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Flag state performance as a crucial element of Human Factor Analysis and Classification System (HFACS) on marine casualty investigations

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THE FLAG STATE PERFORMANCE AS A CRUCIAL ELEMENT OF THE HUMAN FACTOR ANALYSIS AND CLASSIFICATION SYSTEM (HFACS) ON MARINE CASUALTY INVESTIGATIONS

By

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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): ……………………………..

(Date): 21 September 2021

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Abstract

Title of the dissertation: **The Flag State Performance as a crucial element of the Human Factor Analysis and Classification System (HFACS) on marine casualty investigations**

Degree: **Master of Science in Maritime affairs**

This dissertation investigates the connection of marine accidents causation with the Flag State Performance based on the analysis of the accident onboard the vessel CARNIVAL SPLENDOR.

An in-depth look on the international regulatory framework regarding the marine accident investigations as set-up by the IMO and UNCLOS, explains the importance of the accident investigations for the maritime safety and for the prevention of future disasters at sea.

The accident analysis with the application of AcciMap and HFACS-MA illustrated many causal factors on every involved level but the most important result was the identification of the connection between the Flag State and the Recognized Organization to the accident. It was the initial intention of this study to look for contributing causal factors beyond the company's management level at the top of the hierarchy.

Among the many flaws, the results of the accident analysis revealed oversight gaps at the Flag State, which are causal factors of significant importance for the accident and generally for the maritime safety. The analysis of the Flag State obligations deriving from the fundamental maritime conventions indicated the importance for adoption of concrete policies at governmental level regarding the oversight of the Recognized Organizations.

The concluding chapters explains how the incorporation of the Flag State Performance into the 5^{th} layer of HFACS will contribute to the better understanding of the causational factors of marine accidents, as deriving from the governmental level. Furthermore, it is indicated that by connecting the related causal factors at the top level with the Flag State Performance, will assist Flag States and Administrations to evaluate their adopted maritime policies and cover potential gaps.

Keywords: Accident Investigation, AcciMap, CARNIVAL SPLENDOR, Flag State Performance, HFACS.

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List of Abbreviations

Abbreviations	Description
DG	Diesel Generator
EEZ	Exclusive Economic Zone
E/R	Engine Room
ERT	Emergency Response Teams
FS	Flag State
FSP	Flag State Performance
FTA	Fault Tree Analysis
GEMS	Generic Error Modelling System
GISIS	Global Integrated Shipping Information System
HFACS	Human Factors Analysis and Classification System
HOF	Human and Organizational Factors
ILO	International Labour Organization
IMO	International Maritime Organization
ISM	International Safety Management System
LL	International Convention on Load Lines
MA	Maritime Administration
MARPOL	International Convention for the Prevention of Pollution from Ships
MLC	Maritime Labour Convention
OOW	Officer On Watch
PMA	Panama Maritime Authority
PS	Port State
PSC	Port State Control
PSCO	Port State Control Officer
RO	Recognized Organization
SHEL	Software Hardware Environment Liveware
SMC	Swiss Cheese Model
SMS	Safety Management System
SOLAS	International Convention for Safety of Life at Sea
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea, 1982
USCG	United States Coast Guard
WBG	Why-Because Graph

1. Introduction

This chapter aims to introduce the background of marine accident investigations, the dissertation’s objectives and the methodology to be used. Additionally, the difficulties and limitations that have been encountered for the creation of this thesis are also mentioned.

1.1 Background

At the occurrence of any marine accident, many kinds of investigations are performed from the different stakeholders of concern. Investigations can be judicial, administrative or internal investigation inquiries by the shipping company. Each investigation is carried out for a purpose, this thesis will deal with the models used on the incident investigations for discovering the underlying causes that have contributed to accidents, located at the top layers of the organizational structure as well as to identify policy and legislation gaps at governmental level.

Although accidents are inextricably linked to human factors, the approach to investigate and identify these factors relies on a range of parameters to be considered such as the working environment, the background, training and expertise of each individual (Ergai et al., 2016). A model that well addresses those factors is the Human Factors Analysis and Classification System (HFACS; Wiegman & Shappell, 2003). HFACS is a human error taxonomy based on Reason’s well-known ‘‘Swiss Cheese” model of accident causation (Reason, 1990). HFACS is a well-established methodology in several domains including aviation (Wiegmann & Shappell, 2003), mining (Patterson & Shappell, 2010), maritime (Chen et al., 2013), rail (Reinach & Viale, 2006), and medicine (Eibardissi et al., 2007). Another well-known model is the SHEL model (Hawkins, 1987), which is named after the letters: Software (S), Hardware (H), Environment (E) and Liveware (L). Both models aimed to identify underlying factors that could cause an accident.

Weather conditions, the traffic type, operational problems and regulatory gaps are some of the factors that can result into marine accidents (Schröder-Hinrichs et. al., 2020). The International Maritime Organization (IMO) has acknowledged that human errors are one of the main causal contributors to accidents (IMO, 1999). Both Swiss Cheese and SHEL models have been adopted by IMO to propose guidelines for the investigation of human factors in marine casualties and incidents (IMO, 1999, 2008). This means, that the incident investigators should a) take into account the actions of the sharp-end personnel at the time of the occurrence, b) seek for an explanation for the conditions which shape the actions of sharp-end personnel and c) identify latent organizational factors that allowed the unsafe conditions to exist.

The Flag State (FS) has a variety of roles, but is of utmost importance the protection of lives, property and the rights of the state's citizens. The tragedy of the RMS TITANIC shocked the public due the high number of lost lives in the North Atlantic and remedial actions were needed to avoid recurrence. The investigation of an accident aims to provide a remedy with the identification of the accident's root causes and create the frame for the development of safety measures to be applied in the future. Since these matters are of public interest, the FS is responsible to conduct the accident investigations. In the contemporary era of shipping, the statutory work of the Maritime Administration (MA) is assigned to a Recognized Organization (RO) and the Classifications Societies delegating on behalf of the MA as RO. The FS has to oversight the ROs but the accident investigation is an obligation that remains to the FS due to the fact that the root causes could be at the top of the organization so the investigation body is important to be governmental.

Environmental protection is a major priority for a Coastal State (CS) and maritime accidents in most cases are affecting the marine environment, especially when the cargo is oil or another noxious substance. When dealing with maritime safety, the aim is to prevent accidents from happening and create a safety culture that reflects the readiness to the unexpected. The TITANIC disaster in 1912 triggered the creation of the international convention for the Safety of Life at Sea (SOLAS). Other serious maritime accidents, for example the Torrey Canyon, were catalysts for the adoption of the other international maritime conventions. The purpose of SOLAS as well as the many other international conventions like LOADLINE, STCW and the International Convention for the Prevention of Pollution from Ships (MARPOL) is to set safety standards for the ship construction and operation in order to minimize the possibility of an accident that will lead to a casualty and environmental disaster. What is learned from the accident investigations is vital for the shipping industry and leads to the continuous update of those conventions combined with the enhancement of the safety culture.

The sovereignty rights that every State has, allow them to set the necessary regulatory framework that will facilitate the accident investigation on the ships flying its flag as well as to cases affecting the territorial sea of the state. Since shipping is truly an international activity, cooperation between nations is essential for the protection of the marine environment and the conduct of accident investigations. The IMO has a vital role for the shipping industry as an international specialized agency of the United Nations (UN) which promotes the enforcement of international conventions for the protection of the environment, maritime safety and accident investigation. The major international maritime conventions set the obligation for the FS to perform accident investigations and the IMO has issued a significant amount of instruments among the years to support it. The International Labour Organization (ILO) which is also a UN specialized agency has great interest in the accident investigations but is focusing on the labour protection aspects.

1.2 Problem Statement

Even though the marine accident investigations aim to identify the root causes of accidents, the organizational factors are of major importance for an accident especially when deriving from the actions of the MA. The Flag State Performance (FSP) is an indication on how well the FS manages to implement its obligations. The incorporation of the FS performance element in the HFACS taxonomy will assist in the deeper understanding of the contributing causal factors laying at the governmental level. The further development of the taxonomy will be used as a tool to identify gaps that have been neglected by Flag States and improve their control over their ROs. Additionally, the improvement of the FS performance will result in reduction of incidents occurring onboard ships.

1.3 Research Aim and Objectives

The FS is the regulating authority of its maritime industry and holds the full responsibility of the actions taken by the delegating authorities. The marine accident investigation is an obligation that has to be performed by the FS. The performance of the flag is closely related to the number and type of accidents occurring in the fleet. The objectives of the present thesis are to:

- Contribute to the further development of the maritime HFACS taxonomy and add the element of FS performance.
- Determine the significance of the adopted policies and quality management that a FS applies on its maritime industry.

The contribution to the 5th layer in the HFACS taxonomy will result in a deeper understanding of maritime accidents and prevent future casualties at sea. This thesis aims to identify causal factors with the analysis of the accident onboard the vessel CARNIVAL SPLENDOR, which are deriving from the actions of the FS and relate them with the FSP. The objective of the research is to identify if the incorporation of the FSP as an additional category in HFACS, can provide a better understanding for the identified gaps of the FS's overseeing capacity and if the adopted policies are adequate to ensure the implementation of the IMO instruments.

1.4 Research Questions

According to Wiegmann and Shappell (2003), HFACS is structured within four levels: a) The unsafe acts, b) preconditions occurring for unsafe acts, c) lack of supervision and d) organizational influences. Each level of this taxonomy is linked to the previous one (Ergai et al., 2016), leading to the organizational factors that could contribute to the marine casualties. Although the HFACS is considered a great tool to explain and understand accidents, maritime disasters keep occurring and there is a need to go further up in the hierarchy of the taxonomy and identify potential gaps. By analyzing causal factors located at the governmental level and interpret them as low FSP, the taxonomy will assess the following research hypotheses:

- The implementation of IMO requirements combined with well-established policies by the FS ensures a good FSP.
- A FS that implements proper oversight over the organizations delegating on its behalf will result in high safety standards for the fleet and reduced probabilities of serious accidents.
- The further development of the HFACS taxonomy by incorporating the FSP element will provide an additional layer of safety in the maritime industry.

1.5 Methodology

As first step for the investigation of marine casualties is required to have a tool that analyzes and distinguishes the errors. A qualitative method is used in the present thesis in order to determine the contributing causal factors, related to the accident onboard the CARNIVAL SPLENDOR and connect them with FSP. For the present study, the official investigation report from the United States Coast Guard (USCG) is the main source for document analysis. Figure 1 provides the graphical overview of the accident analysis for CARNIVAL SPLENDOR.

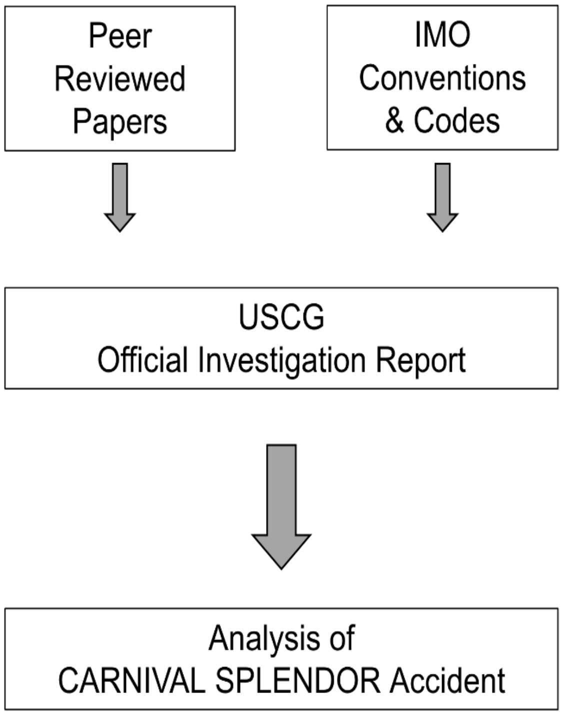

Figure 1. Analysis of the CARNIVAL SPLENDOR accident.

As a primary tool of analysis, AcciMap will be used to identify the causal factors contributed to the accident of the passenger cruise ship CARNIVAL SPLENDOR which resulted in complete loss of power. Jens Rasmussen in 1997 developed the AcciMap which was part of the risk management strategies procedures for sociotechnical systems (Rasmussen, 1997). The development of AcciMap was meant to a tool for analyzing events and decision-making processes which have contributed to the loss of control (Rasmussen & Svedung, 2000). A great advantage of AcciMap is that after the accident analysis, recommendations regarding safety can be extracted and for this purpose it was used by many accident analysts (Hopkins, 2000). The relevant AcciMap procedures followed for the accident analysis of the CARNIVAL SPLENDOR are listed in Table 1 below.

