. However, in order to achieve this objective, a harmonized system of maritime accident investigation is needed. This system is outlined in figure 1, Schröder (2003) above, where a framework is shown that includes an accident causation model. The accident causation model helps to harmonize the performance and the focus of different investigators working in an accident investigation body. Without such harmonization, it is doubtful that meaningful progress can be achieved in maritime safety.

### **1.2 Motivation behind the project**

A safety engineer's point of view regarding the objective of an accident investigation is the identification and description of the real sequence of events (what ,where ,when), identification of the root and direct causes or factors contributing to the accident and identifying risk mitigating measures to prevent accidents in the future (learning) (Sklet, 2002). It is the responsibility of a multidisciplinary team of investigators to conduct investigations on major accidents usually caused by various interconnected causal factors. Suitable and formal accident investigation methods should support such inquiry. All relevant constituents' influence such as technical systems, governments, managers and front line personnel and regulators should be analyzed in a comprehensive investigation (Sklet, 2002).

From the author's perspective, regardless of the fact that conventions under United Nations (UN) and IMO impose the duty on flag States to conduct marine inquiries, some countries in the world (for example The Gambia) do not completely adopt marine casualty investigation principles yet. This is largely due to the absence of an independent accident investigation machinery and capacity to elaborate the importance of casualty investigation. Additionally, it is the researcher's perception that States actively conducting inquiries in marine accidents still have similar accidents reoccurring. This research therefore would be an attempt to provide a better understanding of the importance of marine casualty investigations and models that can be utilized by States with respect to their advantages and disadvantages. In particular, the question which model is chosen for which reason is of particular

interest. Again, accident causation models may help to harmonize the approach of accident investigators, which is a prerequisite that appropriate lessons can be learnt from accident investigations and that different teams looking at the same accident may come to similar conclusions.

This research therefore wants to find out why and how accident causation models are used or are not used.

In order to address the issues highlighted above, this thesis will focus on the following questions:

- What is the purpose of marine casualty investigations and how are the investigations conducted?
- What marine casualty models are widely used in the maritime industry today?
- Why are these models currently used?
- How helpful are they in handling and avoiding marine casualties?
- If models are not used at all or particular models are not used, what is the reason?

### **1.3 Structure of Thesis**

To amend the research questions within the concept of a Master thesis, this research is structured as follows:

Chapter I entails a brief introduction on the subject of this Master thesis, the problem statement of this research and the motivation behind the study.

Chapter II consists of background information relating to marine casualty investigation, a review of marine accidents and the development of regulations, casualty investigation regulatory framework, investigation procedure, a system's complexity and coupling factors, the different accident causation models used by accident investigators and the various marine casualty investigation organizations.

Chapter III presents a methodology used for a questionnaire survey and interviews that facilitated the identification of factors and reasons that influence accident investigators' decision in choosing certain accident causation models.

Chapter IV provides the results of the findings from both the questionnaires and the interviews conducted.

Chapter V summarizes the facts found in the research and presents a discussion based on these facts.

Chapter VI finally presents a conclusion about the issue of application of accident causation models and possible areas for future research.

At the end of the thesis are Annex 1 which consists of definition of terms, Annex 2 which is the questionnaire survey and the list of references.

## 2. BACKGROUND

This chapter provides an overview on relevant issues related to marine casualties. It may therefore help the reader to understand and interpret the data collected in this study. This section discusses understanding of casualty investigations, a review of past and contemporary accidents, marine casualty investigation regulatory framework, complexity and coupling in systems design, the models used in casualty analysis and the various organizations that monitor these marine casualties.

Accidents change maritime regulations. The Table 1 below (Schröder-Hinrichs et al., 2013), shows that every accident caused a regulatory follow up. Examples of such accidents are Titanic, Torrey Canyon, Herald of Free Enterprise, Estonia etc. and more details on such accidents are discussed in this study.

Year of accident	Ship name	Resulting measure/instrument	In force since
1912	<i>Titanic</i>	SOLAS, 1914 <sup>a</sup>	
1967	<i>Torrey Canyon</i>	Intervention Convention, 1969	1975
		Civil Liability Convention, 1969	1975
		MARPOL Convention, 1973	1983
		STCW Convention, 1978	1984
1976	<i>Argo Merchant</i>	MARPOL Convention, Protocol of 1978	1983
1987	<i>Herald of Free Enterprise</i>	ISM Code, 1994	1998
1989	<i>Exxon Valdez</i>	OPRC Convention, 1990	1995
		MARPOL Convention, 1992 amendments (double hull)	1995
1994	<i>Estonia</i>	SAR Convention, 1998 amendments (improvement of cooperation)	2000
1999	<i>Erika</i>	Res. 949(23) Guidelines on places of refuge for ships in need of assistance	2003 <sup>b</sup>
2002	<i>Prestige</i>		

**Table 1:** Selected accidents and the reactive follow-up in IMO

**Source:** Schröder (2004) as cited by Schröder-Hinrichs et al. (2013)

## **2.1 Understanding Marine Casualty Investigation**

A case study will be used to enhance a better understanding for marine accident investigation and therefore, the Formal Investigation into the collision between Merchant Vessel (MV) European Gateway and MV Speedlink Vanguard will be discussed for this purpose.

On 19<sup>th</sup> December 1982, at around 22:51, the European Gateway collided with the Speedlink Vanguard in clear visibility and within ten minutes of the collision, the European Gateway listed and lay on her starboard side with her port side clear of water since it was not in deep waters. The rescue vessel evacuated almost all people onboard the European Gateway. However, some men either jumped or were thrown overboard and 4 crew members and 2 passengers died from these. The questions raised as a result of the incident were:

1. Why did the collision occur?
2. Why did the European Gateway capsize so rapidly?

The first purpose of the investigation was to seek answers for the above questions and to make considerations as to how the loss of lives occurred. Secondly, the lessons that can be learnt from the casualty were another purpose of the investigation. Finally, and subsidiary, to determine whether it was by default or wrongful act of any person that led to the loss of the European Gateway subsequently leading to the deaths and the court having to decide whether to impose penalties on such persons was another purpose of the investigation (Department of Transport London, 1984).

The current IMO mandatory Casualty Investigation Code specifically deals with safety investigations and makes it an obligation for every member state to conduct inquiries into marine casualties. At this point, this study would like to highlight how important marine accident investigation is, simply because out of every maritime accident, certain regulations were made.

## **2.2 Past and contemporary accidents review and the development of safety regulations**

In 1912, the Titanic sank leaving 1503 people dead. Two years after in 1914, the International Convention for the Safety of Life at Sea (SOLAS) was adopted by maritime nations in London where lessons learnt from Titanic were taken into account. The SOLAS 1914 version was superseded by many versions up to the last version SOLAS 1974 which is currently in force. Nevertheless, it has been amended and updated several times. Regulations on life saving appliances and arrangements were included in the convention to ensure that passengers and crew have a greater chance of survival in an event of a catastrophe (Maritime New Zealand, 2012).

Another accident was the grounding of Torrey Canyon in 1967. While entering the English Channel, the vessel grounded spilling a 120000 tons cargo of crude oil into the sea. Up to that period, this incident was the biggest pollution ever recorded. The question of measures to prevent oil pollution from ships was raised and also deficiencies in existing system in order to provide compensation after an accident at sea were exposed. The chain of events that gradually led to International Convention for the Prevention of Pollution from Ships, MARPOL's adoption including a host of Conventions in the compensation and liability domain were triggered by this incident (International Maritime Organization, n.d.).

On December 15<sup>th</sup> 1976, Argo Merchant went aground on Nantucket Shoals. About 183000 barrels of No. 6 Fuel oil were onboard this vessel. This seriously polluted US' Grand Banks and Georges Bank. United States (US) enacted acts such as Port and Tanker Safety Act of 1978 and Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) among others (Cushing, 2013).

Furthermore, in March 1978, a Very Large Crude Carrier (VLCC) Amoco Cadiz, grounded off Britany's coast in France spilling a massive amount of oil. A strong outcry by both public and politics for much more stringent regulations related to safety in shipping resulted from this incident. A more comprehensive memorandum as a result of this pressure was developed dealing with: safety of life at sea, pollution prevention by ships and living and working conditions on board ships. Consequently,

in January 1982, a new Memorandum of Understanding on Port State Control was signed in Paris, France at a Ministerial Conference by fourteen European countries (Paris MOU on Port State Control, n.d.).

The Herald of Free Enterprise on 6<sup>th</sup> March 1987, capsized shortly after departing Zeebrugge Port in Belgium bound for Dover, leaving 193 crew and passengers dead. New regulations were developed by the IMO as result of the incident. Prohibition of an open deck of this length on Ro-Ro passenger vessel and several design improvements of such type of vessel were made. The International Safety Management (ISM) code was the most important development made as a result of the Herald of Free Enterprise (Tarelko, 2012).

Disasters almost similar to the Herald of Free Enterprise' were European Gateway flooding, Estonia and al-Salaam Boccaccio 98. The United Kingdom (UK) Marine Accident Investigation Branch (MAIB) was formed as a result of the Herald of Free Enterprise disaster (Cushing, 2013). On 20<sup>th</sup> December 1987, a passenger ferry Dona Paz, collided with MT Vector an oil tanker. About 8800 barrels of gasoline in addition to other petroleum products were onboard MT Vector. This cargo ignited and caused fire that spread unto Dona Paz. The Dona Paz sank followed by MT Vector. Research shows that approximately 4341 lives were lost. Lessons learned from past incidences have not been heeded and therefore, overloaded vessels sink. Developing countries still encounter problems in this area (Cushing, 2013).

Exxon Valdez in March 1989, carrying 1264155 barrels of crude oil, grounded at North Eastern part of Prince Willian Sound and spilled one-fifth of its cargo. One of the largest crude oil spills in US waters, and one with the biggest media coverage so far, had the US public demand action which they duly attained. The Oil Pollution Act of 1990 (OPA 90) was introduced by the United States and made it mandatory for all calling at Ports in US to have double hulls (International Maritime Organization, n.d.).

Another accident was MV Estonia in September 1994 and IMO in response to this accident together with the Herald of Free Enterprise, adopted a series of amendments to the SOLAS convention (International Maritime Organization, 2015). The loss of

the tanker vessel Erika in 1999 off France's coast resulted in the European Union (EU) adopting several directives mainly for accident prevention at sea and marine pollution prevention. On 27<sup>th</sup> June 2002, Directive 2002/59/EC was adopted by the Parliament and the Council. The directive was later amended by Directive 2009/17/EC. A vessel traffic monitoring and information system was established based on this directive for enhancement of safety and efficient maritime traffic, improved authorities' response to incidents, potentially dangerous circumstances at sea or accidents including search and rescue as well as pollution detection and prevention from ships (European Maritime Safety Agency, 2015).

In 2002 was the Le Joola sinking accident with 1865 lives lost due to organizational factors, some irresponsible ship owners and appropriately regulated by the Maritime Administration. Another major incident in 2002 was the sinking of Prestige, a tanker vessel, which caused massive environmental damage to the Spanish and French coasts up to a billion euros worth. The al-Salaam Baccaccio 98 disaster occurred on 2<sup>nd</sup> February 2006 leaving 1022 people dead. In 2008, the Princess of the Stars sank and left 800 dead. With the al-Salaam incident the owner of the vessel was sentenced to 7 years in prison due to the callous actions of management onboard the vessel (Cushing, 2013).

Costa Concordia, on 13<sup>th</sup> January 2012, nearly sank as a result of striking a large rock. An article written by Adam Piore of Conde Nast Traveler entitled Staying Afloat is perhaps one that helps to explain the various safety issues requiring improvement after the Costa Concordia incident. The article highlights that between 2002 and 2011, only 6 people died in operational incidents out of 153 million passengers carried during the period as compared to accidents or suicides on shore excursions. The public's attention was partly seized with regards to the Concordia catastrophe because this was a state-of-the-art vessel owned by Carnival Corporation one of the world's largest cruise ship operator. Troubling questions were raised as a result of the unexpected vulnerability of one of the industry's most sophisticated ships which proved disturbing. The Concordia resting on a large rock was simply what prevented it from sinking. Otherwise, if the ship had sunk, the abandoning ship

window would have quickly closed leaving thousand dead. *'I thought that after the Titanic, something like that would never happen again,' said ...one of the passengers.*

Cruise Lines International Association's (CLIA) announcement of a voluntary policy for the whole maritime industry for muster drills to be made mandatory was the first major change after the Concordia accident. Vessel design was also another issue raised and under the SOLAS Convention, ships must be designed to withstand flooding of the two watertight compartments that will enable the ship to maintain stability if the hull is damaged. The Concordia investigators considering why the system failed, is a key question. Experts say; it is possible that there was enough damage to the ship's compartments to cause sufficient catastrophic flooding to sink the vessel. Another likelihood which is much discussed is that, due to human error, the doors that seal the compartment were left open. Furthermore, for training, a new Life Boat Loading for training purposes policy was enacted and made effective on or about 24<sup>th</sup> September 2012 as a result of CLIA's review on Cruise Industry Operational Safety (Dickerson, 2014).

What is basically seen is that, the more significant an accident is, the more pressure it exerts on regulators to respond and demonstrate to the public at large that such an accident cannot be repeated. That is why the accident investigation of course is quite important in this context because any safety recommendations that may come out of the accident investigation may be taken up by the regulator and then become part of a new regulation. That is why accident investigation is an important function in the maritime administrative framework and that is why it is part of a lot of regulations which will now be discussed.

### **2.3 Regulatory framework**

The requirements of marine accident investigation can be found in various instruments. Also, when it comes to the UN agencies that are involved, various requirements are found. However, the overall principle is enshrined in the United Nations Convention on the Law of the Sea.

Under the United Nations Convention on the Law of the Sea (UNCLOS 82), it is the responsibility of every Flag State to conduct investigation in any casualty that occurs on board a ship flying the flag of the State (United Nations, 1982). This obligation is also stipulated on the IMO's conventions as stated below:

*UNCLOS, Article 94(7) states that " Each State shall cause an inquiry to be held by or before a suitably qualified person or persons into every marine casualty or incident of navigation on the high seas involving a ship flying its flag and causing loss of life or serious injury to nationals of another State or serious damage to ships or installations of another State or to the marine environment. The flag State and the other State shall cooperate in the conduct of any inquiry held by that other State into any such marine casualty or incident of navigation" (United Nations, 1982).*

This requirement is there for an inquiry to be conducted by States. However, more specific regulations emanate from SOLAS, MARPOL, Standards of Training Certification and Watchkeeping (STCW) and International Load Line conventions (LL 69) etc.

SOLAS 74:-Reg 1/ 21 states that " Each Administration undertakes to conduct an investigation of any casualty occurring to any of its ships subject to the provisions of the present convention when it judges that such an investigation may assist in determining what changes in the present regulations might be desirable."

Article 12 of MARPOL73/78 and article 23 of International Load Line Convention also state more or less same as stated in above conventions.

The IMO's Implementation of IMO Instruments Code (III), resolution A. 1070 (28), is much more specific when it comes to safety functions than SOLAS MARPOL and Load Line etc. The III Code deals with measuring the performance of a Flag State. This means that the State needs to know what happens in their fleet; how many accidents a State has and what the problem areas are. A State is therefore able to determine this with the help of accident investigation. The conventions are very generic and more specific requirements come from the III Code in the Casualty Investigation Code 2008 Chapter 6. This chapter states that: "A marine safety investigation shall be conducted into every very serious casualty". The meaning of very serious marine casualty is stipulated on Annex 1 of this document.

