Analysis of accidents and maritime safety

Manuel Luís Canelas Viana de Lemos

Universidade de Lisboa, Instituto Superior Técnico,
Av. Rovisco Pais, 1049-001 Lisboa, Portugal

ABSTRACT: The objective of this dissertation is to study and understand the theoretical foundations of current maritime safety and its analysis methodology. Technical, human and socio-technological aspects are addressed with different views developed in the last decades. The evolution of maritime accidents is presented from a statistical analysis of accident databases, prepared by various public and private entities, in order to better understand the complexity of the theme. A sample of one hundred “very serious accidents” occurred in 2017 reported by IMO is also analysed in order to substantiate numerically the incidence of major accidents by ship size. Some maritime casualties (stranding and collisions) reported by different entities are analysed and coded using the CASMET methodology, which focuses on the contribution of human and organizational factors to the accidents. The barrier analysis methodology and its importance for preventing accidents or mitigating their consequences is presented and an example of barriers that worked in an accident report is presented. Finally, the concept of "Safety II" as a solution to solve problems that "classic" “Safety” does not solve is introduced. In particular, many of the problems that the traditional Safety studies face and the “Safety II” approach to these problems are presented and discussed.

Keywords: accident analysis, accident analysis methodology, human and organizational factors, safety barriers, Safety II.

1. INTRODUCTION

Maritime safety is a very important economical theme because it moves large sums especially when there are accidents. This work aim is to study and understand the theoretical foundations of current maritime safety and its methodology and analysis. Technical, human and socio-technological aspects are approached with different views developed in the last decades.

Marine structures and equipment are regulated by safety requirements and the organization of the sector reflects existing legislation. Its technical framework is further regulated by the SOLAS (Safety of Life at Sea) convention. In the human and organizational factor, International Safety Management (ISM) code is one of the most important codes. This International Maritime Organization (IMO) legislation is ratified by Portugal, all EU countries and almost all countries in the world. IMO has several more specific safety-related conventions and legislation, such as MARPOL (International Convention for the Prevention of Pollution from Ships) and STCW (Standards of Training, Certification and Watchkeeping for Seafarers) to highlight among many more. For maritime accidents such as collisions and grounding, one of the most important regulations is the IMO’s COLREG (International Regulations for Preventing Collisions at Sea).

The number of accidents per number of ships, are not decreasing, or if they are, it is not proportional to the legislative and technological effort made. In terms of accidents / tonne x mile transported, accidents are decreasing because the world maritime trade is increasing.

Accident analysis has traditionally focused on the study of “very serious accidents” due to their impact on activity and consequences for maritime regulation.

The analysis of maritime accidents is crucial for evaluating the risk and to identify the main causes, contributions and organizational factors that eventually result in the accidents (Guedes Soares et al., 2000).

In the last decades, several methodologies for analysis and investigation of marine accidents have been developed, such as the CASMET methodology that focuses on human behaviour (Kristiansen et al. 1999). This methodology allows analyzing the accident report, detecting faults and omissions.

Safety is at deadlocked, that justify the need for a new approach (Hollnagel & Leonhardt et al., 2013). Accidents are decreasing (in the last decade they have declined slightly due to technological improvements and regulations), but not as desirable. Occasionally, there are new accidents due to progress resulting from unforeseen side effects in the evolution of the maritime industry.

A number of approaches have been developed in recent years to improve the safety of systems such as the concept of barriers and the latest SAFETY II approach, for their importance in current and future safety.

Resilience is the ability to balance a system in a changing and evolving environment (Holling et al., 1973). It aims to achieve goals by acting on performance under changing conditions, anticipating events and improving results. It is based on 4 principles: describe, respond, anticipate and learn. It emphasizes performance adaptation, operations under normal conditions and good daily performance (Hollnagel et al., 2006). It studies the variability of human behaviour, which allows good results, in environments in constant change and evolution.

Hollnagel et al., (2013) defines safety concepts I and II. These are different approaches to the concept of safety. Safety I is currently the most widely practiced and has been successful in quantifying risks and presenting solutions, but for more complex activities that are constantly evolving, it does not respond satisfactorily to events. Safety II aims to complete and improve it.

2. MARITIME ACCIDENTS

There is a wide range of accident types. The types of accidents that may occur include collision, fire and explosion, capsizing, grounding, work acc., flooding, MOB (man over board), among others.

To study the ships accident evolution, beware that values presented in databases, in the last 3 years are incomplete due to the delay in processing more complex information.

The accident classification is divided into four levels: "very serious casualties" are accidents involving the total loss of the vessel or life or severe pollution, "serious casualties" are accidents that are not qualified as "very serious casualties" but involving fire, explosion, collision, grounding, contact, damage due to bad weather, leak or suspected defect in the hull, structural damage that prevent the ship to navigate, pollution, (IMO, 1997). Additionally, accidents can be classified as “Less serious casualties", "marine accidents", incidents, for which reporting is not mandatory.