Table 1. AcciMap analysis procedure

Step No	Step Description
1	Determine the sections / levels of the ACCIMAP analysis
2	Identify the outcome(s) for analysis based on accident data
3	Identify all the causal factors
4	Identify the appropriate ACCIMAP level for each cause
5	Categories causes and labeling them
6	Create the causal lines among the identified causes
7	Fill in the gaps in the causal chain (if necessary)
8	Check the causal logic
9	Formulate safety recommendations

The identified causal factors with the use of AcciMap will be compared with the results of the HFACS taxonomy respectively. The importance of AcciMap for this study is that the relevant policy and legislation gaps at the governmental level can be relatively easily identified and could contribute to the further development of the 5th layer in the HFACS. Figure 2 provides a general overview of the causal factors in an HFACS taxonomy with a 5th layer as external factors. The approach is based on the HFACS-MA developed by Chen et al. (2013). The methods that were adopted and used in the HFACS-MA were selected so the model would be fully compliant with the IMO's guidelines for the investigation of marine casualties (IMO, 1999). Furthermore, with the HFACS-MA approach, accident investigators have a well-developed model to conduct maritime casualty investigations.

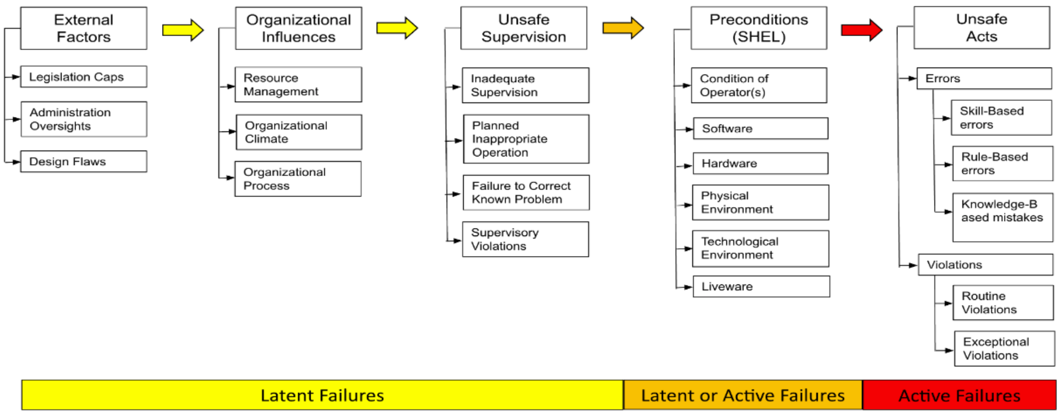

Figure 2. Causal factors in HFACS

Part of the HFACS-MA is the construction of a Why-Because Graph (WBG) as suggested by Chen et al. (2013). For a WBG, the creation of an inventory table is needed and will include all the identified causal factors that contributed to the accident. WBG provides a simple linear way to demonstrate the findings identified from the accident analysis. The accident analysis with the HFACS-MA approach is illustrated in Figure 3.

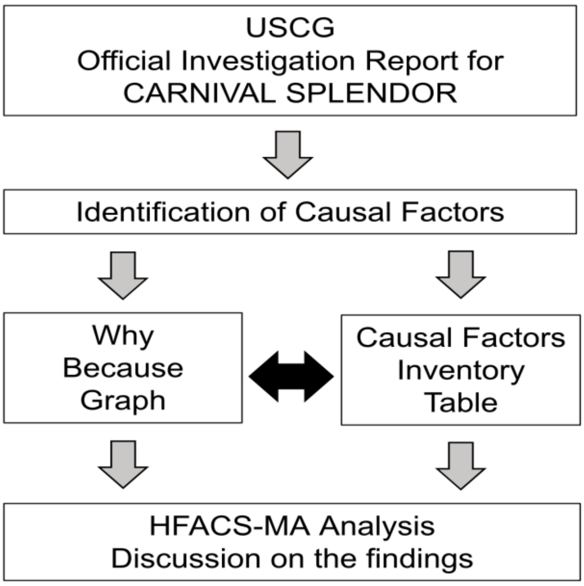

Figure 3. HFACS Analysis Process

The process begins with the review of the USCG accident investigation report for the CARNIVAL SPLENDOR followed by identification of the causal factors based on the evaluation of the available data. The relevant findings are summarized in the inventory table that will be used for the WBG. In the end, discussion will be made on the extracted findings from the HFACS.

For the present thesis valuable material was collected by the library of WMU and from other available internet sources and databases. Additionally, the author's experience and various private sources contributed to this work.

1.6 Research Limitation

Due to limitations in length of this thesis as well as other limitations, it is extremely difficult and vast to analyze in full depth each contributing causal factor and find all possible connections to the actions and decisions of the MA and FS. This research is focused on the fundamental causal factors of the studied accident related to the organizational influences at the top of the hierarchy. Furthermore, to evaluate each and every adopted policy of Panama state regarding maritime regulatory framework is beyond the limits of this dissertation but it is suggested for future research to provide a more holistic approach regarding the FSP and the accident investigation.

1.7 Overview of the Research

This study is structured in three parts with the associated chapters. The first part covers the general background about the accident investigations as described in the introduction. The second part provides an in-depth review of the existing regulatory framework for the accident investigations in chapter two. A literature review of the accident investigation theories and models, relevant to this thesis is presented in chapter three. The results of the analysis, the relevant findings, discussion and conclusions are presented in the final part of the thesis.

2. International Regulatory Framework of Marine Accident Investigations

In this chapter, the relevant international regulatory framework of maritime accident investigations is presented. The approach is done through the analysis of member states obligations based on the fundamental maritime conventions of IMO, ILO and the United Nations Convention on the Law of the Sea (UNCLOS). Additionally, other applicable instruments and codes that have been adopted by the IMO are also analyzed.

2.1 International Law

2.1.1 UNCLOS

The UNCLOS is considered as the “mother convention” that sets out the fundamental legal principles and terms of international rights and obligations for the member states. The operational and technical provisions existing at the maritime conventions and instruments of the IMO, derive from the legal provisions of UNCLOS. In other words, the relations among nations, regarding maritime issues is determined by the UNCLOS “in a spirit of mutual understanding and cooperation” (1982). Many maritime disasters from the Torrey Canyon to the more recent of the X-Press Pearl have caused significant environmental damage. The protection of the marine environment is one of the elemental principles to come across on various international maritime conventions as well as in UNCLOS. Considering the aim of the accident investigations which is to enhance safety and minimize accidents at sea, it can be considered that accident investigation is promoted by UNCLOS.

It is duty for every FS to perform an accident investigation on the ships flying its flag, when those ships are involved in incidents that cause damage to the marine environment, loss of life or any other serious injury. Investigation is also performed for incidents when the vessel caused material loss or damage. It is important to be noted that if the incident has occurred in the territorial sea or internal waters of another state which has jurisdiction over the territory, then both states have to agree on how to proceed for the investigation and cooperate. Those obligations are declared in UNCLOS Article 94. Paragraph 1 of the article expresses the obligation for the FS "exercise its jurisdiction and control in administrative, technical and social matters over ships flying its flag" while paragraph 7 describes the obligation of the FS to "cause an inquiry … every marine casualty or incident" (UNCLOS, 1982).

Jurisdictional matters may cause disputes, concerning the interests between the different states. UNCLOS clearly defines jurisdictional aspects on numerous articles of the convention. Since UNCLOS deals with the high seas, incident investigation for cases occurred in the territorial waters of a state are not regulated by the provisions of the convention but from the national legislation of the country and from other international maritime conventions that will be analyzed further below. The sovereignty rights of the state over its territorial waters allow the CS to initiate an inquiry for any incident that took place in its territorial waters. This is one of the fundamental rights of UNCLOS as described in Article 2, but this right does not stand in vacuum since Article 18 the "meaning of passage" and Article 19 "meaning of innocent passage" complete the regulatory framework for the jurisdictional matters. In other, the CS has no jurisdiction on ships flying a flag of another state unless the incident involving the vessel flying a foreign flag, causes threats to the interests of the CS. The concept of jurisdiction is supplemented by the Article 27 & 28 of UNCLOS for the criminal and civil jurisdiction in relation to foreign ships respectively. Based on the above, the same is applied for the accident investigations.

2.1.2 IMO

The IMO from its creation has adopted numerous conventions, but SOLAS, MARPOL and International Convention on Load Lines (LL) are considered as the pylons for the existing maritime regulatory framework. Based on the provisions of the above-mentioned conventions the MAs are obliged to conduct accident investigation on their ships. The relevant obligations of those conventions are analyzed further below.

2.1.3 SOLAS

As per chapter I part C, Regulation 21 of SOLAS every MA has the obligation to perform casualty investigation to the ships flying its flag, if it judges that this investigation can contribute to the improvement of the convention. Moreover, each contracting government that undertakes an investigation has to provide the relevant findings to the organization. Causes that led to an accident in the majority of the cases, are connected with the provisions of SOLAS; therefore, the investigation findings are important to assess the effectiveness of the regulations and if needed to adopt new or change the existing ones.

2.1.4 MARPOL

The regulatory framework of MARPOL in regard to accident investigation indicates similar provisions as the SOLAS which are found in Article 12 of the convention. The major difference here is on the type of the accident and the investigation is subjected to cases in which the marine environment had been affected. The obligation for the member states of the convention to supply the IMO with the findings from the conducted investigations, also applies here for the same reasons. Additionally, MARPOL requires from the states to report at the IMO and to any other state which may be affected from incidents involving harmful substances.

2.1.5 Load Line Convention

Similarly to SOLAS and MARPOL, the LL in Regulation 23 (as revised by 1988 protocol) describes the relevant obligations for conducting investigations “of any casualty occurring to ships for which it is responsible and which are subject to the provisions of the present Convention” (IMO, 2005). The obligation for the contracting governments to provide the organization with findings from their investigations, has the same scope as in the other mentioned conventions.

Based on the above, different international maritime conventions provide similar obligations for the member states regarding the casualty investigations on ships. Every adopted convention and code is supplementing others in a way to cover all the relevant aspects of safety and environmental protection. Marine investigations have significant importance for the IMO since in the way of learning from the incidents, the maritime conventions are revised and new regulations or codes are emerging in the shipping world.

2.1.6 Casualty Investigation Code

With the aim to promote safety at sea and to have uniformity on the procedures for the accident investigations, IMO from the beginning of its creation has adopted numerous resolutions regarding this issue. According to the provisions of SOLAS Regulation I/21, the MARPOL's Article 8 and 12, the LL's Article 23 and UNCLOS Article 94 there was a need for a unified code that will provide the necessary framework for the causality investigations. Thus, IMO adopted the Code for the Investigation of Marine Casualties. The human factor is interlinked with the causes of marine accidents, for that reason the IMO in 1997 adopted the A.849(20) resolution which provided the guidelines for the investigation of human factors. The importance to understand these factors through the accident investigation has been highlighted and new theories for investigations to detect the underlying causes of accidents have been applied. The MSC.255(84) revoked previous instruments and IMO adopted the new Code of the International Standards and Recommended practices for a Safety Investigation into a Marine Casualty or Marine Incident (Casualty Investigation Code), in 2008. In order to make the code mandatory, the organization amended SOLAS the same year and added the Chapter XI-1 with the provisions of special measures to enhance safety and the relevant obligations are included in Regulation 6.

The Casualty Investigation Code (CIC) aims to provide a unified approach for the conduct of investigations made by the member states and to promote the notion of cooperation among them. The primary scope of the CIC is to prevent potential future marine casualties. Another code's objective is to identify the contributing causal factors of marine accidents. Additionally, the cooperation among states for the casualty investigations is highlighted into the CIC (IMO, 2008). The code urges the need for cooperation between the substantially interested states. This means that in the casualty investigation, apart from the state that has full jurisdiction other states can participate having interest due to the loss.

2.2 IMO Instruments

2.2.1 Resolution A.1075(28): Guidelines to Assist Investigators in the Implementation of the Casualty Investigation Code (IMO, 2013a)

The international maritime conventions provide the general obligations for the member states but specific guidelines have to be established to achieve a unified approach on the maritime casualty investigations. The IMO with resolution A.1075(28) is providing the required framework for the conduct of the investigations and is aiming to assist the MAs and the flag investigators to perform their task. Considering the main purpose of the casualty investigations, the guidelines provided in the resolution A.1075(28) are focused on "identifying safety deficiencies through a systematic safety investigation of marine casualties and incidents" and with the extracted findings to cover gaps at the existing regulations (IMO, 2013a). According to the provisions of this resolution, it is suggested that the safety investigations can be split up to five main areas which are: human, environment, equipment, processes and procedures, organization and external influences. With the identification of causation factors of marine accidents from these five areas is expected to increase the awareness and to enhance the adoption of proactive measures to reduce accidents, save lives and protect the environment. The most important element in this instrument is that it addresses the need to identify organizational and external influences from the accident investigations which are factors having significant contribution to the accident causation and are difficult to be recognized. The purpose of the casualty investigation is not to allocate liability or blame the responsible, but to prevent similar incidents in the future.

2.2.2 Resolution A.1070(28): IMO Instruments Implementation Code (III Code) (IMO, 2013b)

The international maritime conventions are providing a robust regulatory framework for the shipping world. These conventions are setting the rights for the member states, but rights come with obligations and the states have to fulfil and respect them. The IMO in 2013 adopted the IMO Instruments Implementation Code (III) as a way to enhance maritime safety and to protect environment by developing a strategy that will ensure the fulfilment of those responsibilities and obligations from the FS, CS and Port State (PS) (IMO, 2008a). III it is directly referred to the FS investigations and it is related to them since the scope of this code is to "monitor and access" (IMO, 2008a) the effective implementation and enforcement of the relevant IMO instruments. Accident investigation is one of the obligations the FS has and by reviewing the strategies that the state has adopted; an audit can reveal gaps that need to be rectified. Important aspect of the III is that it addresses the review of the set strategy not only of the FS but of the CS and PS which are not clearly highlighted in the other conventions.