There is one specific aspect in resolution 1075(28) under paragraph 5.13 which talks about accident causation models. However, the resolution does not specifically require that certain tools should be used. Nevertheless, it is recognized that accident causation models may be employed by an accident investigator. The question then is, which model can a marine accident investigator apply? Before elaborating on this, a summary of accident investigation procedure will be discussed first.

## **2.4 Investigation procedure**

Once an investigation commences, the site is managed even before investigators arrive at the scene. A start up meeting is then convened if more than one State is involved in the safety investigation. If there exist other substantially interested State(s), their representatives could be part of the meeting. This meeting facilitates knowledge sharing among the investigators, the investigation plan development and task delegation among other things (International Maritime Organization, 2014).

The next step normally is collection of evidence where the investigator's aim is to gather all factual data and evidence that may be of interest to the investigation scope. This could include witness statements, documentary and physical evidence etc. At this juncture, the casualty site could be inspected for further documentation of the site, the ship, other ships involved, fairway where the accident occurred, and conduct underwater survey as well as take videos of the ship's wreckage. Following this, the

Voyage Data Recorder (VDR) and other onboard electronic devices could be taken as physical evidence. Other physical evidence could include logbooks, on-board weather forecasts, nautical charts, fire alarm units, electronic charting units, oil samples, fire and paint residues and broken parts or machinery pieces (International Maritime Organization, 2014).

A skilled person in interviewing techniques should conduct witness interviews for revelation of information by the interviewee. The location and time in addition to requirement of an interpreter and particular needs of the interviewee among others must be considered. After the interview, the documents, records and procedures have to be reviewed and this can consist of ship-related and personal certificates, ship's classification society's report, Master's standing orders and maintenance records etc (International Maritime Organization, 2014).

An assessment of the Ship's Safety Management System from its policy and its implementation should be considered. When relevant, specialized studies can be conducted for establishment of how an incident or casualty occurred. Broken parts of machines metallurgic specialist studies, ship stability reconstruction features, oil and paint analysis, weather and sea condition analysis at the place and time of the incident or casualty, lashing calculation and the usage of simulator for reconstruction and analysis of a sequence of events could all be considered (International Maritime Organization, 2014).

For support of analysis and reconstruction in safety investigation, several methods of organizing evidence exist. However, each of them has its merits and demerits. From a safety perspective, ensuring that a thorough examination of the casualty or incident is made, it is important for the investigation to be conducted from a systemic point of view. This involves not only determining "who did what" but also searching for influential factors of different relevant events even in circumstances that these conditions are found remote from the casualty site. Human factors context involving interactions between machine, man and the organization is considered by the systemic perspective (International Maritime Organization, 2014).

What follows next is reconstructing the casualty events and linking them with their conditions. The initial step here would be to review facts and clarify relevance of the information ensuring that it is as complete as practicable. At this level, the aim of the analysis should be to determine how the marine incident or casualty occurred. Preferably, the reconstruction is carried out with a method that would allow events' sequence graphical description. This is important because it would allow the investigator to present and discuss the case and also particular things like identifying information gaps, conflict in evidence, contributing factors and other relevant aspects. The underlying safety issues causing or contributing to the casualty or incident can be well understood with the safety analysis. However, safety analysis and casualty analysis could be combined as one in some methods of investigation analysis. Furthermore, a direct linkage of some basic analysis method to events reconstruction could be made while different accident causation models could be used as other safety analysis tools and could be even much better when used as stand-alone methods (International Maritime Organization, 2014).

The report has to be made at this stage as IMO MSC-MEPC.3/Circ.4 requires that the final version of the marine safety investigation together with particular marine casualty data to be entered into the Global Integrated Shipping Information System (GISIS) marine casualties and incidents module.

Finally, there will be consultation for rectification of particular matters on the report and then a follow up on safety recommendations for positive reinforcement by making the recommendations public (International Maritime Organization, 2014).

In the following section of the research, there will be a detailed account of the models and methods used by marine casualty investigators for the investigation of marine casualties. At this point, the question; what is the maritime domain? needs to be addressed. Otherwise, there will be difficulties in selecting the right model or making an argument why a specific model should be used. Benner's criteria for rating accident models are used in this study to determine the desirability of an accident model to capture

## 2.5 Benner's criteria for rating accident models

Benner (1985), listed ten criteria that are desirable for accident models as presented on Table 2 (Lundberg et al., 2009). These criteria are also used in this study to determine an accident causation model's desirability by marine accident investigators.

Model evaluation criteria	Definition
Realistic	The investigation should result in a realistic description of the events that have actually occurred.
Definitive	An investigation process should provide criteria to identify and define the data that is needed to describe what happened.
Satisfying	The results should be satisfying for those who initialised the investigation and other individuals that demand results from the investigations.
Comprehensive	An investigation process should be comprehensive so there is no confusion about what happened, no unsuspected gaps or holes in the explanation, and no conflict of understanding among those who read the report.
Disciplining	An investigation process should provide an orderly, systematic framework and set of procedures to discipline the investigators' tasks in order to focus their efforts on important and necessary tasks and avoid duplicative or irrelevant tasks.
Consistent	Model must be theoretically consistent with an agency's safety program concepts.
Direct	The investigation process should provide results that do not require collection of more data before the needed controls can be identified and changes made.
Functional	An investigation process should be functional in order to make the job efficient, e.g. by helping the investigator to determine which events were part of the accident process as well as those events that were unrelated.
Non-causal	An investigation should be conducted in a non-causal framework and result in an objective description of the accident process events. Attribution of cause or fault can only be considered separate from, and after the understanding of the accident process is completed to satisfy this criterion.
Understandable or visible	The output should be readily understandable.

**Table 2:** Benner's (1985) criteria for rating accident models  
Source: (Hollnagel & Speziali, 2008, p. 20)

### 2.5.1 The need for accident investigation models

An accident model has several functions. It helps to focus on the object of investigation and also helps to harmonize the approaches of various investigators no matter the simplicity or complexity of the investigation.

The UN specialized agency responsible for maritime affairs, IMO, among its most important objectives has always been ship safety improvement through accident

investigation. To enhance maritime accident investigation, national and international institutions and bodies made further approaches in addition to IMO. The scientific support on maritime accident investigation has been a main issue apart from pure legal considerations. In this respect, methods have been created to be used for maritime accidents such as SHEL for example, by Hawkins 1987, which is adapted from the aviation industry. (Schröder, 2004).

The above being what IMO started with, they in fact represent a certain class of models. There are different scientists who look at accident causation models from different perspectives. However, what is important is, the model as such determines What-You-Look-For-Is-What-You-Find. This is also highlighted by Schröder (2003) on figure 1. It is the focus of the investigation that is determined by the one who investigates. These investigators search for certain information to extract and therefore what is found is what is fixed (Schröder, 2003).

According to Sklet (2002), various accident causation models direct the different accident investigation methods used to help establish the cause of an accident (Sklet, 2002). The kind of model that influences a method used by accident investigators is assessed since the investigators' view of accident causation is influenced by their mental model. These models used include: Causal-sequence model, process model, energy model, logical model and SHE management model (Sklet, 2004).

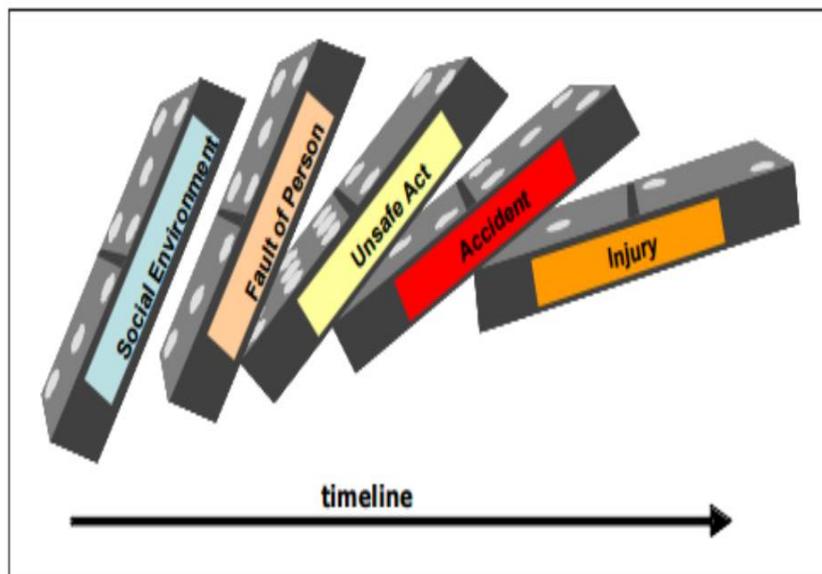
Accident models can be categorized into three major groups according to Hollnagel's proposal (Hollnagel 2004) (Lundberg et al., 2009). A procedure or method is always followed by an accident investigator. Various methods exist both within and between domains and the differences depend on how well established and articulated the methods are. The investigation is directed by the method in order to analyze particular factors and leave others. Initiating an accident investigation, it is simply impossible for an investigator to keep a completely open mind, just as it is impossible to passively see what is going on at the accident scene. What-You-Look-For-Is-What-You-Find (WYLFIFYF) principle (Hollnagel, 2008) can therefore be the characteristic that accident investigations conform to. The corollary then becomes What-You-Find-Is-What-You-Fix (WYFIWYF) principle because people seldom

seek advice for “second stories” since the main purpose of accident investigation is finding remedial measures to prevent future occurrences (Woods & Cook, 2002). This therefore connotes that during an investigation, factors found as causes to an incident are deemed as specific individual problems that have to be fixed during implementation (Lundberg et al., 2009).

## 2.6 Traditional accident model approaches

### 2.6.1 Sequential accident models

Accident causation resulting from a particular temporal order of a discrete chain of events is explained by sequential accident models. Heinrich (Ferry 1988) proposed the Domino theory which is one of the earliest sequential accident models. This theory indicates that five factors are involved in an accident sequence (Qureshi, n.d.) as shown on figure 2.



**Figure 2:** Heinrich’s domino model of accident causation  
**Source:** Qureshi (2008)

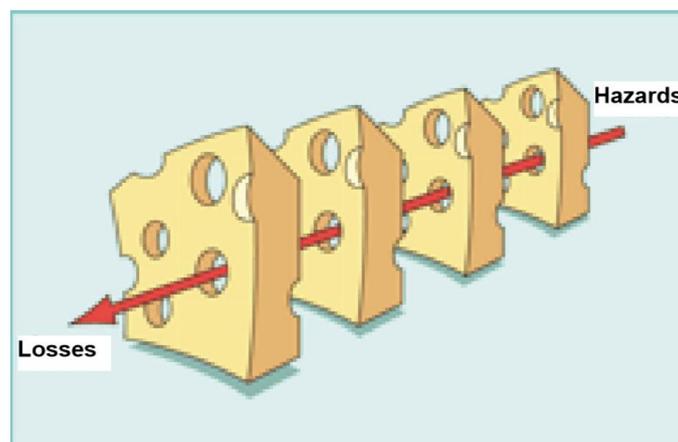
While the focus on early work (eg Heinrich, 1931) was to increase safety in factories by management control of workers, accidents such as the Challenger and the Three Mile Island changed the focus. The focus in addition to operational organization now includes operational conditions, safety climate and safety culture. However, safety culture stems from the Chernobyl investigation. Various relations and components are to be considered because even thorough research depicts that 90% of all industrial accidents are caused by management (Heinrich, 1928). Human, technology, organization and information among others, are criteria that general practitioners and authors in the safety community regard as important factors. These broad criteria require specific areas of expertise and therefore the quality of results becomes critical as there is a challenge with regards to the competences of available specialists, investigators or team (Lundberg et al., 2009).

In literature, the scope and accident model are always described together. For example, three factors were listed by Heinrich (1959) as causes to an accident; social factors (e.g., environment, inheritance), people's faults (e.g., safe practice ignorance, violent temper) and acts that are unsafe (standing beneath suspended loads) (Lundberg et al., 2009). In Heinrich's early model, these three factors were the first section of five stage linear model suitably portrayed as a line of dominoes. As such, management removing any of the three initial factors would prevent the two factors (the accident and injury) from occurring. Faults of people were seen as causing technical faults in this model and also appear in the line of dominoes at the same stage as unsafe acts. Consequently, this linear sequence was a sequence of factors that primarily led to the accident instead of a sequence of events. However, Heinrich's belief was that removal of one piece of domino will prevent the row from falling further and that the fall of the first domino piece will not cause the inevitable fall of the last piece as we see with real domino rows. Additionally, in the 1959 illustration of a domino brick lifted by a hand, from unsafe condition or act went a second line of enquiry, from the line manager to high management focusing on two factors; commitment and control to safety (Lundberg et al., 2009).

## 2.6.2 Epidemiological accident models

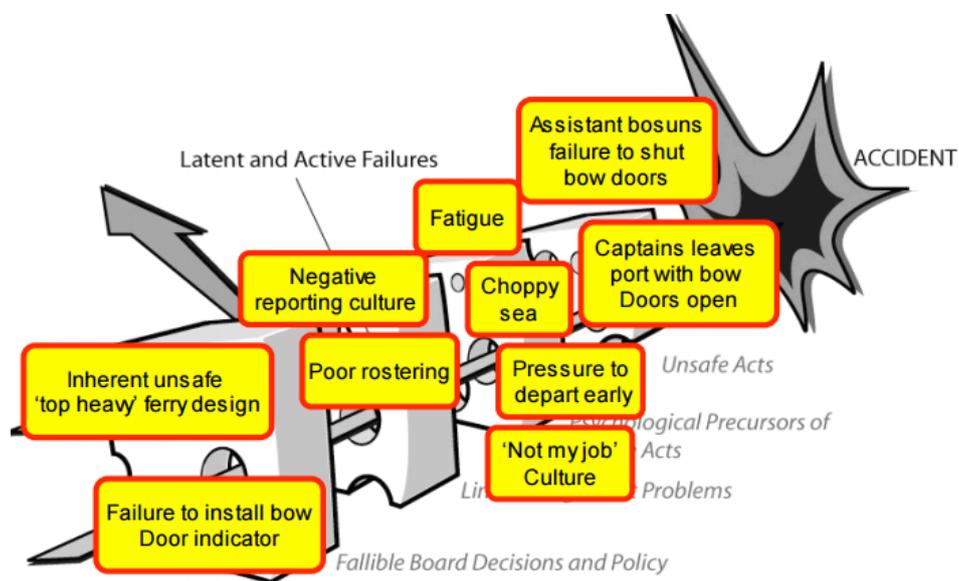
In 1980s the class of epidemiological accident models began to gain popularity as a result for the need of more powerful ways of understanding accidents (Hollnagel 2001). This model regards events that lead to an accident similar to how a disease spreads i.e. as a result of a combination of factors where some are obvious and some hidden (underlying), are present together in time and in space. Reason (1990, 1997) provides an excellent account of this work with emphasis on concepts of organizational safety and how defenses such as human, procedures and material as protective barriers may fail (Qureshi, n.d.).

Reason's (1997) model of organizational accidents, one among the existing models, mix events and factors. In Reason's model, several coinciding events were seen as the causes of organizational accidents. A line of four factors was depicted from each event trajectory. Organizational factors (such as budget, auditing and planning) and local work place factors (such as undue time pressure-error provoking conditions) were the first two factors. Unsafe act (people's faults) from Heinrich's model remained as the third factor. Failed barriers or defenses remained as the fourth factor. Nonetheless, Reason instead of just focusing on one event (one trajectory) as the sole cause of an accident, regarded an accident as a combined event trajectories where each trajectory ends with a failed defense. This resulted in a model widely known as "Swiss cheese model" (Lundberg et al., 2009) shown on Figure 3.