In 2017, very serious accidents, on specific ships are identified. They are studied from the information provided by IMO (till Sep. 2018) in the GISIS database. Vessels are divided into 4 classes: Small (GT< 500 tons), small / medium (500 <GT< 10 000 tons), medium / large (10 000 <GT< 50 000 tons) and large ships (50 000 tons< GT), and for each class in subclasses: type of accident, type of ship, area of accident..

2.1 Small ships (GT< 500 tons)

Figure 1 shows that ¾ of the accidents are with fishing vessels (Fig.1). The main accident is collision (Fig. 2), all with larger ships.

The sample has 28 accidents (30% of the studied), resulting in 62 human losses (dead and missing), resulting in an average of more than 2 human losses per accident (more than double than other accidents). The huge human importance of accidents in small ships should be corrected.

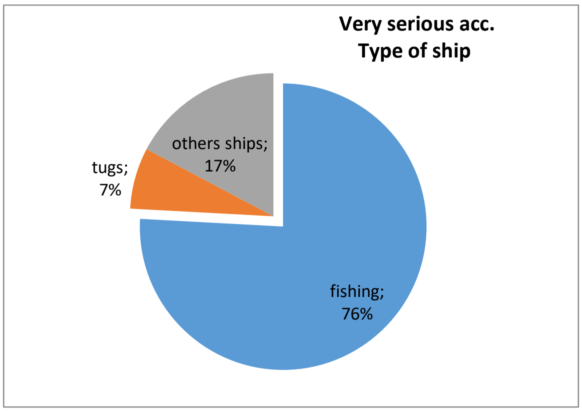

Figure 1 – Fleet accidents distribution.

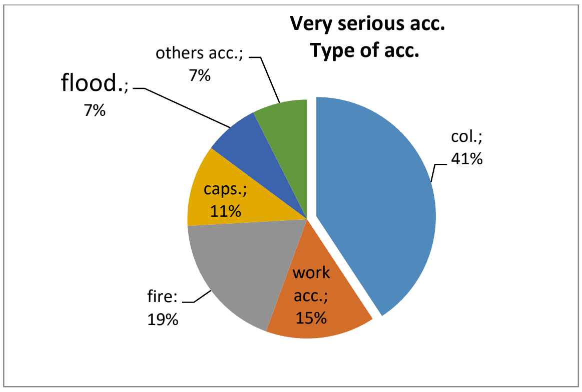

Figure 2 – Accidents type distribution.

2.2 Small / medium ships (500<GT<10,000 tons)

The sample has 29 accidents (30% of the studied), resulting in 32 human losses and 18 ships lost. Collisions (5/6 with small ships) and stranding are almost half of the accidents (Fig.3).

In short, sea vessels up to 3 000 G.T. (8/13 are accidents, connected with bridge performance. The safe manning certificate, for those ships, requires only 2 bridge officers (one is the Master and the other is the Mate) in almost all flags, they do 12 hours watch each, plus river manoeuvres, administrative operations and cargo for both, with little or no time left to rest. They call several ports a week or even more than one port per day. On land, when the shifts change, the ship reacts as the working time goes on, without rest. How can STCW be respected? Only on paper.

In the area of the accident it is found that almost all are in port or at coastal waters (<12 ') (86%, Fig.4), when these ships are more than half time at sea.

Comparing type of vessels with accidents with a sample of the operational ships (Figs. 4 & 5), we can say that there are fewer accidents in tankers than general cargo ships, due to better safety regulations of the first.

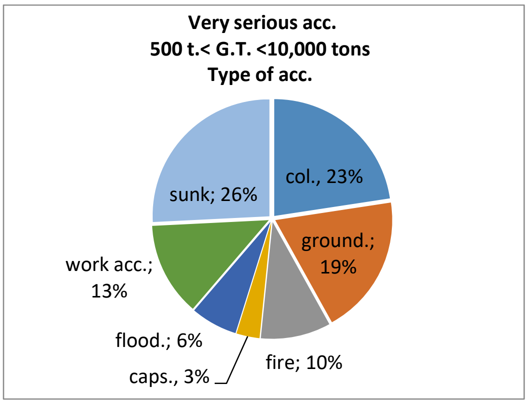

Figure 3 - Accident type distribution.