The III has specific provisions on how the delegation of authority have to be transferred to the ROs as well as how the FS will maintain the proper oversight on them. The work of the ROs and FS surveyors is of crucial importance for maritime safety. Lacks in performing their tasks and failing to meet their obligations can result in fatalities onboard ships and is vital for the FS to have a well-established oversight strategy to identify in advance potential faults. A non-well-structured oversight and monitoring system from the FS, can be connected to the accidents the Flag's fleet has.

2.2.3 The Human Element in Marine Accidents

The regulatory framework initially established by IMO set its focus on the constructional and shipbuilding standards and to the mandatory safety equipment required onboard so ships can operate safely. Just after 2000 the human element started to be considered as important factor and IMO shifted its focus to that (O'Neil, 2003). Apart from the amendments of STCW convention and the adoption of the ISM code, the Maritime Labour Convention (MLC) was a fundamental convention verifying human element recognition.

Even though the MLC is not a purely IMO convention, it was developed with the combined efforts of the IMO and the International Labour Organization (ILO) in a way to recognize the significance of the human element in shipping. MLC 2006 entered into force in 2013 and consolidated the majority of maritime instruments that have been adopted prior to the convention. The MLC covers aspects affecting all the involved parties in shipping, owners, FSs, PSs and seafarers.

Human factors are widely considered as the main cause for the occurrence of maritime accidents (Hetherington et al., 2006) which emerges from the perception that when humans are in a non-ideal situation, they will make errors (Chauvin, 2011). For that reason, establishing the required decent working constitutions for seafarers is a measure to prevent accidents, achieve a safer shipping industry and protect the environment (ILO, 2006).

2.3 Reporting to the IMO

The relevant requirements for the reporting of the casualty investigations to the IMO are included in each convention. The reporting is an obligation of the MA which has to be in accordance with IMO criteria. IMO in order to ensure the implementation of these obligations by the member states has included in the scope of the III Code the analysis of investigation reports made by MA. This procedure firstly aims to facilitate the reporting process of the MA and have a comprehensive knowledge-based mechanism for the identification of trends and rule making process (IMO, 2013b). Moreover, IMO developed a common database to facilitate this work, the Global Integrated Shipping Information System (GISIS). The most important factor is that every investigation report is available to those who may have interest and contribute to the safety of life at sea.

2.4 Summary

Although the available regulatory framework of the IMO regarding the accident investigations not only establishes the requirements but provides the necessary tools for the member states to perform their work. The IMO has outlined the importance of the accident investigations as a tool that will promote safety onboard ships, from its early beginning. The fast technological improvement combined with the development of new psychosocial science theories aiming to the deeper understanding of human factors in the complex sociotechnical systems, made the shipping world to shift its focus on the human element. Since the human element is significantly affected by the organizational influences it is important to find those connections through the accident investigation. For that reason, shipping has adopted strategies, policies and regulations to establish a safer working environment.

3. Accident Analysis

This chapter aims to present the accident analysis models and the reasons why it has been decided to use AcciMap and HFACS for the analysis of the accident onboard the CARNIVAL SPLENDOR. The scope is to present the basic theories of the available models and examine their potentials for the use in the accident analysis.

3.1 Marine Accident

In order to have a comprehensive understanding of the subject the meaning of accident has to be determined. According to Leveson, an accident is described as “An undesired or unplanned event that results in a loss, including loss of human life or human injury, property damage, environmental pollution, mission loss” (Leveson, 2016, p.181). In parallel, the definition adopted by the IMO illustrates the above-mentioned events in more detail adjusted accordingly to fit better into maritime accidents (IMO, 2008).

3.2 Accident Analysis Theories

It is common perception for the shipping industry that for 80% of the accidents the contributing factor is human error and is quoted quite a lot as an example. Common approach is observed in other transportation industries; for example, in aviation it is acknowledged that human error have attributed for the 70-80% of the accidents (O’Hare et al., 2007; Lower et al., 2018). The proportion is significantly high and for that reason it is necessary to investigate what is lying below the widely acknowledged human error.

For the analysis of accidents, using the appropriate model and method is the key element to allow the investigator to discover the underlying factors that have contributed to the accident, especially those located at the top of hierarchy. Our modern society is characterized by complex sociotechnical systems, in the same way accidents are complex and each one has its own unicity. The use of a single model that will fit for all is not a viable option (Reason et al., 2006). Depending on the accident analysis, some models will fit better than others. Complex accidents require comparable models to be used for the analysis while there are cases where a simple model can be used and provide plenty of useful recommendations to avoid recurrence. Each model is designed to identify certain causes; for instance, the Swiss Cheese Model (SCM) is appropriate for finding the latent conditions waiting to be activated. In contrast the Root Cause Analysis is focused on active failures and definitive causes. Man Technology Organization is accurate for finding cause factors that have contributed to an accident. System Theoretic Accident Model and Process is looking for parts of the system that have violated the safety barriers. Cognitive Reliability and Error Assessment Method is good for recognizing a group of actions that will explain the accident. AcciMap through the analysis of events and decision-making processes will demonstrate the loss of control which resulted in the accident. HFACS scope is to identify the human error at each level of the taxonomy and defined at the SCM (Hollangel & Speziali, 2008). Obviously, each and every model follows a different path but the decision of the right method relies on the desired result and is of utmost significance.

3.3 The Human Element Consideration

Back in the 1960 the consideration of the risk assessment begun to be part of the planning process while accident analysis theories became subject of research. It has been realized that a treatment needed, since the size of the accidents increased and the consequences did also, while the public would not tolerate a repetition of a disaster. Those methods established in that era are still applicable for many industries today but evolved among the years due to the technological advance and complexity of the systems. The nuclear accident at the Three Mile Island just before 80s was catalytic for the identification of the human factor and its interaction with safety systems. Furthermore, the Chernobyl disaster triggered a chain reaction for the development of the safety culture, which was beyond the technological systems and incorporated the human element to cover the organizational factors (Hollangel & Speziali, 2008). The developed models acknowledged human error as the cause of accidents. This approach has been heavily criticized over the years since many researchers describe human error as a symptom and not the cause of accidents. There are different ways to look at a problem and each can generate different perspectives. For instance, the acceptance of the human error as a symptom will make an investigation to look for relations between the human element, the organizational structure and technology (Woods et al., 2017, p.19).

The general view regarding human error has changed over the years moving from the old to the new (Hollangel & Speziali, 2008). According to the old view, the human element is accused as the main cause of the accident. Moreover, it is based on the perception that the work can be carried out safely only in the absence of unsafe acts and it is believed that any complex system can operate safely if there are no human errors in place. On the contrary, the human error is considered as a symptom of a deeper trouble in the system, according to the new view and takes for granted that humans make mistakes. The proposed remedy for that is to perform adjustments to the system in order to avoid errors. With the new view the center of attention is on the reasons why accidents occurs and on how to establish measures to avoid recurrence. Comparing the two views, the old one would always result in human error, as the cause of the accident (Dekker, 2014). On the other hand, by investigating an accident with the new view, the human error will be part of the investigation and not the only cause of the accident.

Shipping has been characterized as a tightly coupled system with tendencies defined by various factors (Perrow, 1999; Hollangel & Speziali, 2008). Figure 4 illustrates the position of the shipping industry relative to coupling level (Loose - Tight) in parallel with various accident analysis models. For tightly coupled systems it is difficult to find a way of absolute control, since the results of an event will affect the other parts of the system relatively fast. According to earlier studies (Perrow, 1999; Hollangel & Speziali, 2008), the same is applied to complex systems while restricting the options for conducting operations with safety, since the only purpose is to achieve the determined results.

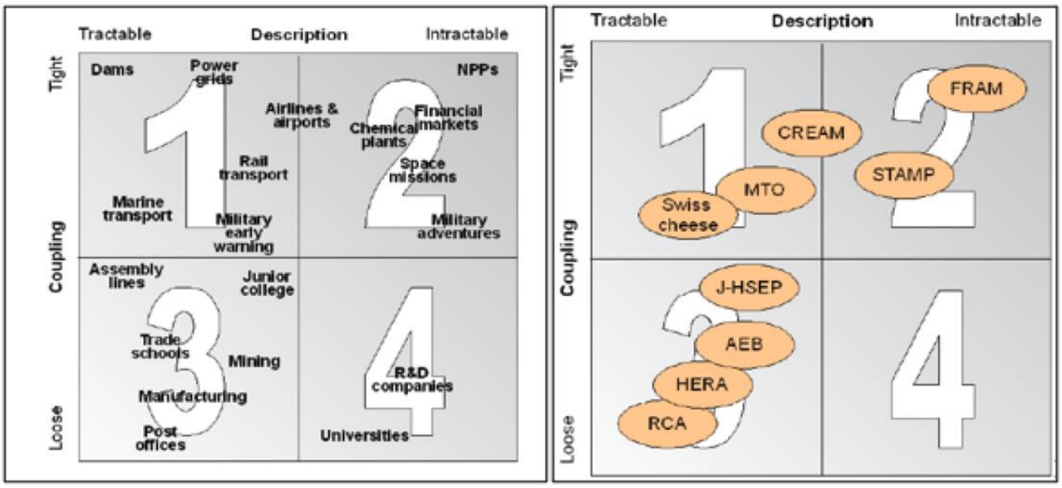

Figure 4. The Loose - Tight coupling diagram and relevant accident analysis models (Hollangel & Speziali, 2008).

3.4 Accident Analysis Models

According to the provisions of the CIC (IMO, 2008) HFACS is the appropriate tool to identify human factors for maritime accidents. HFACS has been widely accepted by many researchers in studies regarding safety and have been used in parallel with other available methods like the Fault Tree Analysis (FTA), blended together and creating new models (Zhang et al., 2019; Sarialioglu et al., 2020). The Shipping industry has adopted HFACS and applied in many of its sectors such as the machinery spaces (Schröder-Hinrichs et al., 2011), cruise and passenger ships and many others (Celik & Cebi, 2009; Chauvin et al., 2013; Chen et al., 2013; Akyuz & Celik, 2014; Theophilus et al., 2017; Ugurlu et al., 2018; Yildirim et al., 2019; Qiao et al., 2020). Even though HFACS has been vastly applied in aviation (Shappell &

Wiegmann, 2000; Wiegmann & Shappell 2003). The adoption of HFACS for accident analysis in different industries and various domains proves that it is a reliable method. AcciMap on the other hand differs from the common FTA models since it does not follow the linear approach but has a more systemic approach (Rasmussen, 1997). AcciMap was developed by Rasmussen in 1997 as part of the proactive risk management strategies following a system-based analysis for the accident with a graphical representation of the failures leading to the accident (Rasmussen, 1997; Rasmussen & Svedung, 2000). The graphical representation allows the investigator to analyze how causal factors, decisions and errors intersect in the accident's flow of events, with the actions of the sharp end personnel, influenced by the organizational or governmental factors located at the top. The ability of AcciMap to identify contributing factors in the company's management level, the regulatory bodies and government level, make it ideal for the investigation of marine casualties in order to discover legislation and policy gaps at the top level.

3.4.1 ACCIMAP

AcciMap is the accident analysis method based on the concept which considers that the contributing factors of an accident can be found on many levels representing the involved domains of an industry. AcciMap requires the building of a tree shaped diagram with the events and conditions that interacted and resulted into the accident. The top levels engulf governmental, regulatory and organizational factors while the lower levels have factors immediately related to the accident. Every casual factor is connected to its effects and in that way it illustrates how that factor affects other factors which have also contributed at the critical event. AcciMap incorporates the events and conditions in a graphical delineation that combined generate an organizational accident.

Since shipping is considered as a complex socio-technical system the AcciMap diagram is divided into six different levels described below. Starting from the top to the bottom:

1. Government policy and legislation
2. Regulatory bodies and associations
3. Company management
4. Technical and operational management involved
5. Accident flow of events and acts
6. Configuration of scenery and equipment

Depending on the industry and type of accident, each level can be modified accordingly to fit the analysis. The parts involved in the decision-making process are depicted in the levels 1 to 4, while level 5 include the flow events to the accident and level 6 demonstrates the environmental and equipment configurations. The main scope of AcciMap is to identify the relations of the causal factors between each level, allowing the investigator to have a vertical analysis for the connection of causal factors (Rasmussen & Svedung, 2000). At the accident flow of events, the critical event in the end, represents the “loss of control of accumulated energy” (Rasmussen & Svedung, 2000) as it is demonstrated in a cause consequent chart which is the base for predictive risk analysis. The buildup of a causal tree demonstrates the connection between critical event and consequent events as the flow is influenced by factors located in the upper levels and human errors (Rasmussen & Svedung, 2000). Figure 5 shows the involvement of various decision-making levels in the controlling of a hazardous process, in a complex sociotechnical system.