**Figure 3:** Reason's Swiss Cheese model  
Source: (Energy Institute, 2008, p. 15)

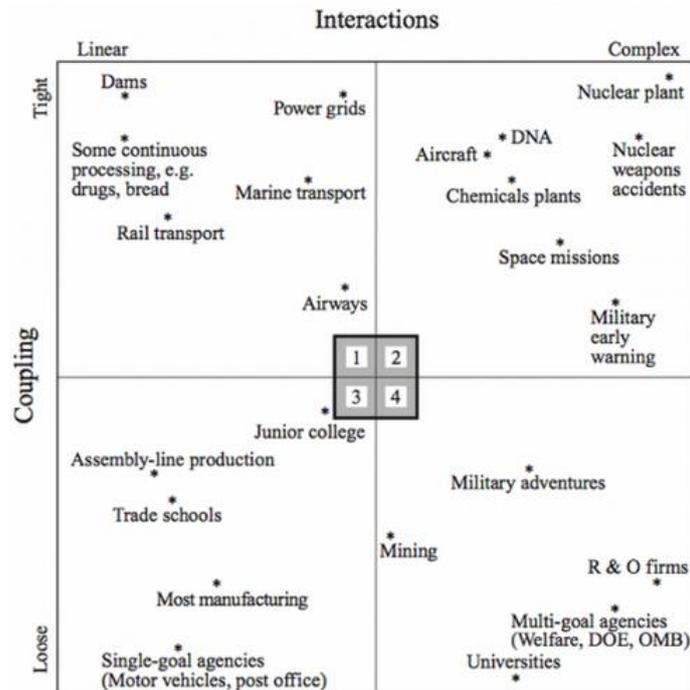
Like Swiss cheese slices, a series of barriers represent an organization's defenses against failure. The holes in the slices of the cheese continuously varying in size and position represent the weaknesses in the system's individual parts. Failure is imminent when all the holes align momentarily thereby permitting "a trajectory of accident opportunity" making it possible for a hazard (figure 3) to pass through all of the holes in all the defenses. The system as a whole produces the failure (Lundberg et al., 2009). A clear example of the latent failures is presented on Figure 4 below regarding the Herald of Free Enterprise disaster.



**Figure 4:** Herald of Free Enterprise's failed defenses  
 Source: Salmon, Williamson, Rubens, Brown, & Lenne, (n.d.)

### 2.6.3 Complex socio-technical systems

A complex and tightly coupled system is the worst possible combination for the potential of an accident. The nuclear power plant with the Three Mile Island accident is Perrow's main example at this point. Figure 5 below expresses Perrow's thesis and is very important with regards to accident investigation methods since the degree of coupling and nature of interactions in a system must be able to be accounted for by an accident's explanation.



**Figure 5:** The coupling - interaction diagram  
**Source:** (Perrow, 1999, p. 327)

Argumentatively, if the four quadrants of figure 5 are referred to for instance, it can then be clearly seen that systems in the third quadrant differ in important respects from the second quadrant's systems. It is unlikely for a method that is sufficient to explain an accident in the third quadrant (for example an injured person working in an assembly line) to be also adequate to explain an accident in the second quadrant (for example an INES event at a nuclear power plant). Although the opposite is not necessarily true, investigating a simple accident may be inefficient with the use of more complex and powerful accident investigation methods. The above diagram therefore provides in addition to more traditional requirements such as usability, reliability, and consistency etc., an external reference frame for accident investigation methods (Hollnagel & Speziali, 2008).

*“Perrow(1999) identifies two interacting variables that specify a space, which fully characterizes accidents. They are coupling and interactions. Interactions are the reciprocal actions among elements of the system. These*

*interactions can be tightly coupled or loosely coupled. Tightly coupled interactions are those that do not tolerate delay. They have invariant sequences and negligible slack. Loosely coupled interactions have the opposite characteristics. The interactions are linear or complex. The term “linear” means simple. The opposite is “complex.” With these definitions, Perrow creates the following framework to classify systems.” (Cyert & March, 2015, p. 2)*

A nuclear power plant with a tight coupling degree is the most complex intractable system. An accident causation models' suitability with regards to coupling and tractability degree are discussed by Hollnagel (2008). His argument is that System – Theoretical Model of Accidents (STAMP) (Leveson, 2004) and Functional Resonance Accident Method (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 (Singh, 2014). Another example of a systemic model is AcciMap Rasmussen (1997) (Singh, 2014).

In modern complex systems, outcome is delivered through collaboration between human interactions with technology. When either humans or technology is left in isolation, such outcomes cannot be achieved. These systems which are made up of human agents as well as technical components are often embedded within complex social structures such as the goals of the organization, culture and policies, political, environmental, legal and economic elements. Human agents and social institutions being integral parts of the technical system and that the objectives of the organization cannot be met by optimizing the technical system alone but by optimization of both the technical and social aspects, is what the socio technical theory implies (Trist & Bamforth 1951). Therefore, an understanding of the interrelationships and interactions between a systems organization, human, technical and social aspects are required in the study of modern complex systems (Qureshi, n.d.)

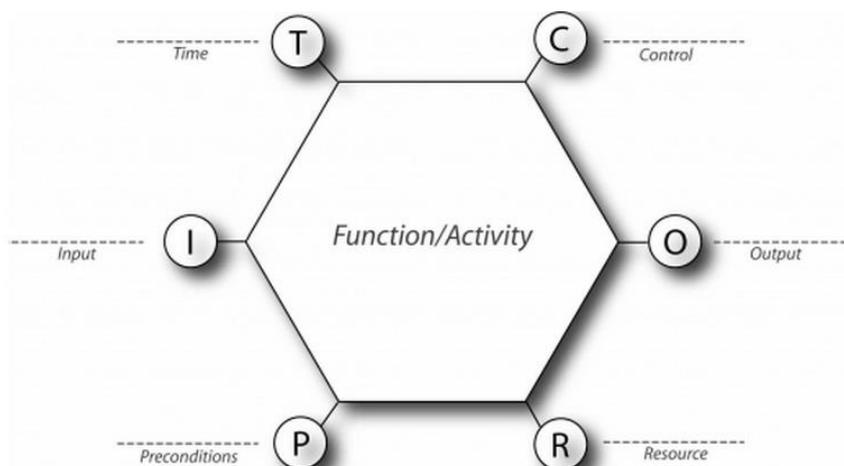
## **2.7 Systems Theory Approach**

A systemic view which considers the performance of a system as a whole was adopted by new accident modelling approaches. In systems models, a coincidental existence of several causal factors such as technical, environment and human in a specific time and space causes an accident (Hollnagel 2004). Accidents are viewed as emergent phenomena by systemic models and arise because of complexity of interactions between components of a system which could lead to systems performance deterioration or cause an accident. Systems theory is where systemic models are derived from. The models, laws and principles required to understand complex interdependencies and interrelationships between components (management, organizational, technical and human) are included in this theory. Modelling in systems theory approach, systems are regarded as consisting of interacting components that have their equilibrium maintained through control and information feedback loops. A system oriented approach is adopted by Rasmussen based on hierarchical socio-technical framework for modelling of contextual factors involved in management, organizational and operational structures which create preconditions for accidents (Rasmussen 1997, Rasmussen & Svedung 2000). An accident causation model called STAMP (Systems-Theoretic Accident Model and Processes) was proposed by Leveson (2004). In complex socio-technical systems, factors such as organizational, technical and human are considered by STAMP model. Based on principles of cognitive systems engineering, two systemic models were developed for accident analysis and safety: the Cognitive Reliability and Error Analysis Method (CREAM); and the Functional Resonance Accident Method (FRAM). CREAM is based on human performance cognitive aspects modelling for human error consequences assessment on safety of a system (Hollnagel, 1998). Driver Reliability and Error Analysis Method (DREAM) for analysis of traffic accidents; and Bridge Reliability and Error Analysis Method. (BREAM) for use in maritime accident analysis, (Hollnagel 2006) are the two versions of CREAM developed for accident analysis (Qureshi, n.d.).

### 2.7.1 Functional Resonance Accident Method (FRAM)

FRAM, a qualitative accident analysis method, presents a description on how a system's components' functions may resonate and generate hazards with the possibility of losing control and lead to an accident (Hollnagel 2004) (Qureshi, n.d.). FRAM (Hollnagel, 2004), one of the contemporary models as shown in Figure 7 describes a function with six aspects and focuses on functions and performance conditions for the functions rather than event trajectories. The system's description is based on the functions necessary to accomplish its purpose and what may affect the variability of each function are the conditions. Input, output, time, preconditions, resources and control are the six aspects that describe the term functions. Except output, every function through its output is coupled to one or more functions and this may constitute the input for other functions (Lundberg et al., 2009).

The possibility for the performance of a function to vary and the variability depending on performance condition in addition to the outputs of other functions is recognized. Training, experience and communication quality among others, are examples of performance conditions. Occasionally, performance may be worse or maybe better from time to time. Functional resonance is therefore the cause of accidents in this model. This occurs when there is coinciding variability of several functions' output to an extent that the safe limit is exceeded by the performance of the system as a whole (Lundberg et al., 2009).



**Figure 6:** A function's description or activity using six aspects  
Source: Praetorius, Lundh, & Lützhöft (2011)

In summary, a linear cause and effect link propagation which corresponds to an event chain are the constituents of Heinrich's domino model. A combination of active failures and latent conditions in a linear form which correspond to various event chains are the constituents of Reason's Swiss cheese model. Hollnagel's FRAM model constitutes interdependent functions and the performance of these functions is reliant on both other functions (via the six aspects of a function as shown above) and on different factors (performance conditions) (Lundberg et al., 2009).

An accident is described by what has happened and therefore it portrays the reality of what the investigation must be presented with. However, the same facets or features of this reality are not what accident investigation methods always focus on. A factor X may be considered by a model as the most important whereas a factor Y may be spotted by another model as most important. Although accurate description of an accident does not exist, based on experience we learn which factors are important and those that are not. Additionally, we also find out that due to the nature of the underlying model of a method, the method may alter factors that others regard as important. This could happen when a method is developed for a different circumstance. For example, domino model was developed to deal with industrial safety problems in 1930s. Consequently, factors that are important now are missed since it focuses on factors that were important then as they are built into a model. Tripod model is a more recent model that has been created as an extension to take extra organizational factors into account (van Schaardenburgh-Verhoeve, Corver & Groeneweg, 2007; Lundberg et al., 2009).

### **2.7.2 Systems-Theoretic Accident Model and Processes (STAMP)**

A systems theory based accident model, STAMP hypothesizes that in accidents particularly involving a system, a useful way to analyse accidents is with systems theory. In this safety conception, when component failures, external disturbances or system components' dysfunctional interactions are not effectively handled by the control system, it is as a result of inadequate enforcement or control of constraints

that are related to safety on operation, design and development of the system. A control problem is what safety can be viewed as and that a control structure embedded in an adaptive socio-technical system manages it. Enforcement of constraints on the development of the system and operation of the system resulting in a safe behaviour is the goal of the control structure. This framework requires determination of the reason for the ineffectiveness of the control structure to understand why an accident occurred. To design a control structure that will enforce the necessary constraints is what is required to prevent accidents in the future (Leveson, 2003).

STAMP views systems as interrelated components kept in dynamic equilibrium state by control and information feedback loops. Conceptualizing a system as such is not a static design- “it is a dynamic process that is continually adapting to achieve its ends and to react to changes in itself and its environment.” (Leveson, 2003)

Enforcement of appropriate constraints on behaviour to ensure safe operation must not be the only consideration in the original design but the continuous operation of the system with changes that might exist must be considered. An adaptive feedback function failing to maintain safety with changes in performance overtime to meet a set of values and goals describes the process that leads to an accident. Safety management is defined as a continuous control task to impose necessary constraints limiting system behaviour to safe adaptations and changes instead of prevention of component failure events. Using this model, accidents can be understood with regards to the ineffectiveness of the controls in place to detect or prevent maladaptive changes through identification of the violated safety constraints and determination of the reason behind the inadequacy of the controls enforcing them. Process models, control levels, control loops and constraints are STAMP’s basic concepts. Based on 12 new models and basic systems theory concepts, each of the basic concepts is now described by a classification of accident factors (Leveson, 2003)

### **2.7.3 The Management Oversight and Risk Tree (MORT)**

MORT is an analytical procedure for determining contributing factors and causes. In 1970s a project was undertaken in which it arose. In order for US nuclear industry to achieve high health and safety standards, the work aimed at providing a competent risk management program. The MORT chart (logic diagram accompanying this text) although was one aspect of the work, it became a popular evaluation tool and hence its name for the whole program. MORT produced several variants of which many are MORT User's manual translation to other languages by public domain documentation's virtue. MORT's durability is a testament to its construction; for an organization to effectively manage risks, it provides a highly logical expression of the functions. A generic description of the functions has been made- rather than it emphasizing on "how", it lays emphasis on "what" allowing its application in different industries. MORT emerging from a far-sighted philosophy which held that making safety an integral part of operational control and business management is the most effective way of managing safety, might be the reflection of MORT's longevity. For giving safety assurance, the MORT program was written by W.G. Johnson titled "MORT: the Management Oversight & Risk Tree" (SAN 821-2, February 1973). In investigation of accidents and incidents relying upon logic tree diagram (the MORT acronym eponymous tree), part of the method was used.

MORT diagram allowed its contents to be applied in a methodical way since it served as a graphical index to Johnson's text. The original text of 500pages was distilled into a 42page question set (the MORT Users Manual<sup>3</sup>) to help investigators especially novices. It is certain in Europe that MORT is now largely independently used as either a method or a program. The MORT User's manual is the most common reference source since in practice the MORT text being SAN 821-2 has been disassociated from MORT chart (International Crisis Management Association, 2014).

#### **2.7.4 HTO (MTO) (Man Technology Organisation) method**

In an accident investigation, organizational, human and technical factors being equally focused, is the basis of MTO procedure. It is based on Human Performance Enhancement System (HPES). There was a need for an evaluation and overview of the MTO method within the incident investigation field in order to understand its comparison to other methods, how well it can find root causes and prevent events from reoccurring (Hollnagel & Speziali, 2008).

MTO might be very time consuming and powerful for simpler incidents level events but for somewhat complex incidents, it is suitable. What is important is that for the root causes to be identified, an individual needs to be aware of their choices, how the results get affected by them and that the method chosen is suitable for a given circumstance. However, incidents are not prevented by just conducting investigations but the need for an organization to deal with the results and ensure that appropriate counter measures are taken is important (Hollnagel & Speziali, 2008).

#### **2.7.5 SHEL Model**

SHEL model is utilized by ICAO for representation of main human factor components. It has an expanded version known as SCHELL model which provides an idea on the human factors' scope. SCHELL means the following:

*“S = software: the procedures and other aspects of work design »*

*C = culture: the organisational and national cultures influencing interactions*

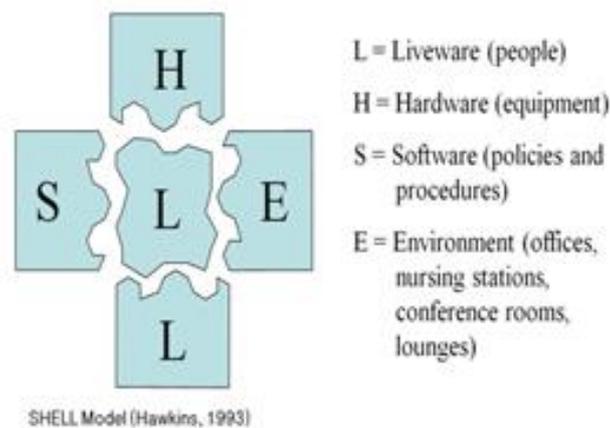
*H = hardware: the equipment, tools and technology used in work*

*E = environment: the environmental conditions in which work occurs*

*L = liveware: the human aspects of the system of work*

*L = liveware: the interrelationships between humans at work.”*

The emphasis of the SCHELL model is on the fact that the system as a whole shapes the behavior of the individuals and that human performance problems may arise if a mismatch or breakdown exists between the two (Australian Government Civil Aviation Safety Authority, 2012).