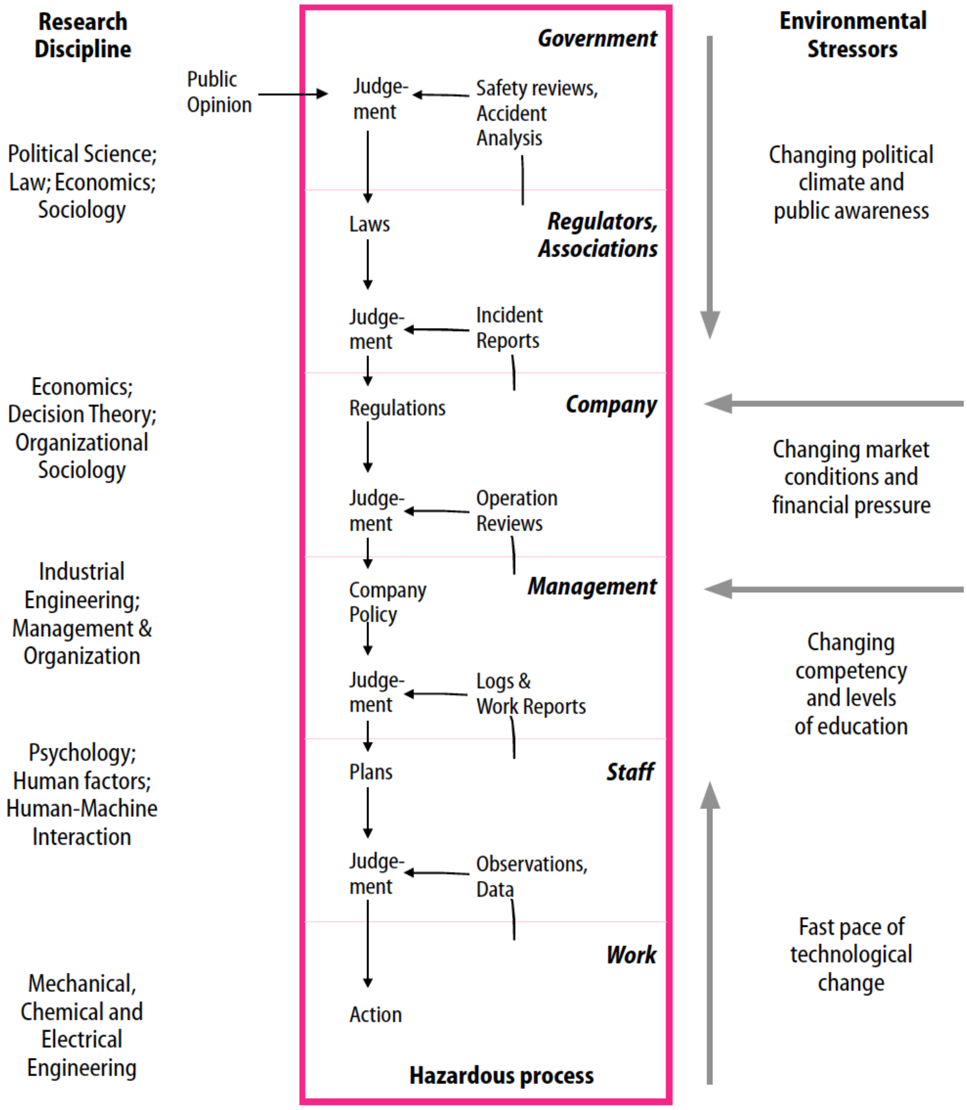

Figure 5. The Involved levels of decision making in risk management (Rasmussen, 1997, p.11)

AcciMap can be identified as a simplistic model since with the use of a single diagram containing causal factors and their connections, the reader can have the full picture of a complex system and its errors. Furthermore, the identification of gaps in the decision-making levels from their connection to the accident, assists legislation and policy makers to reconsider their strategies and adopt new standards. Although

AcciMap has a lot of potentials for accident analysis and investigations, has also limitations, which are summarized below.

AcciMap strengths:

- Based on the risk management theory, simple to use and understand.
- The causal diagram requires the consideration of all contributing factors on each level of the system as well as to identify the connections between them.
- The identification of errors on each level of the system provides a holistic view of the accident.
- Through the exhaustive analysis of the accident, the investigator have a clear accident etiology.
- AcciMap is focused on the system improvement (extracting safety recommendations) and not to blame the human element for errors.

AcciMap Limitations:

- The determination of the causal factors is based on the investigators' perception without a standardized method.
- The results can be relatively vague for the same reason mentioned above. Based on the analyst's focus, separately conducted AcciMaps on the same accident can illustrate different causal factors.
- The organizational system model lacks criteria for the determination of its adequacy.
- AcciMap's approach method for in-depth analysis of the physical factors and the system's parts is limited.
- After the completion of AcciMap a causal analysis in text format is required to provide explanations on the extracted results.

3.4.2 Swiss Cheese Model - SMC

It has been suggested by many safety analysts the use of a unified model that will incorporate the different human error models. The most well-established accident causation model came from James Reason in 1990 (Wiegmann & Shappell, 2003). The first use of SCM was for the aviation industry. Soon enough SCM was adopted in other industries proving its vast application ability for accident analysis. Notwithstanding SMC's wide acceptance, researchers have criticized the model's causation along with the fact that disregards the complex interactions of the system in the incident. (Dekker, 2014; Leveson, 2016, p 17; Erik, 2017). According to Hollnagel and Speziali (2008), the risk management and analysis of human complex systems set the ground for the development of the SMC.

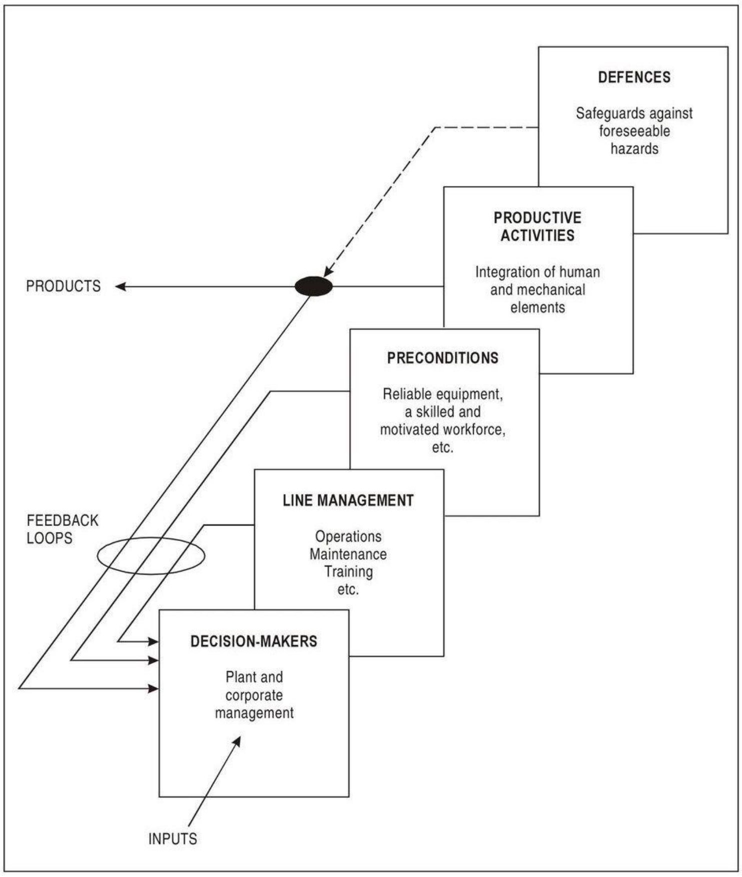

Figure 6. The basic components of a productive system (Reason, 1990, p.200)

Figure 6 demonstrates the fundamental components of any system and the resulting product is the scope of the organization; for example, in our case (CARNIVAL SPLENDOR) the transportation of passengers at sea. These parts are responsible for the decision-making process, determining the required targets that have to be achieved based on the feedback coming from outside of the system. For shipping, the Line Management is the shore-based company responsible for the fleet. Preconditions are the necessary elements in the system for achieving the desired results. A good Line Management must ensure that the required Preconditions are established. Preconditions does not only include the material availability but also the procedures required for the human element, like the training, guidance, crew's wellbeing, etc. The interaction of human and machinery generated the actual outcome of the system which is part of the Productive Activities. Every system is required to have barriers to prevent errors in the system, these are the Defenses which are found in any part of the system (Reason, 1997; Wiegmann & Shappell, 2003).

Despite the fact that barriers are in place, marine accidents still occur and will continue to occur (Ugurlu et al., 2013). Figure 7 provides a graphical representation of the SCM with the active and latent failures leading to the accident. Each hole represents the absence of barriers in the system and the alignment of all those is required for an accident to occur. According to Reason (1990) failures fall into two categories, the Latent and Active failures. Latent failures are contributing factors to the accident, resulted from conditions that were in the system undetected for a period of time. The Active failures are attributed to the sharp end in the system with immediate effect. That is the key difference between latent and active failures since the former will be activated after the alignment with other factors in the system and during an investigation may not detected. Accident is the failure of a system to prevent the alignment of active and Latent conditions by the absence of barriers allowing the hazard to cross every hole (gap) of the system (Hollangel & Speziali, 2008).

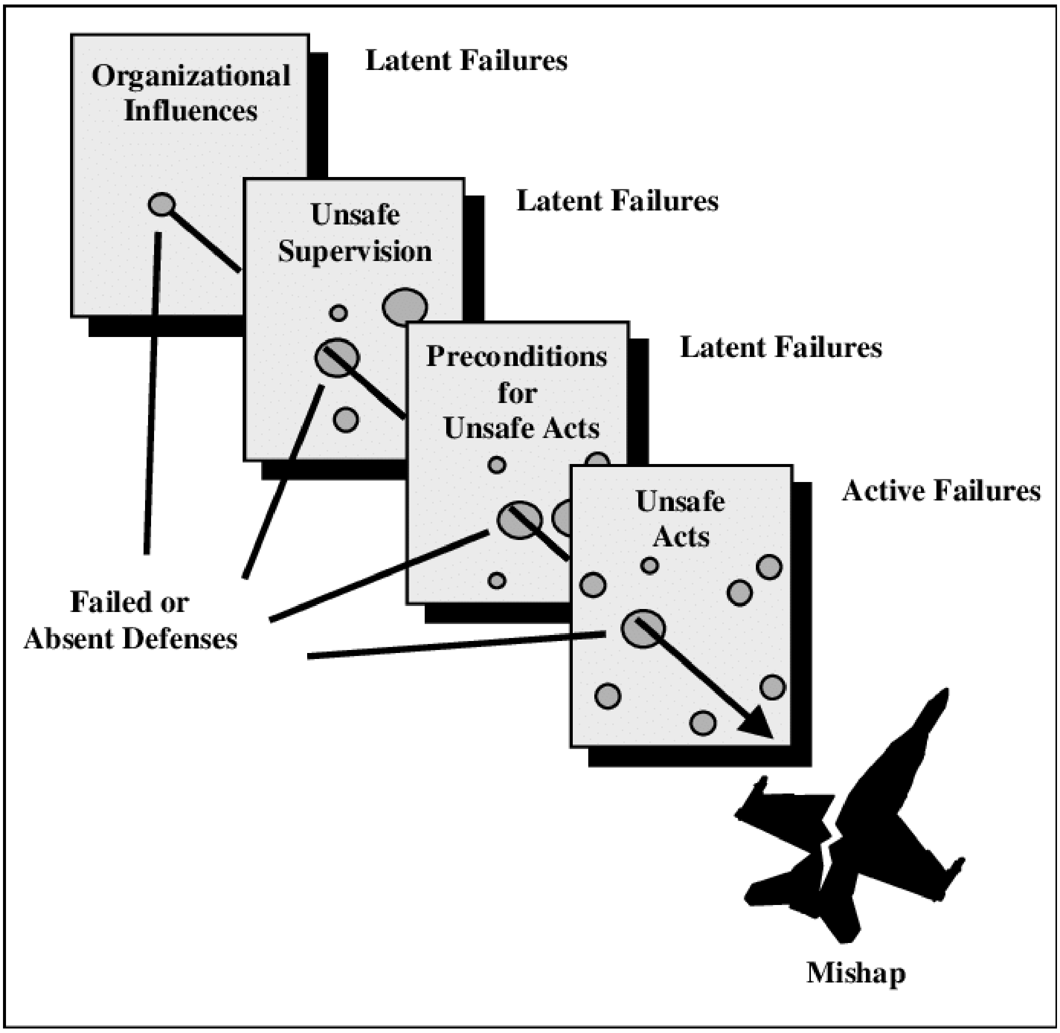

Figure 7. *Reason's (1990) SMC with active and latent failures. (Wiegmann & Shappell, 2003, p.47)*

3.4.3 HFACS

The HFACS model for the accident analysis categorizes each hole of the SCM (Wiegmann & Shappell 2003) resulting in a taxonomy of failures, divided in four levels. From the bottom to the top these four levels are: 1) Unsafe Acts, 2) Preconditions for unsafe acts, 3) Unsafe supervision and 4) Organizational influences. Since the system can have inputs beyond the organizational level the need for an additional level was needed and named 5) External factors. According to Reinach and Viale (2006) the new model firstly used in the railway industry while later on adopted by various other transportation and non-sectors (Celik & Cebi, 2009; Patterson & Shappel, 2010; Schröder-Hinrichs et al., 2011; Chen et al., 2013). As a hybrid model for accident analysis HFACS combines the SCM with the systemic approach and human factors analyzing the causal factors with the incorporation of latent and active failures (Ugurlu et al., 2020). As the provisions of CIC adopted in 2008, Chen et al., (2013) developed HFACS - Maritime Accidents as a modified version of the original HFACS in a way to align the provision of the code with a more suitable model for shipping. Reason's Generic Error Modelling System (GEMS) is integrated in the first level of the new HFACS hybrid model as a mean to define error from violation. Furthermore, Hawkins' SHEL model (Hawkins, 1987) incorporated in the second level of preconditions for unsafe acts, so the HFACS-MA model be fully compliant with the IMO's CIC provisions (Chen et al., 2013). The fifth level at the top of the taxonomy developed to include the governmental, policy and legislation gaps (Reinach & Viale, 2006).