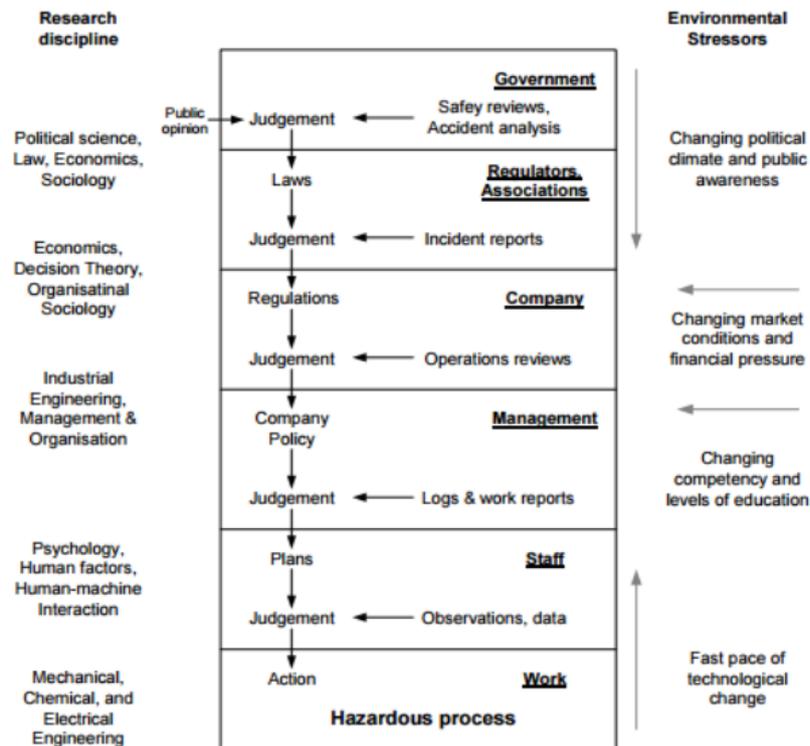


**Figure 7:** SHEL Model  
Source: (Korean Register, 2012)

### 2.7.6 AcciMap Accident Analysis Technique

AcciMap, based on Rasmussen’s risk management framework (Rasmussen 1997, Rasmussen & Svedung 2000) is applied by initially selecting a number of accident scenarios and analysing the events’ causal chains with the use of a cause-consequence chart. A generalization aggregating accidental courses of events set is represented by a cause-consequence chart. Predictive risk analyses are widely based on these charts (Leveson 1995). The choice of the critical event reflecting release of a well-defined source of hazard for example “loss of control of accumulated energy” or “loss of containment of hazardous substance”, defines the choice of set to include in a cause-consequent chart. The causal tree (among potential causes, the logic relation) is connected by the critical event with a consequent event tree (the possible

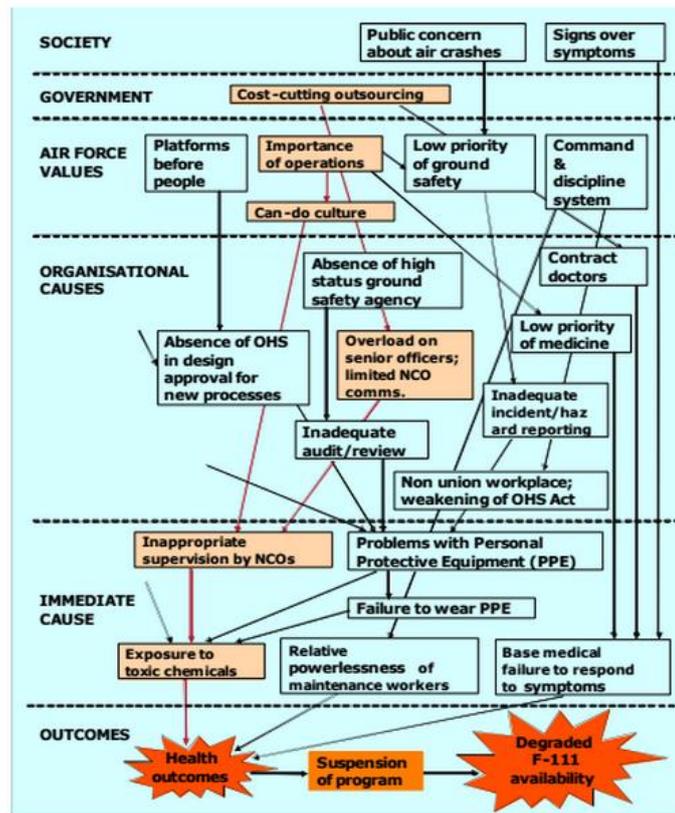
temporal and functional relation among events) clearly reflecting the switching of the flow as a result of automatic safety systems or human decisions (Rasmussen & Svedung 2000). Controlling the hazardous process at the socio-technical system's lowest level is this analysis' focus as shown on the figure 8 below (Qureshi, n.d.)



**Figure 8:** The socio-technical system involved in risk management (Rasmussen, 1997)  
Source : (Sklet, 2002)

The cause consequence-chart representation which specifically includes normal work decisions at the socio-technical system's higher levels is extended in order to carry out a vertical analysis across the hierarchical levels. As shown on figure 9 above, the contributing factors in an accident being mapped onto levels of a complex socio-technical system, is what an AcciMap shows. The figure below shows an AcciMap of the Royal Australian Air Force (RAAF) maintenance workers F-111 chemical exposure based on the official F-111 Board of Inquiry report (Clarkson et al. 2001). Factors lying beyond the RAAF organizational limits and its culture, is what the AcciMap causal flow diagram considers. The conclusion of the analysis

therefore is that the chain of command's failure for optimal operation is predominantly in RAAF's culture and values (Qureshi, n.d.).



**Figure 9:** AcciMap of F-111 Seal Reseal Program  
Source: Qureshi (n.d.)

## 2.8 Importance of accident causation models

Comparisons and generalization of accident investigations cannot be done if different persons with their individual approaches investigate an accident. Accident investigators would be in line when the methods for accident investigation are harmonized based on models.

Hollnagel (1998) says that within the framework of a model is where every casualty investigation should be made, with a subsequent taxonomy and a method supporting the analysis. This framework however requires extension to the investigating body and the focus as shown in Fig 1, chapter 1. All considerations should commence with the question: Which data are expected to the gathered to

answer the investigators questions? The different parties (e.g. scientific, legal and technical) involved are distinct from the focus of an investigation. The specific focus of the investigation has to be served by the selected model and can be one or all of the following models: human behavioral process (e.g. cognition), technical performance of a part of the system (e.g. technical parameters of a certain type of equipment), and man-machine interface/interaction. Different models exist and most of them are general in nature, applied to transportation modes such as the Simple Model of Cognition (SMOC) by Hollnagel. For specific maritime investigation processes, only a few models have been developed so far. CASMET or THEMES are more elaborate models designed within research projects funded by the European Commission (EC). However, in order to strengthen maritime knowledge base, it is important to have specific maritime models. It is not desirable and important to make comparisons between different transport modes. This is because the seafaring industry is complex in nature compared to other transport modes. The related data taxonomy has to be developed based on the model. In order for the desired conclusion to be supported, the central question of the investigation should be the focus of the taxonomy. The investigation method is the last part and depends on all other parts of the framework. This framework's idea is not a representation of recent innovation for publication in a scientific conference.

Nevertheless, the description of the basics is necessary since in practice, they are not actually implemented (Schröder, 2004).

## **2.9 Marine Casualty Investigation Organizations**

The global expansion in transportation (marine, rail, road and aviation) with regards to size, socio technical complexities of systems and their equipment has led to an escalation in the number and scale of disasters (Cushing, 2013).

The National Transportation Safety Board was established in the US in 1967. It is an independent government investigative body. Finland and Sweden in 1990 established an accident commission responsible for all accident types at national

level. A common board is shared by Denmark, Netherlands, Norway and France with the latter forming separate accident commissions (Cushing, 2013).

Following the capsizing of the Herald of Free Enterprise in 1987, the Marine Accident Investigation Branch (MAIB) was formed in the UK. The MAIB reports to the Secretary of State for Transport. The European Maritime Safety Agency headquartered in Lisbon was formed in 2002 by the European Union. Developing a common methodology for maritime accident investigation is one of its many aims. (Cushing, 2013)

An international non-profit organization, the Marine Accident Investigators International Forum (MAIIF) was established in 1992 to foster cooperation between national maritime investigators. Marine Accidents Investigators Forum Asia (MAIFA) initially meeting in Tokyo in 1998, is a similar body that exists in the Pacific region. MAIFA's purpose is to ensure that through exchange of information and cooperation between accident investigators in Asia, safety and prevention of pollution at sea can be achieved. In People's Republic of China, the Maritime Safety Administration (MSA) formed in October 1998, is responsible for its maritime investigations (Cushing, 2013).

### **2.9.1 MAIB**

The MAIB conducts investigations into marine accidents of UK vessels and those in the territorial waters of UK. MAIB's responsibility is to help prevent further marine accidents and not to implicate those involved for blame or liability. In 2014 the MAIB got 1270 reports of various types of accidents and seriousness which prompted 31 different investigations being undertaken. They are an autonomous unit within Department for Transport. A regulatory group bolsters their 4 accomplished accident investigation groups. Situated in Southampton, they have 35 individuals as members of staff. They are in charge of:

- Completing investigations to focus the reasons for accidents adrift.
- Distribute reports that incorporate suggestions on enhancing safety adrift and progress made.

- Expanding familiarity with how marine accidents happen
- Enhancing national and global co-operation in marine accident investigation (Marine Accident Investigation Branch & GOV.UK, n.d.).

### **2.9.2 Transportation Safety Board of Canada (TSB)**

The TSB is an autonomous organization that helps enhance safety by conducting inquiries into accidents in the marine, pipeline, rail and air modes of transportation. The TSB is guided by different industry benchmarks and arrangements are also made within TSB to help guarantee that investigations are led in a deliberate, intensive, and unprejudiced way (Fox, 2015). For about 25 years, TSB has sought to advance transportation safety by conducting investigations into accidents after which, it reports publically on the results. There have been a large number of investigations conducted across the nation adrift, and endless lessons learned. Large passenger vessels are obliged to convey voyage information recorders, and thorough safe towing strategy and techniques have been created for little vessels in ice-invaded waters. TSB's work has incited substantive changes in their government electrical code and enhanced management of pipeline control room. In the aeronautics world, TSB has effectively pushed for more secure non-precision procedures; and rail investigations have led to emergency response assistance plans for transportation of liquid hydrocarbons in large volumes (Transportation Safety Board of Canada, 2014).

### **2.9.3 Australian Transport Safety Bureau (ATSB)**

The ATSB is Australia's national transport safety investigator. ATSB's capacity is to enhance wellbeing and open trust in the avionics, marine and rail transport. It is Australia's prime office for the autonomous investigation of common avionics, rail and sea accidents, incidents and safety deficiencies. The ATSB is established by the Transport Safety Investigation Act 2003 (TSI Act) and directs its

investigations as per the requirements of the Act. Under the TSI Act, it is not ATSB's responsibility to allot blame or determine liability. The ATSB does not investigate with the aim of taking managerial, administrative or criminal action. Most of Australia's imports and exports are transported by sea as well as coastal trading. Another growth industry in Australia is cruise shipping. The ATSB conducts marine investigations regarding accidents and genuine occurrences involving Australian registered vessels in any part of the world, foreign registered vessels in Australian waters, or where there is evidence of an accident involving ships in Australia. Serious incidents and accidents must be accounted for when practicable to the ATSB. Australian Maritime Safety Authority (AMSA) is the authority through which the report is made. Australia, a council member of International Maritime Organization (IMO), effectively takes part in its discussions on accident investigation in light of a legitimate concern for enhancing safe shipping (The Australian Transport Safety Bureau, 2014).

#### **2.9.4 The Marine Accident Investigators' International Forum (MAIIF)**

A non-profit organization, MAIIF's work is dedicated to advancing maritime safety and prevention of marine pollution by exchange of ideas and information obtained in marine accident investigation. The main aim is to improve marine accident investigation, to enhance communication and cooperation between marine accident investigators and also encourage recognition, development, improvement and development of related international instruments where relevant. Marine accident investigators working in an administration and not for commercial or private reasons are eligible to be members of MAIIF (MAIIF, n.d.).

### **3. METHODOLOGY**

This chapter discusses the research methods adopted in the study with respect to the exploration of the practical use and application of accident causation models by experienced investigators.

#### **3.1 Research methodology and sample selection**

This section describes the overall methodological approach and the motivation for the choices. The overall approach towards the research methodology was to employ mixed methods to complement the data as well as to obtain increased response from the target group (Bryman, 2001). In pursuance of this goal, a mixed methods approach comprising questionnaires and structured interviews was adopted towards data collection for the study. The research methods were selected on the basis of the best fit with the research questions and to reach the widely dispersed target group of accident investigators. The methodological approach included the design and dissemination of a questionnaire to the target audience of active marine casualty investigators, which was hosted online for maximum reach and coverage and responses received were analysed and are presented in chapter 4 on results. To supplement the questionnaire, structured interviews were conducted with members of the target group. The questionnaire and the structured interview complemented each other to enhance comparability. The primary data for the study was collected with the help of the online questionnaires and structured interviews.

##### **3.2.1 Questionnaire**

This section describes the sampling strategy employed, the questionnaire design, the operationalisation of concepts in the questionnaire items, and the method of analysis.

The questionnaire study for the dissertation utilizes the principle of non-probability sampling in which the subjective judgement of the research student takes

precedence over probabilistic random sampling techniques. A key justification for utilising non-probabilistic sampling is the lack of access to the population of accident investigators. Since there is no access to the widely distributed population of the target group, probabilistic sampling techniques of simple random sampling, systematic random sampling and stratified random sampling cannot be undertaken. The time and resource limitations with respect to the Master's thesis also drove the choice for non-probabilistic sampling.

Within non-probabilistic sampling, the sampling technique most appropriate for this questionnaire study was 'self-selection' sampling. In this technique the participants are not directly approached by the researcher and they themselves volunteer to take part in the study. This is especially appropriate in the case of the online questionnaire tool designed for this dissertation. The participants themselves filled out the questionnaire after seeing it online and going through the information to the participants and the ethical guidelines followed in the study. The sampling strategy was in line with the research design of the dissertation.

The questionnaire consisted of a total of fourteen questions. The questionnaire tool is provided in Annex 2. The first part of the questionnaire pertained to demographics which covered questions 1-6. The aim of this section was to gauge the spread of the respondents in terms of age, gender, education level, education field, experience as an accident investigator in years and the total working experience of the respondent. The next section pertains to the accident causation models utilized by the accident investigators in practice. Question 7 gauges the main purpose of the investigation, whether safety, compliance or any other.

The concepts are operationalised in the questionnaire with the help of a Likert scale that requires the respondent to rate the questionnaire item from 1 to 10, where one implies that the respondent strongly disagrees with the statement and 10 implies that the respondent strongly agrees.

Question 8 onwards the questionnaire focuses on accident causation models. Question 8 requires the accident investigator to name three accident causation models used by the investigator and rate them on the Likert scale with respect to 3

factors; the ability of the model to capture complex maritime accidents; ease of application of the model; the realism of the model – its ability to realistically capture the maritime sector. Question 9 builds upon the theme of accident causation models and provides a list of 9 accident causation models and requires the respondent to rate them against the 3 factors identified above. This question would enable a picture of a ranking to emerge of these factors with respect to the different accident causation models. Question 10 requires the respondent to rate the importance of 10 factors of accident causation models on a scale. This would enable the student to gauge the importance and ranking of factors in relation to accident causation models. Question 11 allows the respondent to provide additional factors they consider important which are not included in question 10 and they can even provide a ranking for the additional factors identified by the respondents. The final three questions of the questionnaire (12, 13 and 14) probe into the reasons for the use/application or non-application of accident causation models and allow the respondent to enter free text in the text boxes. Question 12 inquires about the reasons for applying the models used by the investigator. Question 13 probes into the reasons for not utilising other models which are not used by the practitioner in his/her work. Question 14 inquires about the reasons for not utilising models and wraps up the questionnaire.

The questionnaire was designed using survey gizmo. It was hosted online for 20 days after which the received responses were extracted and analysed. The responses to the online questionnaire were being automatically entered into an excel spreadsheet from which they could be extracted and manipulated into graphs for facilitating data analysis. The useful total responses received for the questionnaire were 23. The results of the questionnaire study are presented in chapter IV on research findings.

### **3.2.2 Structured Interview**

This section discusses the structured interviews that were conducted as part of the study. The structured interview utilised the same questions of the online questionnaire tool and followed the same order of posing the questions. Since the

structured interview mirrored the online questionnaire, the same is not discussed in-depth here as the questionnaire design has been discussed in section 3.1.1. The presentation of the same questions (of the online questionnaire) in the same order in the structured interview enhances the comparability of the data between the online questionnaire and the structured interviews. A structured interview serves to enhance the reliability of the data by keeping the questions and the order constant and thereby minimising/or keeping context effects constant.

It is not easy to reach accident investigators; they are distributed widely geographically and are extremely busy performing their critical roles. The choice of participants for the structured interviews followed a convenience based approach in which possible participants were suggested by university contacts and were subsequently approached to participate in the study. Given the lack of a population of accident investigators and the difficulty in reaching them, a convenience based approach was the most suitable for selecting participants for the interviews. A total of 4 structured interviews were conducted with accident investigators. As previously stated, the questionnaire tool served as the interview guide for the structured interviews. The interviews on an average lasted from 30 to 45 minutes. The interview modality ranged from conducting the structured interviews face to face with two of the respondents and conducting the interviews via the medium of online technology offered by 'Go To Meeting'. In the two instances of face to face interviews, the accident investigators were available at the university premises and hence were approached to participate in the study, while in the case of technologically mediated conduct of structured interviews, additional planning was required to install and gain familiarity with the software tool and learn its functionalities. The structured interview was similar to the online questionnaire; nevertheless a major advantage of it was the opportunity to obtain responses from experienced accident investigators in addition to those who have responded online and an opportunity to obtain responses to open questions in a personalised setting.

In all instances, permission was taken from the respondents and the interviews were recorded on a digital hand held voice recorder. The audio files of the

interviews enabled the research student to listen to the interviews and identify key issues and thematic categories in the data. Audio recording has the added advantage of being available to the student to engage with the data in-depth and examine as many times as necessary. The audio data was annotated by the research student and thematically grouped to aid analysis. The main focus of the analysis was on accident causation models, their application, the reasons for application and non-application and the factors considered important by practitioners in an accident causation model. The data was grouped thematically and analysed and the findings are presented in chapter 4 of the thesis.

## **4. FINDINGS**

### **4.1 Introduction**

This chapter presents the findings of this study extrapolated from both the questionnaire and interview survey. The data gathered has been analyzed and presented in the form of text, tables, charts and figures.

### **4.2 Findings from questionnaires**

All the data gathered from the questionnaire survey is presented on this section. This includes demographic data of respondents, accident causation models used by the respondents and their reasons for using models or not, the ranking of the models, the ranking of accident causation models factors and finally the countries and cities of the respondents.

#### **4.2.1 Demographic data**

This section of the questionnaire requested for the respondents' age, gender, level and field of education, number of years working as an accident investigator and their total working experience in the maritime industry.

A total of 25 complete questionnaires were received and 23 responses were utilized from this for the purpose of this study. This was mainly due to the participation of a respondent who was not an accident investigator and another respondent who gave responses that were not within the context of the questionnaire. As a consequence, these results were eliminated from the study and therefore a total of 23 responses were maintained for analysis.

Out of the 23 selected respondents, 21 stated their age while 2 participants did not give a response. Data gathered from these are that the maximum age of the respondents is 64 years, the minimum is 30 years and the average age is 49 years. These were 20 male participants and 3 female participants out of which, 7 hold a Bachelor's degree or equivalent, another 7 hold a Master's degree or equivalent, 4 hold a PhD or equivalent and 5 have other qualifications. The other qualifications stated are 2<sup>nd</sup> Class Engineer, Bachelor of Engineering, College degree, Master Mariner and Master Mariner Class-1. There were 11 participants who are involved in seafaring as a navigator, 4 as seafaring engineer, 2 naval architectures or similar and 6 who are involved in other fields such as Coastguard, engineering, fishing master, MSc. (tech) and mechanical engineering.

These participants all work as accident investigators and the stated minimum working experience as an accident investigator is 1 year, the maximum is 22 years and the average is 8 years. The minimum number of years stated as total working experience in the maritime industry is 6 years, the maximum is 45 years and the average is 28 years. All the 23 participants except 1 conduct accident investigation for the purpose of safety while that one individual's investigation is for enforcement purposes.

The respondents to the questionnaire are from the following nations:

1 respondent from Malta	2 respondent from Indonesia
1 respondent from Norway	7 respondents from Canada
1 respondent from Peru	3 respondents from United Kingdom
1 respondent from Finland	3 respondents from Sweden
3 respondents had their regions not shown.	

These respondents are a highly qualified and well experienced group who come from areas where organizations have strongly embraced accident causation models of the old IMO Casualty Investigation Code 1999.

#### **4.2.2 Models used by respondents for marine casualty investigation**

On this section of the questionnaire, the investigators were requested to outline three different models they use in their accident investigation. Out of the 23 participants, 8 respondents use 1 model only, 3 respondents use 2 models, 8 respondents use 3 models and 4 respondents do not use any models at all.

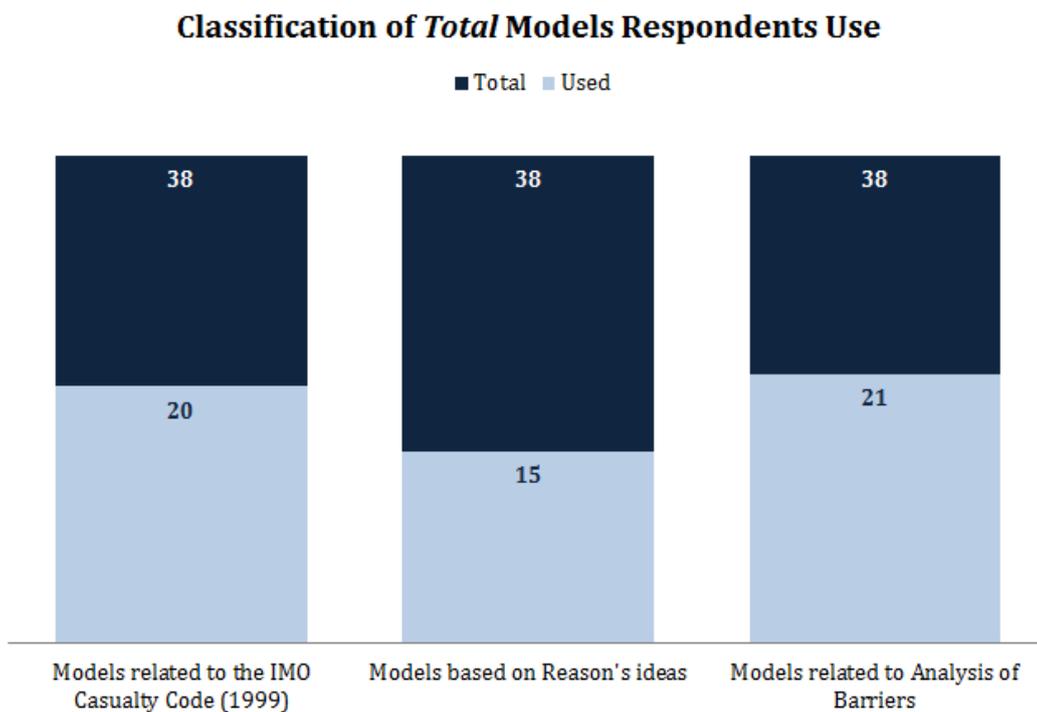
The Table 3 presented below shows the accident causation models used by respondents and are analyzed based on the following criteria:

1. Old IMO Casualty Code 1999
2. Reason's Swiss Cheese
3. Models related to analyzing barriers

S/n	Name of models used by respondents	Analysis of accident causation models used by respondents based on three criteria		
		Models present in old IMO Code 1999	Models related to Reason's Swiss Cheese	Models based on analyzing barriers
		Number of respondents	Number of respondents	Number of respondents
1	SHEL/SHELL	7	0	0
2	Reason's Swiss Cheese	5	5	5
3	ISIM	4	4	4
4	TSB Canada model	2	2	2
5	AcciMap	0	0	4
6	ATSB	1	1	1
7	IMO Casualty Code (?)	1	1	0
8	Tripod B	0	1	1
9	HFACS	0	1	1
10	Bowtie	0	0	2
11	Barrier analysis	0	0	1
12	Event and Causal Factor Analysis	0	0	0
13	STEP	0	0	0
14	STAMP	0	0	0
15	MTO/HTO	0	0	0
16	Why-Because	0	0	0
<b>Total number of respondents</b>		<b>20</b>	<b>15</b>	<b>21</b>

**Table 3:** Accident causation models used by respondents based on three criteria

Table 3 above shows the results of the findings and it can be seen that majority of the respondents use SHEL/SHELL model followed by Reason’s Swiss Cheese Model which is one of the models included in the old IMO Marine Casualty Code 1999 and ISIM is an integrated method with strong similarities to this old IMO Casualty Code 1999.



**Figure 10:** Total number of respondents that used models related to IMO Casualty Code 1999 or Reasons Ideas or Analysis of Barriers

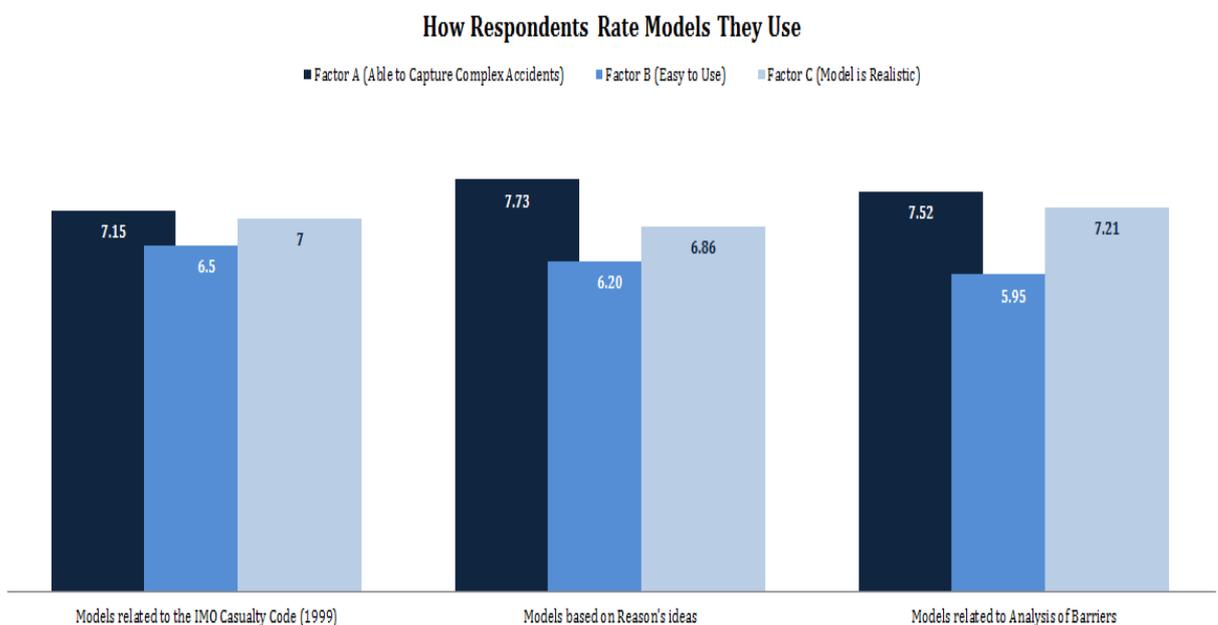
Figure 10 shows that 20 respondents use models in the old IMO Marine Casualty Code 1999, 15 respondents use models based on Reason’s Ideas and 21 respondents use models based on Analysis of Barriers.

#### 4.2.3 Ranking of accident causation models used by respondent

The models used by the respondents were rated based on three statements using a rating scale of 1 to 10; where 1 implies strongly disagree and 10 implies strongly agree. The statements were;

1. Factor A: This model is able to capture complex maritime accidents;
2. Factor B: The application of this model is easy i.e. it does not require intensive training ;
3. Factor C: This model is realistic i.e. it captures the maritime sector very well.

Figure 11 below shows the results of accident causation models rankings by the respondents.



**Figure 11:** Ranking of accident causation models used by respondents

From Figure 11 above, it can be seen that models based on Reason's ideas have been rated as those with the highest capability of capturing complex maritime accidents while models related to Analyzing Barrier have been rated by the respondents as being able to capture the maritime sector very well. However, models related to the IMO Casualty Code 1999 have the least rating for capturing complex maritime accidents and models related to Reason's ideas also have the lowest rating for capturing the maritime sector very well by the respondents.

#### 4.2.4 Models known by respondents for marine casualty investigation

Table 4 shows how many respondents know models stipulated on the questionnaire survey and how many use the ones they know.

For this section, the ranking of the models known by the participants is consistent with the previous statements and therefore did not provide further input to this study. However, participants know more models than they use but to a lesser extent, SHEL and Reason's Swiss Cheese model are the leading models.