3.5 Summary

To sum up the relevant accident analysis theories described in this chapter provide the necessary framework for accident investigations. Their reliability has been proven by the wide application on many domains of transportation and other industrialized sectors. The identification of human error at the sharp end level is prerequisite but the recent history showed that the investigations have to go beyond that and look for the organizational and governmental influences. The ability of the AcciMap model to identify causal factors beyond the administrational level is of great importance for this study since it can reveal factors that might be neglected from other models. Since the subject of this thesis is the maritime accidents the CIC's provisions are extensively considered and the use of HFACS verifies that is in line with IMO's recommendations. For the incident of CARNIVAL SPLENDOR, AcciMap and HFACS will be used and the extracted findings will be compared.

4. Research Results

This chapter is presenting the findings from the analysis of the CARNIVAL SPLENDOR incident. Firstly, the description of the incident with all the relevant information of vassel is provided followed by the general findings. The extracted results of the AcciMap and HFACS analysis are provided in detail respectively. The basic source for this case is from the investigation report of the USCG (USCG, 2013).

4.1 General details of the CARNIVAL SPLENDOR

The CARNIVAL SPLENDOR is a passenger cruise ship owned by the Carnival corporation and was built at the Italian shipyard of Fincantieri in Genoa. For construction phase Registro Italiano Navale (RINA) was the classification society performing the oversight and transferred to the Lloyd's Register (LR) upon the delivery in 2008.

The power plant installed is composed of six identical Wartsila 46 diesel engines configured into 2 Engine Rooms (E/R) that powers two propulsion motors. The vessel's particulars and the installed machinery specifications provided in Appendix 1 and 2 respectively.

The Panama Maritime Authority (PMA) was the responsible agency for conducting a maritime safety investigation as the FS of the vessel. USCG was also a substantially interested state having the responsibility to investigate this marine casualty. Both agencies after agreement decided that the USCG will be the leading marine safety investigation state. PMA upon the review of the investigation report have agreed with the conclusions and recommendations of the report.

4.2 The incident onboard CARNIVAL SPLENDOR

On November 8, 2010, the vessel suffered a mechanical failure in No5 Diesel Generator (DG) resulted in the ejection of lube oil and fuel from the engine casing that eventually ignited (pool fire). The vessel was underway with 3299 passengers onboard and crew of 1167. The DG No5 was at the aft E/R and the pool fire ignited the cables running overhead the DG and resulted in the generation of significant smoke that restricted the ability of the crew to locate and extinguish the fire. The Hi-Fog system activated with 15 minutes delay and by that time the fire at the cable runs was beyond the range of the system. The fire in combination with the excessive heat, caused extensive damage to the cables of the aft E/R and led to a complete loss of power. It took two hours to locate the fire in the cables above DG No5 by the Emergency Response Teams (ERT), while the attempts to extinguish it did not have satisfactory results. The excessive heat and the absence of cooling in the E/R allowed the fire at the cable runs to continue burning. After five hours of firefighting efforts, it was decided to activate the fixed CO_2 system for the aft E/R. Two attempts were made to activate the system, the first from the remote location activation point and then manually from the CO_2 room. None attempt was successful, the system was inoperative with the only release of CO_2 to be made inside the CO_2 room due to leaks from numerous fittings and hose connections. Seven hours after the ignition, the fire in the cable runs was extinguished due to the absence of oxygen in the room, resulting from the closure of the watertight doors and dumpers during the attempt to use the CO_2 system. Afterwards, the engineers of the vessel made several attempts to restart the unaffected DGs with no results since the damage to the cables in the E/R was extensive. The only available source of power the vessel had, was by the Emergency DG and the back-up battery system. At the day of the incident the vessel was located off the coast of Mexico and due to lack of propulsion it was towed to the port of San Diego in California which arrived on 11 of November. Likely there were no injuries or fatalities to the crew or the passengers. It is important to mention that on November 7, 2010 a day before the accident, the USCG conducted the annual control verification exam onboard the CARNIVAL SPLENDOR, no outstanding deficiencies found regarding the material condition of the vessel (USCG, 2013). A full-detailed timeline of the accident is available in Appendix 3.

4.3 General Findings

Soon before the start of the fire in the aft E/R the DG No5 experienced a torsional vibration alarm followed by a fail start alarm the next minute. The E/R was manned by three engineers who were on duty. In response to the alarm the Second Engineer on watch ordered the Second Engineer and the Cadet to investigate the D/G No5 failure, while the two latter immediately reported hearing an explosion and seeing black smoke at the Deck C of the E/R. In a short time, the E/R filled with smoke and flames observed near DG No5. Engineers on watch informed the Chief Engineer about the situation, initiated the emergency procedures for E/R fire and evacuated the space. The Hi-Fog system for local protection was not manually activated by the engineers before their evacuation. The follow up is a sequence of events consisting of wrong decisions in the sharp end as well as underlying causal factors on every level of the organizational structure.

The Engine Failure. The incident investigation revealed that the mechanical failure and explosion at the DG No5 occurred due to many contributing factors such as the design of components and the engineers' failure to identify the real cause of alarms that occurred prior to the incident. A hydrolock event was the main cause for the bend of the connecting rod in the DG No5 that went undetected causing a fatigue fracture to the components of the engine. The poor design of the air cooler system led to the deterioration of the system that contributed to the hydrolock event. Furthermore, the Carnival and Wartsila were fully aware about the issues of their cooler system and it was a common problem for the "Dream Class" vessels built at Fincantieri shipyard. Despite the fact that Carnival took steps to prevent and manage the air cooler issues onboard the vessel in July 2010, those steps were short term fixes requiring human interventions. The investigation showed that the necessary procedures to solve the problem were not routinely followed. The evidences show causal factors regarding the design of the system, the qualification capacity of the operators and at supervision from the company in regard to the following of the procedures. On top of that, Carnival decided to prolong the slow turn interval time of the DGs from 30 minutes to two hours despite the recommendation of Wartsila, that such action will increase the risk of not detecting a hydraulic lock at the DG. The decision was made as a cutting cost measure to reduce the space required for air bottles (starting system of the engine). The removal of a safety barrier necessary for preventing hydrolock was a causal factor of great significance and catastrophic result.

The Fire and the Hi-Fog Suppression System. The Hi-Fog system is acting as the first line of response, providing local protection of the covered area. The initial fire was the result of the fatigue fracture of DG No5 components and the ejection of fuel and oil from the engine casing. It was a pool fire that did not last very long and probably burned out on its own. The 15-minute delay for the activation of the Hi-Fog was a result of the combination of three factors. Firstly, the onboard installed Hi-Fog system was programmed with a 40-second time delay in the automatic activation sequence for the system. Secondly the engineers never activated the system manually, while they had initiated all the other emergency procedures for the E/R. Thirdly, the Bridge OOW performed a general reset on the fire detection system twice. The result of his action was the return of every smoke and fire detector to a normal status. Afterwards, the fire detectors above DGs No5 & No6 were in fault status since the flames destroyed them and the automatic activation was not available anymore for the area of DGs No5 & No6. If the system had been manually activated or the Bridge OOW never interacted with it, the loop fire would have been extinguished and most probably would not had ignited a second fire above the DG at the cable runs which was beyond the range of the Hi-Fog nozzle. It is obvious that the crew lacked situational awareness regarding the emergency procedures. Furthermore, the 40-second activation delay parameter, evidence that the system lacked effective barriers to ensure its uninterrupted operation and readiness.

The Firefighting Efforts. The firefighting efforts of the crew to extinguish the fire in the cable runs above DGs were ineffective for a variety of reasons including the non-implementation of the company’s SMS procedures. The quick response team’s lack of familiarity with E/R layout coupled with the use of inadequate extinguishing means resulted in time loss and allowed the fire to further spread. The temporary control of the fire combined with the lack of cooling at the cable conductors increased the heat which allowed the burning of the cables' insulation. The ineffective maintenance of smoke boundaries resulted in the spread of smoke to nearby areas of the E/R activating the fire and smoke detectors as well as the Hi-Fog system in unaffected spaces, making difficult to identify the exact location of the fire. Finally, the decision made by the Captain to ventilate the E/R before the fully extinguish of the fire and without the flow of water on the scene of fire allowed the fire to reflash. The above evidence shows that the crew lacked familiarity with the company procedures, the vessel's spaces and firefighting techniques. The factor of inadequate training was verified by the post casualty evidence regarding the performed drills onboard and the quality of the company's drill program. The duration of several drills was less than 30 minutes while the crew had not performed any fire drill in the E/R for the last six months. Furthermore, the Captain and the bridge team did not appear to take part in the performed drills. The absence of a system for the verification and qualification of the drilled program by the company was a catalytic contributing factor to the spread of the fire and the crew's incapacity to extinguish it. Additionally, during the annual control verification exam, the Port State Control Officers (PSCO) did not identify the actual crew competence regarding the emergency preparedness, indicating enforcement gaps into the system.

The Fixed CO_2 System. The installed CO_2 system was inoperative and ineffective to extinguish the fire. The evidence showed the system was affected by incorrect installations of equipment dated back to the building of the vessel. On the first annual service of the vessel's CO_2 system in 2009 the technicians discovered numerous issues in the system's equipment. A backward installed non-return valve and a plug obstructing the main discharge line were some of the many. Despite the company's actions to rectify the deficiencies on the vessel and ensure that "Destiny Class" sister vessels inspected for similar issues, the CO_2 system had more undetected problems. Another causal factor of the system's failure was the operational procedures for the release of the CO_2 approved by RINA (the classification society for the building phase). The instructions described the operational procedure in a reverse order, and were in contrast with the provisions of the 2006 resolution MSC.206(81) and the amendments of the Code for Fire Safety Systems, regarding the CO_2 systems using ball valves. Post casualty evidence revealed issues that should have been identified at the initial or the subsequent inspections of the vessel by the shipyard, the company, the FS and the RO. These causal factors reveal organizational influences, regulatory and policy gaps, enforcement gaps and company's negligence deriving from the top of the organizational hierarchy.

4.4 The AcciMap Analysis Results

Based on the methodology described in chapter 3.4.1 this section will provide an in-depth analysis for the case of the CARNIVAL SPLENDOR, divided into the six levels which include the different involved actors. An overview of the AcciMap analysis is illustrated in Figure 8. The identified contributing factors have grouped into frames of the same color coding respectively to each level.