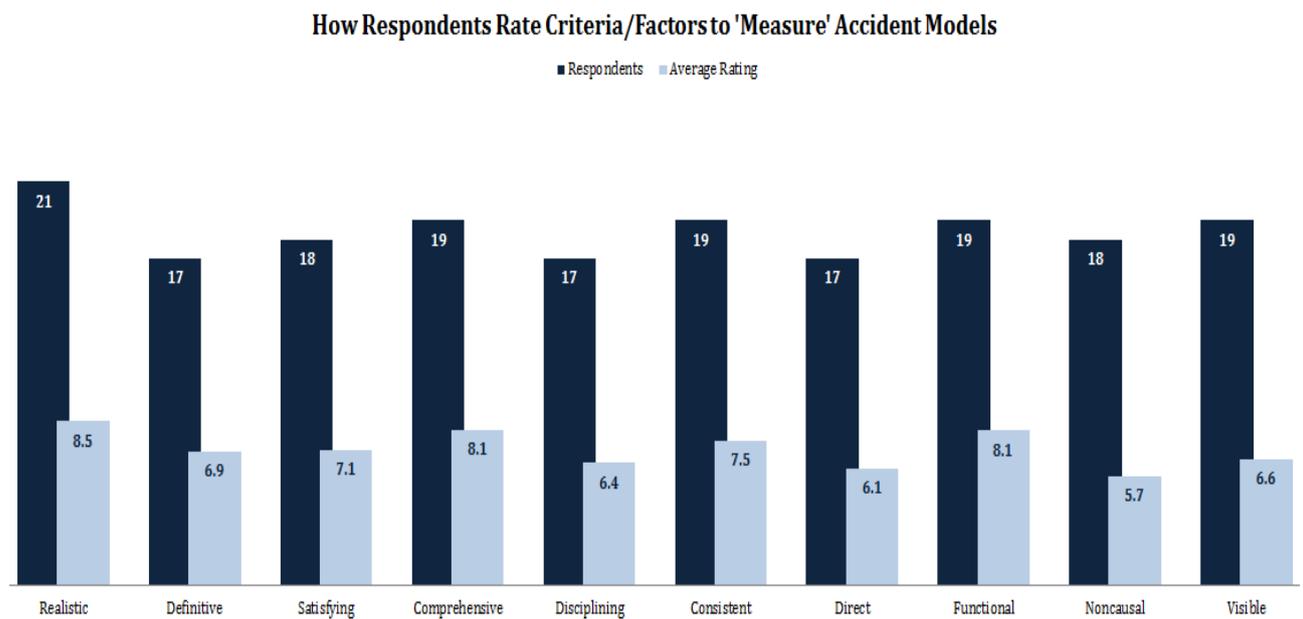
S/n	Listed models on questionnaire survey	Number of respondents that know the model	Number of respondents that use the model
1	SHEL	14	7
2	Reason's Swiss Cheese	18	5
3	STAMP	2	1
4	MORT	1	0
5	MTO/HTO	4	2
6	FRAM	1	0
7	Heinrich's Domino	2	0
8	ACCIMAP	7	4
9	SEMOMAP	1	0
<b>Total responses</b>		<b>50</b>	<b>19</b>

**Table 4:** Number of accident causation models known by the respondents from the list of models stated on the questionnaire survey

From the above table, it can be seen that from the accident causation models outlined in the questionnaire survey, 5 different models are used by a total of 19 respondents.

#### 4.2.5 Ranking factors for accident causation models

As part of the survey, the questionnaire requested for respondents to rate the importance of the factors for accident causation models on a scale of 1 to 10 where 1 means not important and 10 means very important. The results of the average rankings based on the factors are shown on Figure 12 below.



**Figure 12:** Accident causation models ranking factors

Out of 23 respondents, 16 respondents rated all 10 categories, 1 respondent rated 8 categories, 1 respondent rated 5 categories, 2 respondents rated 4 categories, 1 respondent rated 1 category and 2 respondents did not rate any category.

It is very clear from the figure above that the most important factors for the respondents regarding accident causation models are how realistic they are with an average rating of 8.5, how comprehensive they are averagely rated at 8.1 and how functional their application is with an average rating of 8.1. The least important factor is non-causal averagely rated at 5.7.

Some categories might not have been understood by individuals who participated in the survey. However, in principle, the ranking is in line with comments made later on where “easy to use” is often mentioned as a requirement for a model.

#### **4.2.6 Additional accident causation models ranking factors stated by respondents**

The respondents for this survey were requested to indicate additional factors that should be considered for accident causation models and rank them using a scale of 1 to 10; where 1 means not important and 10 means very important. Table 5 below presents the original statements of 9 respondents regarding additional factors to be considered for accident causation models.

<b>Additional factors stated by respondents</b>
<b>1.</b> Easy to use -10
<b>2.</b> Easy to use when writing analysis
<b>3.</b> Learning-10 Complex thinking approach-8 Vulnerability-8
<b>4.</b> Simplicity but robust (cover everything handily: 2 )
<b>5.</b> To choose the right model for the right type of accident is important.
<b>6.</b> The easiness to understand by a range of investigators with variety of academic background. I'll give scale of 10.
<b>7.</b> Iterative (score 10) - must review itself and catch safety significant events that may have been missed or not analyzed.
<b>8.</b> I don't use a special model. Models are just different ways to describe the same thing - sometimes it's obvious that it's just a copy of another model.
<b>9.</b> Normally it depends on the perceived complexity of the accident. An accident which may be seen as clear in terms of its dynamics may be addressed using Reason's model, whereas other complex accidents which may involve significant interactions between the stakeholders, may be addressed using AcciMap.

**Table 5:** Additional accident causation model ranking factors

The main factor highlighted by majority of the respondents is the ease of use of accident causation models. There is one comment that is not related to the factors and the remaining statements address general opinions of what model to use and also what a model should be.

#### **4.2.7 Reasons of respondents for the application of particular accident causation models**

The questionnaire survey requested for the respondents to state their reasons for utilization of particular accident causation models and the Table 6 below shows the reasons these accident investigators stated.

### Reasons stated by respondents

1. Company policy
2. Company provided
3. Mandatory by my employer
4. Not a model fan-work on experience
5. The model was very easy to use and is well suited for the investigations I conducted
6. Training, ease of use, ease of application
7. Mandated to use ISIM, trained in SHEL and Swiss Cheese
8. The selected models are the most easy to apply and can be kept in the investigators' minds during the collection of evidence (in the field) and the analysis stage.
9. They are easy to learn - can be used in investigation groups where external experts that are not trained investigators participate.
10. To explain the accident from the main event into contributory stage so we can determine the root cause and propose recommendation to prevent or at least reduce the likelihood of the event
11. To do a safety analysis and determine the underlying factors in which the report will be based on.
12. To get a quick idea about the accident. To approach as much as possible the complexity thinking perspective.
13. We try to use the best available models. AcciMap is so far the best, but there are some problems with it also.
14. They are realistic - sufficiently complex but still manageable. Not too prescriptive, leaves room for own experience and judgement, variation.
15. ISIM (Integrated Safety Investigation Methodology) is our organization's model that integrates the iterative investigation, safety deficiency analysis and communication processes.
16. Mostly, it is a way of generating discussion about the accident. The ISIM forces us to look at the accident from a variety of vantage points and to consider the underlying factors rather than the easy answers.
17. The model initially used by the founder of the organisation. Because of the poor of regeneration, the established bosses prefer to choose a familiar model which is the easiest one, though the model has been left by many organisations.

**Table 6:** Reasons stated by respondents for application of particular accident causation models

The use of particular models by 6 respondents is solely due to it being made mandatory by their organizations. Another main reason is the ease of use of models particularly those related to Integrated Safety Investigation Methodology (ISIM), have been stated by 5 respondents. However, one respondent highlights that the use of a model does not deliver the quickest results. Other reasons stated are based on general opinions of the respondents on the particular benefits of a named model.

#### **4.2.8 Reasons of respondents for not applying the accident causation models that they know and do not use**

The survey respondents for this study were further asked to state their reasons for not applying particular accident causation models and the Table 7 below depicts their statements.

<b>Reasons stated by respondents</b>
<b>1.</b> Do not find them helpful
<b>2.</b> Employer won't take it into consideration
<b>3.</b> I was not familiar with them
<b>4.</b> ISIM is adapted from Reason and SHELL
<b>5.</b> ISIM works, for the most part.
<b>6.</b> Linear models are not the right models to learn something. Or I am not familiar with models.
<b>7.</b> This model is designated by my employer
<b>8.</b> Time.
<b>9.</b> The three models we use are adequate to cover off everything we need
<b>10.</b> We've no enhancement for long time as lack of leadership which has put the organizational quality behind other factors.
<b>11.</b> Because those I've chosen seem to be sufficient for my needs, and I'm still learning how to take full advantage of them. I will try to learn and test out other Methods in the future, but this seems like a good place to start.

**Table 7:** Reasons stated by respondents for not applying other models

Some of the reasons highlighted are employer focus stated by 3 respondents. Furthermore, 6 respondents stated that they are satisfied with the models they utilize. However one respondent does not support the use of the models mandated by the employer. Another respondent stated that there is insufficient time to work with other models. Finally, unfamiliarity with other models has also been stated by 2 of the respondents but it is unclear if this is considered as an organizational deficit or simply because they are happy with what they have available.

#### **4.2.9 Reasons of respondents for not using any model**

This part of the survey requested for the respondents to indicate their reasons for not applying any models at all during their marine accident investigations and their reasons stipulated are shown on Table 8.

<b>Reasons stated by the respondents</b>
1. Every case is different.
2. I am blissfully unaware of many of the models you mention.
3. I will not like to use a model which is not realistic and easy to use.
4. Linear models, you don't learn from these models.
5. Mostly we use it for simple case which does not need deep analysis.
6. Use the IMO casualty Investigation Code and the MAIIF investigation manual.
7. I do not use a model. I prefer to sit and work out the problem using notes I make and questions that I ask and maybe have to find further information on. Questions such as What if/Did it contribute/What would still happen if something did not happen earlier/Would it happen again if this part was removed/Is it a reasonable expectation to be able to remove or mitigate this factor/If every factor is viewed what is the chance of them coming together again in the same manner/Was this a reasonable action by the person in response to an event, if not why not/Training, age, experience, language, familiarity with others on board and the ship or its equipment/cultural background?
8. There are investigations where the model is not used. This is mainly in those

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investigations which we call simplified investigations - investigations which pretty much address the actions of the sharp end only and do not go into detailed organizational factors. Simplified investigations are carried out in accidents which we perceive to be simple enough to an extent that they do not warrant a full safety investigation.

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9. There is no need. An experienced investigator doesn't need a special model. A model increases some aspects, but decreases others.
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**Table 8:** Reasons of respondents for not utilizing accident causation models

From the 9 respondents, 2 indicated that they use models. One respondent stated that learning benefits are not achieved from linear models and 3 respondents indicated that accident causation models cannot capture reality. Other 3 respondents stated that they do not use a model, accident causation models are irrelevant for experienced investigators and that, every case is different respectively.

### **4.3 Interview findings**

This section of the dissertation presents data gathered from four marine accident investigators that were interviewed for the purpose of this study. This enabled the researcher to gather more data regarding additional models that were not considered within the structured interview guided by the designed questionnaire. Furthermore, additional factors that are considered important for an accident investigation were stated by some of the participants. The interview allowed for the researcher to provide further explanation of the factors within the context of selecting accident causation models which the questionnaire did not provide. This clearly defined what role each factor plays and thereby allowed the interviewees to give appropriate responses. Data gathered from the interview are therefore as follows:

### 4.3.1 Demographics of interview participants

The participant demographics highlight a very qualified and experienced group of accident investigation professionals.

**Participant 1:** This individual holds an extra Master's Certificate of Competency and has been involved in a wide variety of marine safety investigations. He has formally been working as a Marine Casualty Investigator for 15 years. Since then, he has been working as a consultant trainer in accident investigation for 6 years now and has accrued a total working experience of 46 years in the maritime industry.

**Participant 2:** This participant has obtained a Master Mariner Class 1 Unlimited Certificate of Competency. He is currently pursuing a Master's degree at the World Maritime University and has been working in the maritime industry for a total period of 21 years. As the Deputy Harbour Master of a Ports Authority in a West African State, he has been the individual delegated to conduct marine safety accident investigations for the past 3 years.

**Participant 3:** This individual is a Marine Engineer, Master Mariner. He obtained his Master's degree from a Scandinavian University and is also pursuing another Master's degree. He is the head of a Marine Accident Investigation Board. According to him, his institution investigates accidents all over the world. He has been working as a marine accident investigator for about 4 years and 6 months and has a total working experience of 16 years in the maritime industry.

**Participant 4:** This participant is a lady who has obtained a PhD which focuses on ergonomics and human factors. She sailed for 12 years as a Marine Engineer and has also worked at a shipyard as a Safety Engineer. She works as a Marine Accident Investigator at the Accident Investigation Authority of her country on a temporary contractual bases and is not a permanent employee. According to her, the reason is that the Accident Investigation Authority has quite a small number of investigators and therefore the authority contracts the services of experts in different specialties for a particular accident type when necessary. This is to avoid for example

employing 20 accident investigators on a permanent basis according to her. In this capacity with the investigation authority, she investigated one accident which took two years to complete and she has been working in the maritime industry for a total period of 25 years.

#### **4.3.2 Models applied by practitioners**

**Participant 1:** A highly qualified and experienced marine casualty investigator, this individual mainly utilizes SHEL model, Reason's Swiss Cheese Model, the ATSB model and Event and Causal factors diagrams for determining marine casualty causation. However, he principally uses Reason's based models.

The interview setting provides an added advantage with respect to opportunities for additional data collection; this participant further mentioned an additional model known as IMO-MAIIF model that is under development at the IMO which was not covered by the list of accident models within the structured interview.

**Participant 2:** This investigator stated that he investigated three accidents and never utilized any particular accident causation model. However, based on his experience he carefully studies the events that took place out of which he derives the causes of the events together with their consequences.

**Participant 3:** Interestingly, this participant stated that his institution in investigating accidents uses all of the models and also does not use any at all. In this case the models he uses were based on Path Dependency together with Cognitive Interview Techniques. SHEL model, Reasons Swiss Cheese model, HTO, FRAM, Heinrich's Domino model and AcciMap are however all the models they use in addition to path dependency. He further stated that Reason's Swiss Cheese model is used by his institution for accidents that involve simple systems. Examples he gave where that when a person gets trapped on a winch with fishing nets on a fishing boat, linear models are used for this circumstance because there is not much complexity attached to the system. According to him again, linear models are especially used if

they have very technical accidents for instance marine accidents related to a shaft exploding, tearing a hole on the ship and the ship sinks, in explaining why this happened, a linear model is used but explaining why people survived or died from it, is a different matter.

**Participant 4:** This participant stated that her organization explicitly uses the MTO model and that during her investigation the same model was used.

**In summary:** The models applied by practitioners ranged from none to a plethora of models. The SHEL and Reason's Swiss cheese model were common to two of the participants while the other models mentioned were the ATSB, IMO-MAIIF, HTO, FRAM, AcciMap, MTO and Heinrich's Domino model. The utilization of event and causal factors diagrams was also mentioned along with path dependency. This highlights the diversity in the available models.

#### **4.3.2.1 Reasons for application of particular models**

**Participant 1:** The interviewee rated Reason's model and the ATSB model (which is based on Reason's Swiss Cheese model but is slightly different) as very good models because of their great ability to capture the maritime sector well including complex accidents. He principally suggests them as an aide memoire to help gather the right evidence and he uses them slightly differently. According to him, Reason's model deals with organizational accidents and is based on human errors and human factors rather than mechanical failures. Furthermore he stated that the Swiss Cheese model along with SHEL and ATSB models do not require intensive training for their application. However, among all the models this individual utilizes or is familiar with, he considers the IMO-MAIIF model as the best with regards to its effectiveness in capturing complex maritime accidents and the less intensive training required for its application. He stated that the IMO-MAIIF is similar to the ATSB model but simpler.

**Participant 2:** Although this participant does not apply a particular accident causation model, he stated that his approach towards accident investigation does not require very intensive training and that it captures the maritime sector and complex maritime accidents very well. Furthermore, he stated that members of his team are not very experienced in the field of accident investigation but nevertheless, they are able to understand and apply his approach.

**Participant 3:** According to this interviewee, Cognitive Interview Technique is a strategy for collecting data to apply on the different ways they think about accidents which is Path Dependency thinking. Furthermore, he stated that Path Dependency is based on five different research areas as follows: 1. Practical drift; 2. Fine tuning; 3. Normalization of deviance; 4. Drift into failure and 5. Control model by Jens Rasmussen. According to him, this means that accidents are as a result of gradual change and gradual degeneration sometimes. He further stated that all these five are based on the idea that accidents have a history, that, history matters, and that history changes things. Furthermore he added that we do things differently all the time and that we adapt and this adaptation also takes us to a place where risks become abysmal. His reason for using path dependency is that it clearly captures the way complex systems evolve and provides a framework for collection of motivational data. He further stated that in his institution, FRAM thinking is also utilized which also captures complexity. According to him FRAM does not explain anything and that it only describes how processes work in complex systems. However, he stated that Path Dependency explains why things happen to an extent and that FRAM describes how reality looks like and not why it is like that.

This participant further explained that we need one model to explain why things happen technically and then apply a different model to explain how they managed it. He stated for example that they had a big fire, this is explained with a linear model, explaining how they extinguished it or why they all died from it is complex. His organization therefore uses complex models and simple models in conjunction to explain different situations.

This participant ranked Path Dependency as the model that best captures complex maritime accidents. This was followed by FRAM and HTO. (SHEL and ACCIMAP) were averagely good but Reason's Swiss Cheese Model and Heinrich's Domino model were ranked as models that least capture complex accidents. According to him, FRAM and Path Dependency require a lot of intensive training. The next model he stated as requiring some intensive training after the above two is Reason's Swiss Cheese model. HTO, AcciMap to an extent require training according to him and that SHEL and Heinrich Domino model do not require any intensive training. Finally ranking the models in order of how well they capture the maritime sector, he rated FRAM as the best, followed by Path Dependency, HTO, AcciMap respectively and SHEL model, Reasons Swiss Cheese model and Heinrich's Domino model as ones that do not capture maritime sector well at all.

**Participant 4:** This individual stated that it is a mandatory requirement by her organization for accidents to be investigated from an MTO perspective. In this regard, she stated that all investigations should be conducted with a comprehensive view as much as possible and not only be looking at the nuts and bolts but also giving considerations to all the different human and organizational perspectives. Furthermore she stated that MTO was successful in capturing human, technological and organizational factors. According to her, the leader of the investigation she was involved in realized from the beginning that a lot of non-technical factors would be present and therefore the focus of their investigation was very clear. This being the case, the focus of the investigation was not only the pipe that broke and caused the fire but also on the Maritime Administration that makes all decisions.

This participant further stated that her investigation was successful with the use of MTO and it probably would have achieved the same success rate if SHEL or FRAM was utilized. She added that the key is not to really look at the direct causes like the little pipe breaking but the underlying factors. She also stated that SHEL has four dimensions to it includes the environment and that FRAM focuses on different functions and tasks than the linear models, which she does not subscribe to since the linear models are far too simple.

**In summary:** The reasons the participants gave for the utilization of models largely depended upon the ability of the model to capture maritime accidents including complex accidents and the level of training required in the application of the model. The ability of the model to address organizational aspects rather than mechanical failures was highlighted. Also highlighted was the juxtaposition of models – that is utilizing a model to identify the technical aspects of the accident and another to explore how it was managed. Another reason highlighted was the requirement by the organization which mandated the model to be used.

### **4.3.3 Models not applied by practitioners**

**Participant 1:** STAMP, HTO (MTO), Heinrich’s Domino model, AcciMap and Sequential Timed Event Plotting (STEP) are models he is familiar with. Among these he attempted to explore the use of FRAM, STAMP and AcciMap to an extent but discontinued.

**Participant 2:** SHEL Model, Reason’s Swiss Cheese model and SEMOMAP are among the accident causation models he knows but has never applied. However, STAMP, MORT, AcciMap, FRAM and Heinrich’s Domino model are unfamiliar to him.

**Participant 3:** MORT, STAMP and SEMOMAP are models this individual does not use and does not possess knowledge about.

**Participant 4:** SHEL, Reason’s Swiss Cheese model, MORT, HTO (MTO), FRAM, and Heinrich’s Domino model are the models this participant has knowledge about and has never used before. She however is not familiar with STAMP, AcciMap and SEMOMAP and has never used them.

**In summary:** A host of models not applied by the participants have been named which have been identified as FRAM, STAMP, AcciMap, MORT and SEMOMAP. Since one participant does not use any model and another does not use anything

except MTO, the list of models not applied by participants is long and includes all models including the five models mentioned previously.

#### **4.3.3.1 Reasons for not applying models at all or particular models**

**Participant 1:** The interviewee stated that for most marine investigations, the models not applied are too complex and require too much depth in the investigation in order to be useful. He added that generally, the investigators do not have the time, the material and financial resources to get all the information necessary to apply systemic models and therefore in reality, simpler models that can be easily applied are the ones that will be used. He therefore considers models he does not use for his investigation as very complex and requiring more knowledge than he already has as a lecturer in marine casualty investigation. Furthermore, he added that not many investigators use tools for their investigations. Most of them rely on their intuition and experience.

**Participant 2:** This participant stated that his unfamiliarity with accident causation models is the main reason he refrains from their application during his accident investigations.

**Participant 3:** Additional information was provided by this participant as to the reason why his institution uses all models but none of them. According to him, accident causation models all capture different ways of looking at things. He further stated that once an individual has knowledge of one model and also has knowledge about a new model, a third and a fourth model, then that individual does not neglect the old models. He added that it is embedded in the way the individual thinks about things and that everything that one has learned is embedded in their thinking and is applied for new things learned. Further, he stated that in that sense, it is difficult to separate models and that one should be aware that his institution's sole mandate is to conduct accident investigation. He stated that for his institution to use only a

particular model for this view of the world is not really suitable. He further stated that his institution possesses the resources and time to use a wide body of thinking whereas it is seen that companies and private contractors use models because they are financially cost efficient.

In addition, this participant stated that one gets controversial and that accident investigation is a social construct and therefore they can make different reports but only choose one. He further added that their value is that it is not problematic to use one way but an individual should know why they use a particular model and why not a different one. For him, what is really challenging is thinking that there is only one model and not using the right one. He further elaborated that when we look at accident investigation processes throughout the world, we are concerned with the tendency to think that one is creating a ground truth about what happened. He reiterated the importance for an individual to be aware of the reason for selecting or deselecting models.

**Participant 4:** This participant stated that as at the time she was conducting her accident investigation under the Accident Investigation Authority, it was mandatory for her to only utilize MTO and not any other accident causation model.

**In summary:** The reasons cited by investigators for not applying any models or particular models were – the complexity of a model – if a model was too complex requiring too much depth, time and resources, then that acted as a deterrent for the application of the model; unfamiliarity with model – if the participants did not possess knowledge of a model and were unfamiliar with it, then the model was not utilized. If a model was not cost effective, then that could be a deterrent. Making a particular model compulsory by an organization deters the application of other models.

#### **4.3.4 Factors impacting applicability of models and their level of importance**

**Participant 1:** This individual stated that the most important factors to be considered for ranking of accident models are their realistic nature and functionality. The second important factor is that it has to be non-causal. A model having to be satisfying, direct and visible are the third important factors stated. The fourth factors indicated are that a model has to be definitive, disciplining and consistent. Finally, he stated that a model ought not to be overly comprehensive because in a complex investigation not one size fits all and that an investigator may want to use more than one model.

**Participant 2:** Factors this participant considers as most important regarding his accident investigation approach are it being realistic, definitive, comprehensive, consistent, direct, functional, noncausal and visible. The second important factors stated by this participant are that it should be satisfying and disciplining.

**Participant 3:** This participant stated that the most important factor for a model is for it to be visible. The second important factor to him is for a model to be noncausal. The third important factors are for models to be realistic, satisfying and consistent. The fourth factors according to him are that, a model need not to be overly comprehensive and functional. The fifth factors are that it is not very important for a model to be definitive and disciplining. Finally, he stated that it is not important for a model to be direct at all.

**Participant 4:** A model being visible is the most important factor for this participant. The second important factors for this individual are for a model to be realistic, disciplining and non-causal. The third important factors are for a model to be functional and definitive and finally, a model being averagely satisfying, comprehensive, consistent and direct are the last important factors stated by this interviewee.

**In summary:** The rankings of the different factors varied greatly between the participants. For three of the four participants, the factor of ‘visible’ was ranked the

highest, implying that the characteristic of being clear was the most important to them in a model. Another factors that got the consensus from three participants was 'non-causal'. 'Realistic' and 'functional' nature of a model was scored highly by two respondents. 'Comprehensive', 'consistent' and 'direct' scored low, highlighting that no one size fits all and the participants were wont to use more than one model according to the situation

#### **4.3.4.1 Additional factors and their level of importance according to participants**

**Participant 1:** In short, this participant stated that a model has to be relatively simple, straightforward, easy to understand, easy to apply, portable and perhaps without the need for software, other than a paper and pencil. He further stated that this is because, the analysis begins and evidence is being collected and an investigator needs to apply this on the field; interviewing people and collecting documents. He further added that the ATSB accident causation model and Reason's model are quite straightforward and he understands them very well; they allow for clarification of his thoughts and are applicable to the investigations he conducts irrespective of how complex or simple they may be.

**Participant 2:** An accident investigation model being easy to use is an extra factor this individual stated.

**Participant 3:** This participant stated that the data available determines the model to be used.

**Participant 4:** No additional factors were stated by this participant. According to her, the structured interview had exhausted all the factors.

**In summary:** The participants had the opportunity to list additional factors and give their importance. The main additional factors identified were that the model should be easy to use; it should be simple, straightforward, and easy to understand

and apply. Portability of the model was mentioned by one participant that would facilitate application of the model.

#### **4.4 Summary of findings**

This section summarizes the main findings of the dissertation from both the questionnaire and the interview study and compares and contrasts the findings obtained from these two methods. Since the interview was structured and based upon the questionnaire tool, the data gathered is largely similar in both methods; the only subtle differences coming from the modality of the methods – self-selection in the online questionnaire and a more personalized setting in the interviews.

##### **4.4.1 Participants' country of origin and demographics**

The participants of the study are qualified and experienced and largely come from Western Europe and the North American continent. Pursuing an MSc in an institution of the United Nations, affords the opportunity to come into contact with individual from different countries, however, the bulk of the participants come from developed Western countries and only a couple from the far East and one from a West African state.

##### **4.4.2 Models used by participants**

The models used by the participants have been categorized into models present in the old IMO code 1999, models that are based on Reason's Swiss cheese and models related to analyzing barriers. In this respect, the findings indicate that the number of respondents who use the models present in the old IMO Code 1999 is nearly equal to the number of respondents who use models based on analyzing barriers. With respect to the modality, the personalized interview setting serves to encourage participants to reflect and suggest additional models that may not be covered in the structured interview, as in the case of the IMO-MAIIF.

#### **4.4.3 Models used and ranking across factors**

The participants have ranked the models utilized by them across three factors – the ability of the model to capture complex maritime accidents, the realistic nature that enables the model to capture the maritime sector and the training requirement of the model which can contribute to ease of use. In this respect, the models' ability to capture complex maritime accidents was scored high, followed by realistic in capturing the maritime sector and ease of use. In the models used by the investigators, the Reason's based models scored high followed by those based on the analysis of barriers in their ability to capture complex maritime accidents; with respect to realistic, the models based on analyzing barriers scored high followed by models included in the old IMO code; The models that were scored easy to use were those included in the old IMO code 1999, followed by those based on Reason's ideas.

Even though the same questions of the questionnaire tool were asked in the same order to the participants in the interview setting, the personalized setting of the interview (whether face-to-face or technologically mediated) enabled the participants to reflect and provide in-depth answers rather than merely providing a rating. The participants justified their choices in the interview setting and gave reasons for their answers and this was an added advantage as it enabled a more comprehensive picture to emerge; as in the case of interview participant 3, who rated the Reason's based models low on their ability to capture complexity and their ability to realistically capture the maritime sector and followed the rating up with in-depth explanation of the same.

#### **4.4.4 Models known and used by investigators**

Overall, the investigators know more models than they use in practice and Reason's Swiss Cheese and the SHEL models are by far the most well known to most investigators and are utilized by them in their work. This highlights that the knowledge and awareness of available models, including the complex systemic

models is limited in the study participants and consequentially the real world application of these models is also low.

#### **4.4.5 Factors of models and their rating**

The ratings of the factors of models in the questionnaire study reveal that 'realistic' scored the highest, followed by 'comprehensive' and 'functional', implying that the respondents consider these as important attributes of a model. The difference between the data obtained from the questionnaire and the interview study is that respondents may skip ranking factors for several reasons, including if the meaning of a particular attribute is not clear to them. The data analysis overcomes the issue of non-responses by averaging out the ranking of a factor by the number of respondents who responded to a particular question. In the interview setting, the student interviewer could clarify the meaning of a particular attribute and the personalized setting encouraged the participant to engage with the interviewer and provide answers to all questions. Non-responses are minimal in the interview setting. After clarifying the meaning of 'visible' to interview participants, that it implied clarity, three of the interviewees rated it as the most important factor, followed by realistic and functional.

Overall the top four factors of models considered important by the investigators are realistic, functional, comprehensive and visible. The study participants also provided additional factors not covered by the questionnaire and structured interview and 'ease of use' featured high as an important attribute of a model. Ease of use was desired by the practitioners in a model to support its application on the ground.

#### **4.4.6 Reasons for application of models**

The reasons cited by the respondents for the use of particular models largely pertained to the company. Organizational policy largely determines the model or

models to be used by the investigators. This highlights the importance of the organization as a key stakeholder group that acts as a gatekeeper for application of model(s) by the investigators in the field. Other reasons cited for the application of the models were the ease of use and application and the ease of training.

#### **4.4.7 Reasons for non-application of models which are known to investigators**

Several models are known to investigators, however not all of them are utilized by them. The reasons cited by the investigators for non-application of models they are aware of are – employer mandate restricts them in what they can use, highlighting the importance of the employer; the investigators have also cited satisfaction in the models they are currently using and therefore do not require additional models. The complexity of a model is a deterrent to its application; if it requires too much depth and training and time and financial resources then its use will be limited. Other reasons cited for non-application were that participants were unfamiliar with models and therefore could not use them and some also found them unhelpful and therefore did not apply them.

#### **4.4.8 Reasons for non-application of any model**

Most of the respondents use a model, however a total of four participants in the study (both questionnaire and interview) have stated that they do not use any model. The reasons given for the non-application of a model are that they are not required by experienced investigators, they are not required in simple investigations, one doesn't learn from linear models, the investigator would like to think through a problem without being restricted by the framework of a model and a lack of familiarity/awareness is also one of the reasons for not applying any model.

#### **4.4.9 Summary**

The models largely used by the investigators are those included in the old IMO Code 1999 and those based on analysis of barriers. The Reason's Swiss Cheese and the SHEL models are by far the most well-known and utilized by investigators in their work. The investigators considered the models' ability to capture complex maritime accidents as important, followed by the model being realistic to the maritime sector and ease of use. The four factors of models considered important by accident investigators are that the model should be realistic, functional, comprehensive and visible. Company policy is deterministic of the model or models to be used by the investigators. Other reasons for the application of the models are ease of use, application and training. Company policy is a key reason for the non-application of models along with increased complexity of particular models and time and resource constraints.

## 5. CONCLUSION

This study aimed at identifying the marine accident causation models marine casualty investigators use for investigating marine accidents and the reasons that inform their decisions with regards to the particular models they apply. The study further sought to determine the reasons why certain accident investigators do not use particular accident causation models at all.

In the research, 16 unique accident causation models that are used by accident investigators have been identified by some of the 23 respondents of the questionnaire survey. In addition to the 16 unique models identified by the 23 respondents were 2 additional unique models (IMO MAIIF model and Path Dependency) that were introduced in this study by the interview participants. These models all have their strengths and weaknesses with regards to how they capture the maritime sector, complex maritime accidents and how easy or difficult they are to understand and apply. The study therefore sought answers to be following questions: (1) what is the purpose of marine casualty investigations? (2) What marine casualty models are widely used in the maritime industry today? (3) Why are these models currently used? (4) How helpful are they in handling and avoiding marine casualties? (5) If models are not used at all or particular models are not used, what is the reason?