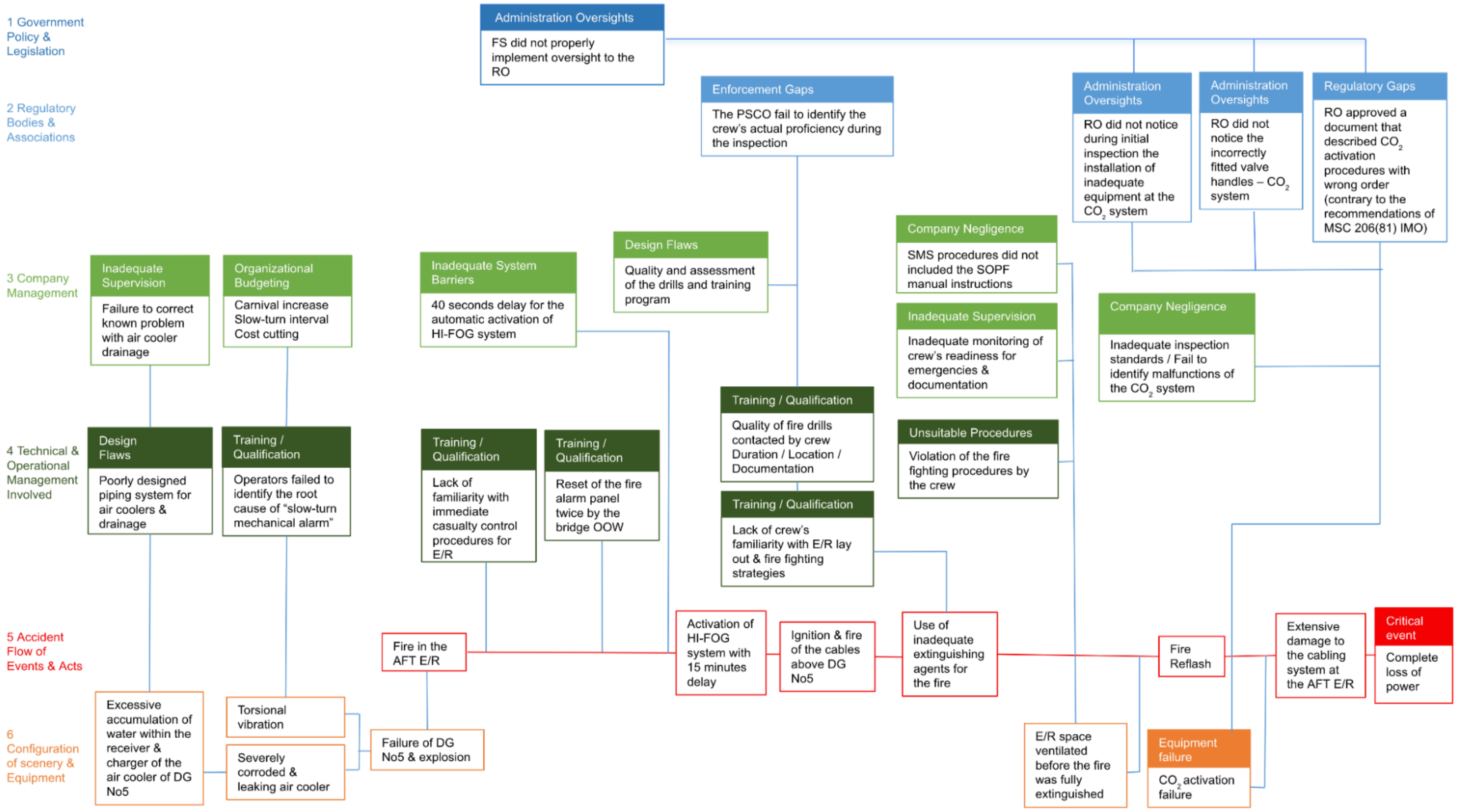

Figure 8. The AcciMap diagram for the CARNIVAL SPLENDOR

Accident Flow of Events and Acts. The accident onboard the CARNIVAL SPLENDOR is outlined from a series of events at the level five with chronological order, starting from the left towards the critical event at the right end. After the explosion at the DG No5 in the aft E/R (analysis regarding the equipment is provided at level 6), oil and fuel ignited creating a small pool fire between DGs No5 & No6. The automatic fire detection system was activated at 06:00 (local time) and the engineers on duty as well as the bridge OOW were aware of the situation. The area where the DGs were located was covered by the Hi-Fog system, acting as a first line of defense against fire but the system activated 15 minutes after the ignition of the fire, for the area of DG No5 & No6. Furthermore, the Hi-Fog system first started drenching water in areas of the E/R that were unaffected by the fire. The delay in activation of the Hi-Fog system resulted in the start of a second fire at the cable runs above DG No5, producing a significant amount of smoke while the initial fire most probably self-extinguished after consuming all the flammable materials (Fuel and lube oil). It took two hours for the ERT to locate and extinguish the fire at the cable runs, with the use of CO_2 and dry powder extinguishers which were not considered as most suitable means for the size of the fire. As a consequence, the fire reflashed and the extensive heat allowed the cable insulation and jacket material to continue to burn. All the attempts to control and extinguish the in the E/R made by the crew were insufficient and the fire self-extinguished due to the lack of oxygen when the watertight doors and dumpers were sealed for hours during the attempt to use the fixed CO_2 system. The damage to the cabling system of the E/R was irreparable resulting in the total loss of power for the vessel which was towed to the port of San Diego.

Configuration of Scenery and Equipment. This paragraph indicates the factors related to the equipment and is explained in parallel with the accident flow of events. The initial fire was the result of the explosion of the DG No5. According to the analysis the excessive accumulation of water in the air cooler of the engine was a known issue and the cause for the hydrolock in the engine (hydrolock is the event when water which is uncompressed, enters the combustion chamber of an engine reducing the travel distance of the piston and possibly damaging engine components). The severely corroded air cooled allowed the accumulation of rust at the drain valve not allowing the release of the excess water and giving the impression to the operators that it was empty. Despite the preventive measures the system has, a hydrolock event occurred in the past and created a fatigue fracture at the connecting rod resulting in torsional vibration and the explosion of the DG. The other factor of the scenery is the ventilation of the E/R space before the fire was fully extinguished. The order came from the Captain as a way to “clean” the E/R from the smoke which allowed the fire to reflash and lead to the decision for the use of the fixed CO_2 system which was totally inoperable.

Technical and Operational Management Involved. The first revealed factor is the design flaw regarding the piping system for the air coolers and the cause for the fatigue fracture at the components of the DG. Additionally, the engineers in the past wrongly identified what caused the “Slow turn mechanical failure alarm” revealing aspects regarding the qualification and capacity to perform their duties and the oversight they had from Carnival. The delay in the activation of the Hi-Fog system was a major contributing factor for the further development of the fire. Both operators' actions (engineers did not activate the system prior to evacuation and the reset of the fire alarm panel by Bridge OOW) show that they lacked proper training and qualification regarding the response in emergencies. The issue of the training and preparedness of the crew is supplemented from the prolonged time to detect the fire, the lack of familiarity with the E/R layout and the use of inadequate means to extinguish the fire at the cable runs. The response of the crew does not stand in vacuum since the investigation showed that the procedures regarding the drills were not followed at all. The decision to ventilate the E/R while the fire was not in control reflects the crew’s reduced capacity for contingencies and the unawareness of relevant firefighting strategies and procedures.

Company Management. In this level, the identified contributing factors revealed underlying causes related decision making that affected equipment and errors at the sharp end. The air cooler issue was known since 2009 and was common for the whole Dream class fleet, despite that Carnival did not take the appropriate measures to rectify the problem. Furthermore, the decision to increase the duration of the slow turn interval for the start of the DGs while knowing that this action may not prevent a hydrolock event shows that the management was focused on budgeting and lacked of a proactive approach that would have prevented the initial problem with the DG. The 40-second-delay parameter at the activation of the Hi-Fog system is another sign of poor hazard assessment and lack of preventing barriers. The instant activation of the Hi-Fog system would have extinguished the first fire and prevented the development of the second one at the cables, also the system would not have been affected by the human decisions at the sharp end. The crew's preparedness for emergencies reveals flaws in the design of the drills and training program established by the company, lack of supervision and gaps regarding the procedures for contingencies. The company in the past had developed a policy named "Standard Operating Procedures for Shipboard Firefighting" (SOPF) as additional guidance, but it was not integrated in the SMS of the company. Additionally, the absence of evidence that the procedures described in the SOPF had been followed during the drills, verifies the fact of poor supervision and quality of the training program. The fact that the company did not incorporate the SOPF procedures in the SMS was a reason to create confusion at the sharp end; Størkersen et al., (2017) have revealed many examples where issued documents form the company, the management decisions and the SMS are self-contradictory. Finally, the reasons why the CO_2 system was inoperative are leading to the company's lack of procedures regarding the inspection standards for the equipment. During the first annual service inspection of the system, the technicians revealed numerous deficiencies related to the equipment. Despite the actions of the company, deficiencies still remained undetected together with the CO_2 activation instructions which were in wrong order and identified at the post casualty investigation.

Regulatory Bodies and Associations. A day before the accident, the USCG had conducted an annual control verification exam onboard the vessel. According to the inspection, the vessel was fully compliant with the ISM requirements and the PSCO did not identify any shortcomings at the crew's capacity to deal with emergencies. However, the post casualty investigation showed the opposite and revealed gaps in the guidance on how to evaluate the fire drills conducted by the crew. The reduced capacity to recognize the actual preparedness of the crew for emergencies was a factor that contributed to the development of the incident. Administrational oversights factors are of major importance engaging the actions of the RO to the accident. At the delivery of the vessel the inspection conducted by the RO failed to detect the deficiencies related to the CO_2 system or the issue with the activating instructions which was in contrast with the Code for Fire Safety Systems. The use of the CO_2 in the E/R would have been the last line of defense but the RO's neglect to detect the issues and removed a significant safety barrier from the system resulting in adverse consequences.

Government Policy and Legislation. At the top of the hierarchy, it has been identified gaps regarding the oversight of the RO by the FS. The neglects made by the RO had a significant impact at the flow of events and deriving from the poorly implemented oversight from the FS.

4.4.1 Summary of AcciMap

The analysis of the identified causal factors with the AcciMap for the incident onboard the CARNIVAL SPLENDOR revealed errors in the sharp end, flaws in the design of equipment, lack of procedures and a profit-oriented managing company with limited concerns regarding safety and supervision. However, the factors with most significant importance were in level one and two. The gaps at the FS's administrational level connected to the RO's actions, which contributed to the development of the accident. The connection of the FS and the RO derive from the obligation the FS has, to properly oversee the action of the RO acting on its behalf. Gaps in the established policy by the FS to control the organizations acting on its behalf, combined with a low level of the governmental will to deal with aspects of maritime safety can contribute to the development of marine casualties. The FSP is an indicator of how well the MA manages to fulfil its obligations and is related to oversight of the ROs.

4.5 The HFACS-MA Analysis Results

In this section the indent onboard the CARNIVAL SPLENDOR is presented based on the HFACS as described in chapter 3.4.3. In Table 2, the identified causal factors are listed and coded respectively. With the use of HFACS-MA it was possible to identify 27 contributing factors related to the accident. There were numerous preconditions and organizational factors that contributed indirectly in the development of the accident that were lying below the actions of the sharp end.

Table 2. Inventory of HFACS causal factors for CARNIVAL SPLENDOR

Category	Description
TE	Complete loss of power for the CARNIVAL SPLENDOR
EV1	Bend of the connecting rod and fatigue fracture of the DG components
EV2	Torsional vibration of DG No5
EV3	Failure of DG No5 and explosion
EV4	Fire in the aft E/R
EV5	Activation of the Hi-Fog system with 15 minutes delay
EV6	Ignition and fire of the cable runs above DG No5
EV7	Fire reflashed
EV8	CO_2 System activation failure
EV9	Extensive damage to the cables at the aft E/R
A1	Engineers fail to identify the real cause of the “slow turn mechanical failure alarm”
A2	Engineers did not manually activate the Hi-Fog system prior the evacuation of the E/R
A3	The bridge OOW performed a general reset of the fire detection system twice
A4	Use of inadequate extinguishing means to control the fire on the cables
A5	E/R ventilated while the fire was not fully extinguished - Firefighting
A6	Poor maintenance of smoke boundaries - smoke spread to adjacent areas
A7	Delay of the ERT to locate and extinguish the fire
P1	Poorly designed piping system for the air coolers and drainage
P2	Excessive accumulation of water within the receiver and charger of the air cooler of DG No5
P3	Severely corroded and leaking air cooler
P4	Hydrolock
P5	Lack of crew familiarity with the E/R Layout and fire-fighting strategies
P6	Poor quality of the fire drills performed by the crew
P7	40-seconds delay for the automatic activation of the Hi-Fog system
P8	CO_2 activation instructions in wrong order
P9	CO_2 system leaks
S1	Short-term fixes - Carnival, Wartsila and Fincantieri were aware about the problems with the air coolers since 2009
S2	Inadequate means to monitor the crew's preparedness for emergencies and its documentation
S3	Carnival failed to identify the malfunctions of the CO_2 system on the delivery of the vessel and at the first annual inspection
O1	Over-voluminous SMS procedures / SOPF manual instructions were not included in the SMS
O2	Carnival increases the Slow-Turn interval from 30 minutes to 2 hours
O3	Quality and assessment of Company’s drills and training program
O4	Inadequate inspection standards and procedures regarding the equipment by the company
E1	FS, Negligence in performing its duties / Panama did not perform the appropriate oversight to the RO
E2	RO, Negligence in performing its duties / Fail to identify deficiencies at the installation of the CO_2 system
E3	RO, Negligence in performing its duties / Approved instructions for the activation of the CO_2 system, which were described in wrong order
E4	PSC, Insufficient guidance for evaluation / The PSC officers did not identify the crew’s actual proficiency regarding the preparedness for contingencies during the inspection

The Human and Organizational Factors (HOF) have been identified in accordance with HFACS-MA and are listed into their respective categories at Table 3.

Table 3. The demographics of the HOFs associated with the CARNIVAL SPLENDOR accident using HFACS-MA

HFACS-MA Category	Inventory	N (%)
External Factors		**4 (14,8%)**
Legislation Gaps	E4	1 (3,7%)
Administration Oversights	E1, E2, E3	3 (11,1%)
Design Flaws	-	0 (0%)
Organizational Influences		**4 (14,8%)**
Resource Management	O2	1 (3,7%)
Organizational Climate	O3	1 (3,7%)
Organizational Process	O1, O4	2 (7,4%)
Unsafe Supervision		**3 (11,1%)**
Inadequate Supervision	S2, S3	2 (7,4%)
Planned Inappropriate Operation	-	0 (0%)
Failure to correct Known Problem	S1	1 (3,7%)
Supervisory Violations	-	0 (0%)
Preconditions (SHEL)		**9 (33,3%)**
Condition of Operator(s)	P5	1 (3,7%)
Software	P1, P7, P8	3 (11,1%)
Hardware	P2, P3, P4, P9	4 (14,8%)
Physical Environment	-	0 (0%)
Technological Environment	-	0 (0%)
Liveware	P6	1 (3,7%)
Unsafe Acts		**7 (25,9%)**
Skill-Based errors	A2, A7	2 (7,4%)
Rule-Based mistakes	A1, A4	2 (7,4%)
Knowledge-Based mistakes	A3, A5, A6	3 (11,1%)
Routine Violations	-	0 (0%)
Exceptional Violations	-	0 (0%)

Note: The percentage numbers relate to all 27 identified causal factors.

HOFs have been identified on every level of the taxonomy, but not in every category. The unsafe acts (25.9%) coupled with the preconditions (33.3%) account for the majority of the contributing factors (59.2%) as active failures. Based on the results of the HFACS-MA it is obvious that the human element is the main contributing factor to the accident but the combined percentage of the contributing factors from levels one to three (40.7%) shows the significant influence these factors had to the accident. In Figure 9, a WBG illustrates the 27 identified contributing factors with their causal connection.

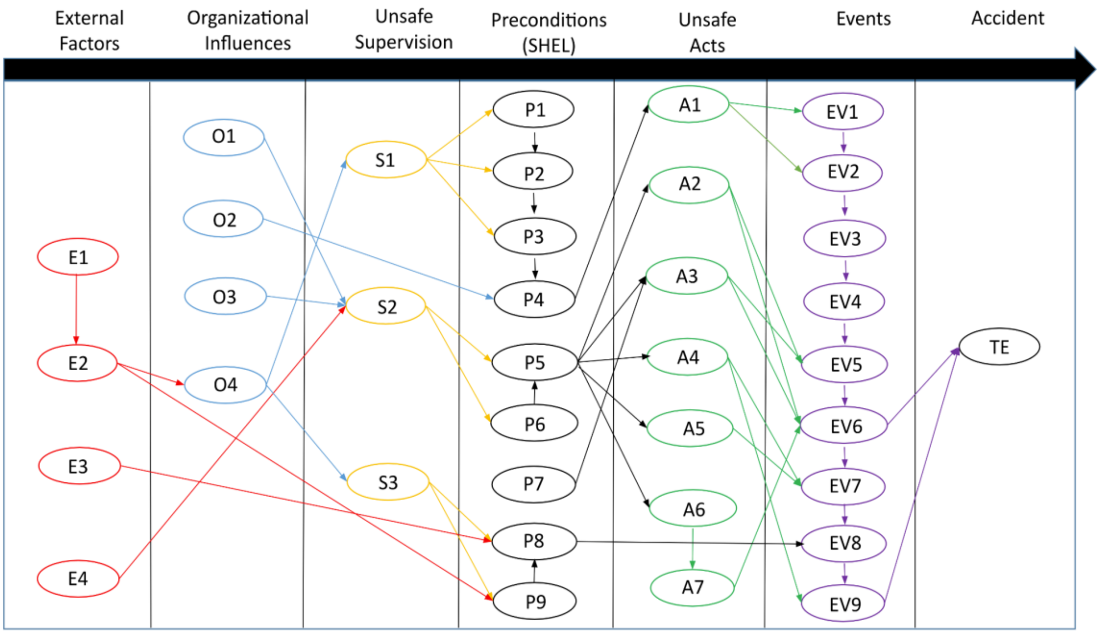

Figure 9. WBG for the CARNIVAL SPLENDOR

As it is obvious from the graph the nodes O2 (Increase of the slow turn interval for DGs) and O4 (inadequate inspection standards and procedures for the equipment) had significant influence on the underlying factors that directly or even indirectly triggered the line of events with DG failure and explosion.

The lack of familiarity of the crew regarding the E/R layout and firefighting procedures P5 was influenced by many factors starting with the O1 (SMS did not include the SOPF manual) connected to S2 (inadequate supervision from the company). The node of E4 (Evaluation capacity of USCG PSCO) to S2 is made since the scope of the inspection is to detect deficiencies to ensure safety onboard ships; the result of the inspection had indirectly affected the final event. The S2 was also influenced by O3 (the quality of the drills and training program) reflecting the safety culture of the company. Furthermore, the importance of the O1, O3 and S2 latent failures is evidenced from the connection of P5 with five active failures A2, A3, A4, A5 and A6.

The E3 node goes straight to the P8 (CO_2 activation instructions in wrong order) which is coupled with P9 and connected to EV8 the activation failure of the CO_2, the last line of defense against fire in the E/R. The EV6 is highly possible to have contributed to the top event significantly but the EV8 was the last barrier to prevent the further development. Additionally, the nodes E1 (FS oversight) to E2 (RO negligence) leading to P9 (CO_2 system Leaks) supplemented by O4 and S3 at the company's management level.

At the precondition level the P7 (40-second-delay for the automatic activation of the Hi-Fog system) node lacks connections with nodes on the higher levels. Despite the USCG recommendation to Carnival for removing this parameter from the fire detection system, the decision remains at the company's management. The time delay for the activation varies widely among the different manufactures and shipping companies. The regulatory bodies have to consider and assess the risks deriving from the existence of such parameters for the activation of the Hi-Fog systems.

4.5.1 Summary of HFACS-MA

The analysis of the accident with the use of HFACS-MA identified organizational influences and lack of supervision as the causal factors of the limited capacity of the crew to deal with emergencies (P5); furthermore, the same two factors are related to design flaws of the machinery equipment (P1). The most important connection is between the FS (E1) and the actions of the RO (E2) regarding the issues of the fixed CO_2 system. This connection reveals gaps for the oversight of the RO by the FS that have to be seriously considered and investigated further.

5. Discussion

In this chapter, the main research results are reviewed and discussed further in order to identify the answers to the research questions. Furthermore, the integration of the FS performance into the 5th layer of the HFACS as a possible contributing factor will also be discussed.

The results extracted from the AcciMap analysis revealed design flaws and interesting findings on the technical, operational and company management as well as on the regulatory bodies and the governmental level. On technical and operational management level, design flaws of the DG's equipment, poor familiarity with the available equipment and procedures as well as insufficient training of the crew coupled with limited risk awareness have been identified as the reasons for the errors at the sharp end. The crew is responsible for the operation and proper maintenance of the equipment onboard and for that reason is mandatory to have the right qualification to do so supplemented with the required supervision and support from the company. Apart from that, the insufficient training and the limited risk awareness were factors with significant contribution to the accident. It is Master's responsibility to ensure that the crew is adequately familiar with the emergency procedures, the equipment and be sufficiently trained for emergencies. In addition to that, it is also the company's responsibility to verify the crew's competence to deal with hazards onboard the ship, with a well-established system that will monitor the implementation of the mandatory procedures.

On the company management level, it has been identified poor decision making and risk management regarding the actions of the company to rectify a known problem which had led to the deterioration of the equipment and the fire in the E/R. Furthermore, organizational and budgeting factors had also contributed to that. Poor risk assessment was also identified in the firefighting systems since the activation delay parameter for the Hi-Fog system was a significant contributing factor for the development of the accident. Despite the over-voluminous SMS the company had, the procedures described in the SOPF manual were not part of the SMS which is a company's management negligence. The poor quality and assessment of the drills and training program combined with the inadequate supervision of the crew's performance at the drills were factors that have influenced the flawed actions of the crew during the firefighting efforts. The flaws at the CO_2 system are related to company management and further up in the hierarchy. The system's deficiencies could have been detected on the delivery of the vessel if the company had established an adequate inspection program in order to ensure that the CO_2 system is operational and the procedures are in compliance with the IMO standards.

On the regulatory bodies and associations level, the analysis revealed contributing factors to the accident, deriving from the RO and the inspection of the USCG. When the PSC conducts an inspection, it is necessary to verify that the safety standards are maintained and the provisions of the international regulations are fully implemented onboard the ships. During the annual examination conducted by the USCG, the lack of training should have been identified prior to the departure of the vessel. Although the actions of the PSCOs did not directly affect the flow of events, the analysis indicates that the existing guidelines for the evaluation of drills have to be revised. On the other hand, the actions of the RO had a direct impact on the activation failure of the CO_2 system. The RO did not detect at the final inspection of the vessel on the delivery, the numerous deficiencies related to the installed equipment. The analysis evidenced administrational oversights and inadequate inspection standards by the RO. Furthermore, the approval of incorrect activation instructions for the CO_2 system apart from the devastating consequences it had, was also in contrast with the provisions of the Code for Fire Safety Systems. The above evidence indicates the connection of the FS to the actions of the RO.

On the Government policy and legislation level, the analysis indicated oversight flaws for the RO by the FS. As the RO acts on behalf of the FS, the latter have to implement the adequate oversight on the RO and its actions. The post-casualty inspection revealed that the problems with the CO_2 system should have been detected by the initial or a subsequent inspection. It can be concluded that the FS should continuously monitor the ROs acting on its behalf to ensure that the vessels flying its flag are safe and seaworthy.

The extracted results from the HFACS-MA analysis, revealed organizational influences and lack of supervision related to the unsafe acts at the sharp coupled with flaws found on the safety equipment. The WBG provided an overview of the causal factors and their connections. Considering the SCM principle, the removal of holes from the cheese is interpreted as the removal of the connection link among the factors not allowing the accident to occur. It is argued that the human error is main causal factor to accidents, something that has been verified also in the case of CARNIVAL SPLENDOR but the most important finding of the analysis is that the external, the organizational influences and the unsafe supervision combined, accounts for the 40,7% of the contributing factors. Such a high percentage verifies the need for the accident investigations to look deeper for organizational influencing causes that are difficult to identify and may be neglected. Moreover, the use of HFACS-MA revealed factors at the top of the hierarchy related with gaps of administrational oversight.

Summing up, the use of AcciMap and HFACS-MA have identified similar causal factors for the accident of CARNIVAL SPLENDOR. Beyond the human factors, the most valuable result generated from both models was the connection of the FS and the RO's actions that have significantly contributed to the accident. The reasons for the issues the CO_2 system had was lying at the top level of the hierarchy, reflecting the quality of the established policies regarding maritime safety at the governmental level. Every FS has the responsibility to establish the appropriate measures to ensure the effective implementation of the IMO instruments to which they are a party (IMO, 2001). In resolution A.912(22), it is stated that every FS should take measures to ensure the safety at sea regarding the construction, equipment and management of ships, as well as the training of crews (IMO, 2001). These are few of the areas that have to be covered by the legal framework of the FS and relevant to the case of the CARNIVAL SPLENDOR since flaws and gaps have been identified in each of these areas. The delegation of the statutory responsibilities to ROs does not mean that the work of the FS is completed, in fact it continues with the implementation of a rigorous oversight to the organizations acting on its behalf. Furthermore, every RO has to be scrutinized and verified that complies with the specifications on conducting statutory surveys and certification (IMO, 1995).

A FS in order to have hi-performance is mandatory to adopt the necessary policies on how to implement the international regulations and define clear strategies for the MA on how to monitor the capacity of the ROs. A FS with poor oversight over the ROs will result in low FSP which might increase the possibilities for accidents on the fleet. The case of CARNIVAL SPLENDOR identified the FS's oversight gap as contributing factor for the accident and it can be identified as a factor of low FSP and possibly incorporated in the 5th layer of HFACS. Chen et al., (2013) with HFACS-MA incorporated 3 categories of factors, with the administrational oversight generally addressing a wide range of involved factors. It is the author's belief that the incorporation of the FS performance into the HFACS is needed to properly address the FS's oversight gaps.

6. Conclusion

Many marine investigations have shown that an accident is not a product of a single error. The occurrence of an accident requires the conjunction of several errors committed either at the sharp end or at the decision-making level of the organization; and as this study showed could be even higher. The human element is undoubtedly a crucial factor related to marine accidents and the HOFs still require further research to fully understand. The accident investigation is a key element to identify and analyze casualty factors. Furthermore, it creates the framework for the development of new safety regulations that will prevent accidents. Many accident investigation models are focusing on the identification of human errors as the causal factors without searching deeper.

Shipping is considered as a heavily regulated industry with significant increase of the applied regulations in the last decades. The fundamental basis for those regulations to work is the establishment of a harmonized national regulatory framework that has to be based on the obligations of the international maritime conventions (Kristiansen, 2008). UNCLOS has set the fundamental provisions for the investigation of casualties but it is related to accidents occurred on the high seas. It is also an obligation for the FS to conduct casualty investigations on the ships flying its flag; however, the establishment of a safe shipping is on the will of each government. The adopted policies combined the available national legislation are crucial for the quality of accident investigations and directly connected to the FSP. Policy and legislation gaps found on the governmental level will have significant impact on the causation of marine accidents since the organizational and human factors lying below the top level are directly affected. The regulatory framework available is setting the obligations but the development of methods to further analyze accidents at sea is needed for the identification of the underlying gaps in the top level of hierarchy.

The case of the CARNIVAL SPLENDOR which was analyzed with AcciMap and HFACS-MA demonstrated how a poorly implemented oversight to the RO by the FS, contributed to the accident. Moreover, it indicates that every casualty investigation has to look beyond the human errors and identify underlying causal factors in the company management, administration and even at government level. The FS has the obligation to ensure the safety at sea on the ships entitled to fly its flag through the adopted policies and strategies regarding maritime safety. Since the statutory work of the FS is conducted by the delegation of authority to the ROs, a well-structured overseeing system is mandatory for the FS to ensure the provisions of international maritime conventions are well implemented onboard the fleet. The incorporation of the FS performance into the HFACS taxonomy has a binary scope. The first is to contribute to the marine casualty investigations since the category of low FSP will identify factors related with the oversight of the ROs and reveal gaps on the adopted policies of the FS. Second to assist FSs and their MAs to improve and further develop their adopted policies and strategies regarding the monitoring of the ROs.