Chapter 4 of this research presents the main empirical findings. These findings have been summarized within the respective sections of the chapter. A synthesis of the empirical findings to provide answers to the research questions is necessary at this juncture. 1) What is the purpose of marine casualty investigations? It is shown in this study that most marine accident investigators conduct marine accident

investigations for the sole aim of ensuring safety. 2) What marine casualty models are widely used in the maritime industry today? It is however obvious that different accident investigators use different accident causation models and they more or less have varied opinions about how well the various models capture complex maritime accidents, how much intensive training is required for the various models and how well they are able to capture the maritime sector. (3) Why are these models currently used? It is evident that marine accident investigators can possibly utilize certain models relying upon the accessible circumstances of an incident for the sole aim of determining the causes of the accidents. This study shows that most casualty investigators use particular accident causation models due to their ease of application or as mandated by the company policy. (4) How helpful are they in handling and avoiding marine casualties? Majority of the marine casualty investigators from this study use SHELL and Reason based models. These are models that have been excluded in the new mandatory IMO Casualty Investigation Code. The reason for this might probably be that the accident causation models in the former IMO Code for Investigation of Marine Casualties and Incidents have not been effective in contributing to reduction of marine accidents in order to help improve safety in the maritime industry. However marine accident investigators still utilize these models and prominent institutions have them as their company policy. Furthermore, all the participants in this study did not indicate willingness to embark on the use of systemic approaches. As a result, this study has not been able to answer how helpful these models are for the purpose of their investigations. (5) If models are not used at all or particular models are not used, what is the reason? The reason for accident investigators using particular models from this study is as a result of its ease of use or the model being mandatory by the investigators' organization as previously indicated. However, sufficient experience, not being able to learn from linear models and lack of familiarity with certain models are among the reasons why certain investigators in this study do not apply any models at all.

This research did not have a representative sample considering that there were 27 participants in total mainly from the developed Western countries and there are 171 IMO member states. It is also important to consider how accident investigation is conducted with regards to open registries. However, interesting facts have been identified and that is, the Reason's based models are still being used by large influential organizations and they apparently seem to influence the discussions in MAIIF. As a result of that, Reason's ideas are still in MAIIF. The main argument for their application is that, the ideas of these models are easy to understand and apply without intensive formal training. Additionally, it apparently helps investigators who have been mandated to carry out formal safety investigations to work within that framework.

Further research in this area would be required in order to answer the questions: what determines if and when an accident causation model should be used and how do models help to contribute to safety by reducing the number of accidents.

The researcher did expect that the sole aim of marine casualty investigations would be for the purpose of safety and that there might be a possibility of different accident investigators using various models for their investigations. However the researcher did not expect the wide variations with regards to the investigators' opinions on how well a particular model is able to capture complex maritime accidents, the maritime sector and the level of intensive training required; the rating/ranking according to one investigator may be the complete opposite for another. However, it is important that whatever model/models an accident investigator decides to choose or not, he or she must be aware of the reasons or implications of such actions. Various reasons have been stipulated by the marine accident investigators for their preferences of using particular models or none at all.

The reduction of marine accidents and/or the increase in maritime safety due to the utilization of accident causation models could not be confirmed within the limited scope and context of this dissertation and therefore further research would be required to explore the contribution of accident causation models to maritime safety.

## ANNEX 1

### Definition of terms

A common agreement of definition of concepts in the field of accident investigation does not exist. While investigators such as (DOE, 1997) for example focuses on causal factors, other investigators such as (eg., Kjellén and Larsson, 1981) focus on determining factors, (e.g., Hopkins, 2000) on contributing factors, (e.g., Reason, 1997) active failures and latent conditions, or (Hendrick & Benner, 1987) focus on safety problems.

**Accident:** ‘A failure in a subsystem or the system as a whole, that damages more than one unit and in doing so disrupts the ongoing or future output of the system’ (Perrow, 1999, p. 66).

**Accident model:** “An accident model is the frame of reference or stereotypical way of thinking about an accident that are used in trying to understand how an accident happened” (U.S. Department of Energy, 2012, pp. 1-2).

**Causal factor:** ‘An event or condition in the accident sequence necessary and sufficient to produce or contribute to the unwanted result. Causal factors fall into three categories; direct cause, contributing cause and root cause (DOE, 1997)’ (Sklet, 2002, p. 10).

**Complexity:** “In physical systems, complexity is a measure of the probability of the state vector of the system” (Baianu, 2011, p. 25).

**Complex system:** “a system with numerous components and interconnections, interactions or interdependence that are difficult to describe, understand, predict, manage, design, and/or change” (Magee and de Weck, 2004) (NAGT, 2015).

**Consequence:** ‘A result or effect, typically one that is unwelcome or unpleasant’. A consequence may be split into two components: Nature – e.g. – economical, sociological, loss-of-life, etc. Severity/Magnitude – e.g. – \$1,000,000, 50 jobs (Mehdi, n.d., p. 2)

**Contributing factors:** “A condition that may have contributed to an accident event or worsened its consequence (e.g. man/machine interaction, inadequate illumination) resolution”(International Maritime Organization, 2014, p. 3).

**Coupling and Interactions:** *“Perrow identifies two interacting variables that specify a space, which fully characterizes accidents. They are coupling and interactions. Interactions are the reciprocal actions among elements of the system. These interactions can be tightly coupled or loosely coupled. Tightly coupled interactions are those that do not tolerate delay. They have invariant sequences and negligible slack. Loosely coupled interactions have the opposite characteristics. The interactions are linear or complex. The term “linear” means simple. The opposite is “complex.” With these definitions, Perrow creates the following framework to classify systems.”* (Cyert & March, 2015, p. 2).

**Event:** An occurrence; something significant and real-time that happens. An accident involves a sequence of events occurring in the course of work activity and culminating in unintentional injury or damage (DOE, 1997) (Sklet, 2002, p. 10).

**Failure:** ‘The inability of a system or process to conform to its normal design operation’ ‘A deviation from normal, expected performance’ Failures in a hazardous environment lead to undesirable events which may or may not have potential consequences (Mehdi, n.d., p. 2)

**Hazard:** ‘A source of potential harm or a situation with a potential to cause loss’ (Aus/NZ Standard). ‘A source of possible damage or injury’ (US Presidential/Congressional Commission) (Mehdi, n.d., p. 2)

**Human Element:** *“There is no accepted international definition of the term ‘the human element’.The IMO, through its Resolution A.947(23) - Human Element Vision, Principles and Goals for the Organization – refers to the human element as:*

*‘A complex multi-dimensional issue that affects maritime safety, security and marine environmental protection. It involves the entire spectrum of human activities performed by ships, crews, shore-based management, regulatory bodies, recognized organizations, shipyards, legislators, and other relevant parties, all of whom need to co-operate to address human element issues effectively.’In the maritime context, it can be taken to embrace anything that influences the interaction between a human and any other human, system or machine onboard ship” (Alert!, The Nautical Institute, n.d.).*

**Human Errors:** “Performance of humans that deviates from the desired performance” (American Bureau of Shipping, 2005, p. 5).

**Incident:** An incident involves damage that is limited to parts or a unit, whether the failure disrupts the system or not. By disrupt it is meant that the output ceases or decreases to the extent that prompt repairs will be required (Perrow, 1999, p. 66).

**Interactions:** Interactions are the reciprocal actions among elements of the system (NAGT, 2015).

**Interactive complexity:** This “refers to the presence of unfamiliar or unplanned and unexpected sequences of events in a system that are either not visible or not immediately comprehensible” (Marais, Dulac, & Leveson, n.d., p. 1).

**Loosely coupled or decoupled systems:** These are systems that “have fewer or less tight links between parts and therefore are able to absorb failures or unplanned behavior without destabilization” (Marais, Dulac, & Leveson, n.d., p. 1).

**Marine Casualty:** *“An event or a sequence of events, that has resulted in any of the following which has occurred directly in connection with the operations of a ship:*

- 1. the death of, or serious injury to, a person;*
- 2. the loss of a person from a ship;*
- 3. the loss, presumed loss or abandonment of a ship;*
- 4. material damage to a ship;*
- 5. the stranding or disabling of a ship, or the involvement of a ship in a collision;*
- 6. material damage to marine infrastructure external to a ship, that could seriously endanger the safety of the ship, another ship or an individual; or*
- 7. severe damage to the environment, or the potential for severe damage to the environment, brought about by the damage of a ship or ships.*

*However, a marine casualty does not include a deliberate act or omission, with the intention to cause harm to the safety of a ship, an individual or the environment.”* (International Maritime Organization, 2008, p. 3).

**Methodology:** “The procedures and techniques used to collect, store, analyze and present information; a research process” (The Investigation Process Research Resource Site, 2009).

**Near miss:** “(i) An incident with no consequences, but that could have reasonably resulted in consequences under different conditions. OR (ii) An incident that had some consequences that could have reasonably resulted in much more severe consequences under different conditions.”(American Bureau of Shipping, 2005, p. 6).

**Process:** ‘a series of actions or steps taken in order to achieve a particular end [or objectives]’ Just like maritime systems, maritime processes can be complex as well! (Mehdi, n.d., p. 5).

**Resolution:** The disposition of a recommendation (American Bureau of Shipping, 2005, p. 8)

**Safety:** “The ability of a system or process to mitigate the negative consequences of undesirable events that arise due to a combination of passive hazards & active failures (Mehdi, n.d., p. 4).

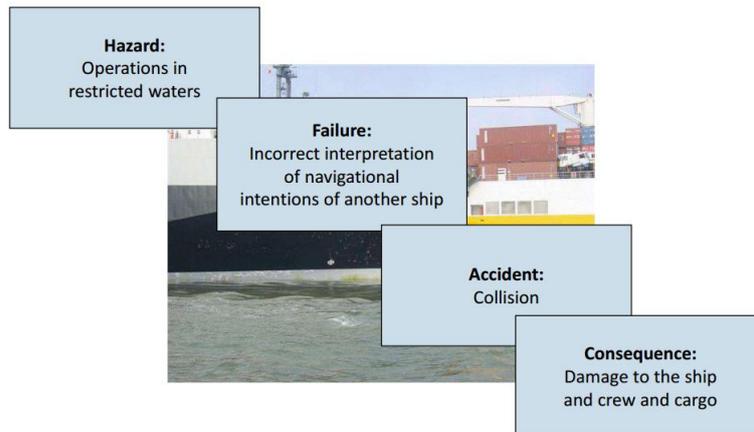
**System:** ‘a set of connected things or parts forming a complex whole’. Maritime systems are complex, socio-technical systems which influence, and can be influenced by a wide range of factors & stimuli (Mehdi, n.d., p. 5).

**Theory:** “systematically organized knowledge applicable in a wide variety of circumstances; especially, a system of assumptions, accepted principles, and rules of procedure devised to analyze, predict, or otherwise explain the nature or behavior of a specified set of phenomena" (Benner, 2009).

**Tightly coupled system:** “This is one that is highly interdependent: Each part of the system is tightly linked to many other parts and therefore a change in one part can rapidly affect the status of other parts” (Marais, Dulac, & Leveson, n.d., p. 1).

**Very serious marine casualty:** “Means a marine casualty involving the total loss of the ship or a death or a severe damage to the environment” (International Maritime Organization, 2008, p. 6).

**Marine safety investigation:** ‘An investigation or inquiry into marine casualty or marine incident conducted with the objective of preventing marine casualties and marine incidents in the future’ (International Maritime Organization, 2008, p. 4).



**Figure 1: Understanding some terms defined**

**Source :** (Schröder-Hinrichs, 2015, p. 13)

## ANNEX 2

### Questionnaire

#### Maritime Casualty Investigation Models

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#### Introduction

#### Dear Respondent,

Please find a short and completely strictly confidential questionnaire designed to assist in a research work on " A study on marine casualty investigation models employed by active marine casualty investigators". This is a requirement towards completion of a Master of Science Degree in Maritime Safety and Environmental Administration at the World Maritime University in Malmo, Sweden. The main aim of this study is to evaluate and analyse what constitutes a good marine casualty investigation model in order to help improve existing models and innovation of new ones for future use by marine casualty investigators worldwide.

This questionnaire should not take more than 30 minutes of your valuable time to complete. The results of this survey will be used for statistical analyses in a collective form and be attached as an annex to the masters dissertation. Please bear in mind that this research is strictly confidential and therefore your honest responses and opinions are required to help identify areas that need improvement.

Your responses and views are highly appreciated.

Your participation is completely voluntary, and all the answers will be completely anonymised. You can withdraw your participation at any stage.

By participating in this study, you agree with the following statement:

*I consent that the answers I provide to this questionnaire can be used for this research study, and any related publications. I also understand that all data collected in this questionnaire will be held and processed in the strictest confidence by the researcher.*

After the study is completed the original response files will be destroyed to maintain confidentiality and anonymity.

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## Demographics

3 1) What is your age, in years?

0 \_\_\_\_\_ [ ] \_\_\_\_\_ 100

4 2) What is your gender?

- Male
- Female
- Other

5 3) What is your level of education?

- BSc. or equivalent
- MSc. or equivalent
- PhD or equivalent
- Other - Write In (Required):  \*

6 4) What is your field of education?

- Seafaring - Navigation
- Seafaring - Engineering
- Naval Architecture or similar
- Other - Write In (Required):  \*

7      **5) Please indicate the duration for which have you been an accident investigator, in years.**

0 \_\_\_\_\_ [ ] \_\_\_\_\_ 100

8      **6) Please indicate your total working experience, in years.**

0 \_\_\_\_\_ [ ] \_\_\_\_\_ 100

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**Models You Use**

9

10 7) What is the purpose of your investigation?

Enforcement

Safety

Other - Write In (Required): \*

11 8) Please fill in the names of 3 accident investigation models that you use, then rate them for each of the 3 factors using the scale. If you use less than 3 models, leave the remaining rows blank.

1 means you Strongly Disagree with the statement; 10 means you Strongly Agree.

	Model Name	This model is able to capture complex maritime accidents										The application of this model is easy; it does not require intensive training										This model is realistic; it captures the maritime sector very well										
		1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	
1	___	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()
2	___	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()
3	___	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()

**Other Models**

12 9) We have identified a series of accident models. Please rate them for each of the 3 factors using the scale. Only rate the models that you are familiar with and leave the rest of the rows blank.

1 means you Strongly Disagree with the statement; 10 means you Strongly Agree.

	This model is able to capture complex maritime accidents										The application of this model is easy; it does not require intensive training										This model is realistic; it captures the maritime sector very well										
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	
SHEL	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )
Reason's Swiss Cheese	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )
STAMP	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )
MORT	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )
HTO (MTO)	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )
FRAM	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )
Heinrich's Domino	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )



Noncausal	<input type="radio"/>									
Visible	<input type="radio"/>									

14 11) Are there any other factors that you consider when choosing a model? How would you rate these on a scale of 1 to 10?



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## Final Questions

15 12) Why do you use the models that you use?

An empty text input field with a light gray background and a thin border. It features a vertical scrollbar on the right side and a horizontal scrollbar at the bottom, both with standard arrow and track icons.

16 13) Why don't you use other models?

An empty text input field with a light gray background and a thin border. It features a vertical scrollbar on the right side and a horizontal scrollbar at the bottom, both with standard arrow and track icons.

17 14) If you do not use a model, why not?

An empty text input field with a light gray background and a thin border. It features a vertical scrollbar on the right side and a horizontal scrollbar at the bottom, both with standard arrow and track icons.

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**Thank You!**

18 Thank you for taking our survey. Your response is very important to us.

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