This thesis investigated a single accident and looked deep for causal factors lying at the top levels of the hierarchy as well as for their connection on every level. It is suggested that further research is needed for the adoption of the FS performance into the HFACS. Research that will investigate a bigger sample of accidents combined with the evaluation of national adopted maritime policies is considered to be extremely beneficial for the maritime community and accident prevention.

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Appendices

Appendix 1 – Vessel Particulars (USCG, 2013)

Category	Details
Owner	Carnival Corporation
Flag	Panama
Hull Number	6135
Call Sign	3EUS
Classification Society	Lloyd's Register
Lloyd's Register Number	9333163
IMO Number	IMO 9333163
Gross Registered Tonnage	113,300
Net Registered Tonnage	85,850
Deadweight Tonnage	99.5
Number of Decks	17
Total Lifesaving Capacity	4,914
Maximum Guests	3,734
Maximum Crew	1,180
Length Overall	290.2 meters
Length P-P (Perpendiculars)	247.7 meters
Beam at Waterline	35.5 meters
Beam at Bridge Wings	41.6 meters

NOTE: The Information of the Appendix 1 are cited exactly as in the USCG investigation report.

Appendix 2 – Vessel's Machinery Data (USCG, 2013)

Machinery Equipment	Specifications
Diesel Engines	6 x 12 cylinder, Wartsila 46C 1050 kW/cylinder
Total Installed Power	75.6 MW
Generators	6 x 14,000 Kva 3 Phase AC; 60 Hz; 11,000 volt
Emergency Generators	1500 kW Isotta Fraschini-Marelli
Propulsion Motors	2 X 21 MW 146 rpm; 2830 volts, reversible
Automation System	Valmarine, APSS Damatic XD
Switchboard	M.V. Imesa L.V. Schneider
Fire/Smoke Detection System	Autronica – Norway
CO_2 Extinguishing System	Wormald
Water Mist/Sprinkler System	Marioff Hi-Fog® Fire Protection System Marioff-Finland

NOTE: The Information of the Appendix 1 are cited exactly as in the USCG investigation report.

Appendix 3 – CARNIVAL SPLENDOR – Timeline of the Accident (USCG, 2013)

Subj: INVESTIGATION INTO THE FIRE ONBOARD THE CRUISE SHIP CARNIVAL SPLENDOR ON NOVEMBER 8, 2010 — 16732, 24 JUN 2013

5. Timeline of Events
(ALL Times are Pacific Standard Time using a 24-hour clock unless otherwise noted)

Planned Itinerary for Cruise Commencing November 7, 2010

Sunday	November 7, 2010	Long Beach, California
Monday	November 8, 2010	At Sea
Tuesday	November 9, 2010	At Sea
Wednesday	November 10, 2010	Puerto Vallarta, Mexico
Thursday	November 11, 2010	Mazatlan, Mexico
Friday	November 12, 2010	Cabo San Lucas, Mexico
Saturday	November 13, 2010	At Sea
Sunday	November 14, 2010	Long Beach, California

November 7, 2010 - Passenger Changeover and Pre-departure Activity

At 0712, the Carnival Splendor tied up to its berth in the port of Los Angeles / Long Beach, California. The vessel had returned from a recent trip to the Mexican Rivera and was preparing for another seven day trip by disembarking passengers, taking on consumables, food supplies and fuel, and embarking new passengers.

In addition to embarking passengers, U.S. Coast Guard inspectors boarded the Carnival Splendor to perform a Port State Control Cruise Ship Examination. This exam focused primarily on various safety equipment and procedures, and included observation of fire fighting and emergency drills, and rescue boat and lifeboat evolutions as well as a thorough check of all the vessel's statutory certificates and documentation.

At 1700, a passenger muster drill and safety briefing was conducted. At 1735, the ship was unmoored and transited out of the harbor, letting go of the Harbor Pilot at 1803. The vessel began its first leg of the seven day cruise with all systems operating as normal. The vessel departed port with 3,299 passengers and a crew of 1167.

November 8, 2010 – At Sea

On the morning of November 8, 2010, the Carnival Splendor was underway in the Pacific Ocean approximately 150 nautical miles South of San Diego in approximate position 30-09.76 N, 116-45.65 W. The vessel was on a heading of 158.6 degrees making approximately 20 knots, en route to Puerto Vallarta, Mexico.

At 0551, the Second Engineer, Third Engineer and an Engine Cadet were on watch in the engine room. The Second Engineer was in the Engine Control Room (ECR). The Third Engineer and Engine Cadet were on roaming watch in the engine room. Diesel Generators 2, 3, 5 and 6 were online and equally loaded providing power to the propulsion motors and for ship service power. The engine room ventilation dampers and watertight doors for the aft engine room were open in accordance with company policy.

Subj: INVESTIGATION INTO THE FIRE ONBOARD THE CRUISE SHIP CARNIVAL SPLENDOR ON NOVEMBER 8, 2010 — 16732, 24 JUN 2013

Event – Catastrophic Failure of Diesel Generator 5

At 0558, Diesel Generator 5 (DG 5) experienced a torsional vibration alarm.

At 0559, DG 5 experienced a fail start alarm. In response to the alarms, the Second Engineer on watch sent the Third Engineer and the Engine Cadet to investigate. As they made their way to the lower engine room on Deck C, the Third Engineer and Cadet reported hearing an explosion followed by the rapid development of black smoke. The Third Engineer and Cadet retreated to the ECR which began to fill with smoke. The second engineer simultaneously trained his CCTV camera in the area above DG 5 and momentarily noted flames before his camera view was obscured by smoke. Shortly after the ECR filled with smoke, the engineers on watch evacuated the ECR.

At 0600, Second Engineer shut down DG 5 and 6 and notified the Chief Engineer of the situation in the engine room. The engineers on watch initiated emergency procedures for an engine room fire, which included shut down of the machinery space ventilation system, and closure of the engine room dampers, fire screen doors, watertight doors and quick-closing fuel valves. The Hi-Fog system was not manually activated by the engine room watchstanders.

Event – Fire in Aft Engine Room

At 0600, the automatic fire detection system in the aft engine room was activated and numerous visual and audible alarms were activated on the bridge Emergency Management System (EMS) panel. In addition, the engineers on watch phoned the bridge to notify them of the situation in the engine room.

At 0601, the deck officer announced, "There is a fire, is a fire" to the personnel on the bridge and then initiated the crew response. Then, via the Public Address system, the deck officer ordered the Alpha Team to proceed to the diesel generator aft.

At 0601, two fire/smoke detectors above DG5 and DG6 were activated. Within seconds of activation of these detectors, a bridge watch officer performed a general reset of the fire detection system. As a result of this action, all fire/smoke detectors returned to a normal status.

By 0603, the fire and smoke detectors above DG5 and DG6 were in a fault status. As a result, the Hi-Fog system for local protection was not automatically triggered by the fire detection system.

At 0604, the Captain arrived on the bridge and took command of the firefighting efforts.

Event – Activation of the Hi-Fog system

At 0604, the Hi-Fog system for local protection is activated in the Fuel Oil Purifier room (Deck C, Fire Zone 4).

[This was the first area where the Hi-Fog system was activated. The Hi-Fog system was subsequently activated in other machinery spaces as recorded in the EMS log. However, activation of the Hi-Fog system in the vicinity of the DG5 and DG6 did not occur until 0615.]

At 0606, the Quick Response Team (QRT) arrived in the staging area followed shortly afterward by Fire Teams Alpha, Bravo and Charlie. The staging area for all fire teams was at the Deck 0 engine room entrance.

At 0609, the QRT entered the engine room to assess the situation.

[The following timeline entries have been abbreviated and only denote the significant events or actions in the firefighting effort. From 0609 to 1054, all of the Fire Teams were rotated in succession to assess the situation and extinguish the fire. The coordination of Fire Teams is best captured in the Captain's Firefighting Timeline as well as the Voyage Data Recorder transcript.]

Event - Loss of Primary Power

At 0610, DG3 and DG6 tripped offline and the vessel lost all sources of primary electrical power. Shortly thereafter, the Emergency Diesel Generator (EDG) automatically started.

Event - Loss of Emergency Power

At 0611, the EDG stopped running. As a result, the ship's battery system kept critical safety systems online, such as the emergency lighting system.

At 0611, the Hi-Fog system pumps experienced a fault condition. As a result, Hi-Fog system pressure was maintained by the back-up nitrogen cylinders.

At 0614, the Cruise Director informed the passengers of the situation via the Public Address system.

At 0615, the Hi-fog system for local protection was automatically activated in the vicinity of DG5 and DG6. As a result, the machinery section valves for the aft engine room were opened and water mist was supplied by the Hi-fog nozzles above DG5 and DG6.

At 0625, the Cruise Director ordered all crewmembers to their general emergency stations, and ordered all passengers to the open decks.

At 0631, the general emergency alarm was activated.

At 0636, power from the EDG was restored. As a result, the Hi-Fog system pumps came back online.

At 0806, Fire Team Charlie entered the engine room accompanied by the Staff Chief Engineer and the Second Engineer.

Appendix 3 – CARNIVAL SPLENDOR – Timeline of the Accident (continue)

At 0821, Fire Team Charlie located the fire above DG 5. The team observed that electrical cables were burning, and observed no oil or additional combustible materials.

At 0830, the Captain ordered the fire teams to use portable dry powder and CO2 extinguishers on the fire.

At 0851, QRT and Staff Chief Engineer extinguished the fire above D/G 5 with the portable dry powder and CO2 extinguishers.

At 0905, Captain ordered staff to activate ventilation and to open doors to aft engine room to remove smoke from the space.

At 0947, Staff Captain reported that the fire above DG 5 re-flashed and that the aft engine room was filled with smoke. QRT extinguished fire with portable extinguishers.

At 1015, Fire Team Charlie reported the fire above DG 5 re-flashed. Fire Team Charlie extinguished with portable extinguishers.

At 1021, the Captain ordered staff to close all shell doors and engine hatch cover.

At 1054, the Chief Engineer reported that there was a fire on DG 5.

At 1054, the Captain decided to activate the CO2 system in the aft engine room. Prior to releasing the CO2, the Captain requested the Chief Engineer verify that the engine room dampers were closed and the space was evacuated.

At 1103, watertight doors 7 (forward door to the aft engine room) and 8 (aft door to the aft engine room) are closed.

At 1104, the hard switch dampers and ventilation closure stops for Fire Zone 2 (the aft engine room) are activated. Activation was unsuccessful due to several elements being in fault condition. All fire teams are evacuated from the engine room and ordered to staging area.

Event – Remote Activation of CO2 System Failed

At 1113, the Captain ordered the Chief Engineer to release CO2 into the aft engine room. The Chief Engineer attempted to release the CO2 by using the remote station on deck zero located outside the ECR. The CO2 activation was unsuccessful.

Event – Loss of Emergency Power

At 1126, the EDG stopped running.

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Event – Activation of CO2 System Failed

At 1146, the Captain ordered activation of the CO2 system from the back-up local controls in the CO2 room on the 11th deck port side. The Staff Captain and Staff Chief Engineer used the master panel to activate the valve to Section A for the aft engine room. The pilot manifold filled up and provided an indication alarm, but the start and discharge sequence failed. Upon entry into the CO2 room, the crew observed the valve on the pilot cylinder leaking and the valve for Section A remained closed. The crew also observed numerous gas leaks from the flexible connectors between the CO2 cylinders and the manifold. The crew switched the system to the other pilot valve and attempted to activate the system manually by opening the manifold valves at the heads. Upon opening of the manifold valves, the crew observed gas leaking from multiple fittings in CO2 system. Closer inspection revealed that the arm of the gas activated piston that admits CO2 to the aft engine room (Section A) fell off. The officers attempted to use a wrench on the valve stem and were unable to open it. The gauge on the system above the valve indicated 50 bars of pressure. No CO_2 was released except incidentally into the CO_2 room due to leaks at fittings, hoses, and connections.

At 1215, power from the EDG restored.

Event - Fire above DG5 and DG6 Extinguished

At 1315, the Staff Chief Engineer entered the engine room. He observed smoke in the engine room, but no fire. He reported the temperature in the engine room was 165°F.

At 1358, the Staff Captain reported that there was no fire on DG 5 and that the engine room temperature was decreasing.

At 1431, the crew installed a fan to supply cold air to the engine room, which in turn dropped the temperature in the aft engine room to 74°F.

At 1511, the crew extinguished a small fire in the cabling above DG 4. Fire patrols were set up to monitor the aft engine room throughout the night.

Action – Vessel Towed to Port

Following the fire, ship's crew was unable to restart the diesel generators. As a result, the vessel had no power for the propulsion motors and the vessel was towed to the port of San Diego, California. During the transit, the EDG provided power for emergency services.

No passengers or crew were injured as a result of the engine failure and subsequent fire.