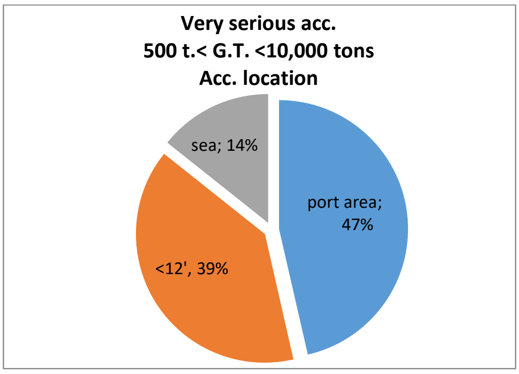

Figure 4 – Location of accident.

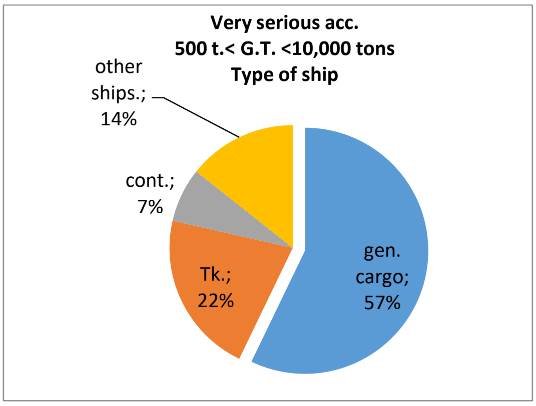

Figure 5 – Vessel's type in acc.

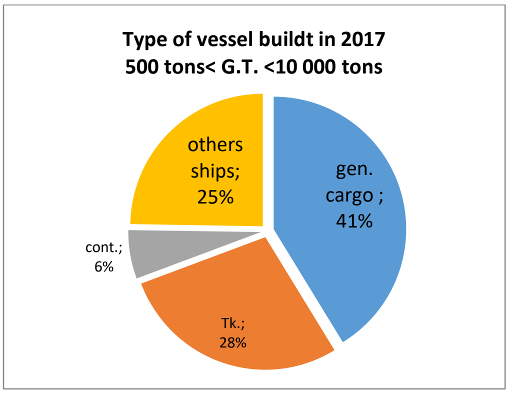

Figure 6 – Type of vessels operating.

2.3 Medium/large ships (10,000<GT<50,000 tons)

The sample has 31 accidents, resulting in 18 human losses and 4 ships lost. The collisions are mainly with small ships (2/3). Work accidents gain relevance (Fig. 7) in relation to smaller boats (Fig.3 & 2), as the machinery and spaces are larger (and more powerful. The 2 deaths from cargo accidents are with stevedores, crew deaths from fall in the hold are work accidents.

The fatal (and missing) waterfalls begin to matter, they are 4 and some may not be accidental. Long voyages on large ships, allied with brief stays at a "port" away from lead to isolation of the crews from months of considerable psychic disturbance. There were no MOB's in the container ships, which are faster ships.

Ships of this size spend most of her time at sea. The number of accidents is mainly near land (55%), this area is still the most dangerous, especially the territorial waters (<12 ') with a high number of accidents in just a few hours of crossing per month (Fig.8).

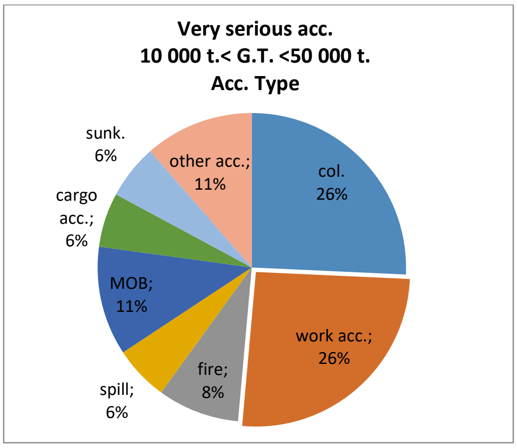

Figure 7 - Accident type distribution.

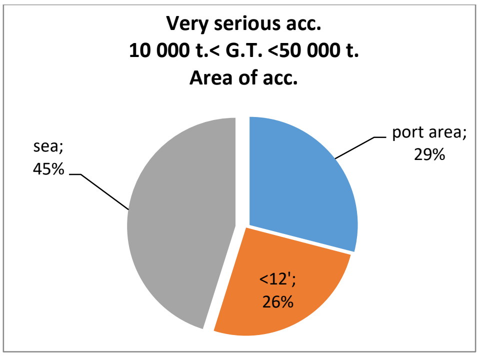

Figure 8 - Location of accident.

2.4 Large ships (GT> 50,000 tons)

The sample has 12 accidents, resulting in 12 human losses and none ships lost. These ships move cargo between continents (except for cruise ships).

The main accidents are at work (Fig.9) due to the size of the equipment concerned. The MOBs are increasing in relation to the previous class (Figs. 9 & 7). The problem of crew isolation is increasing in this class.

Regarding the location of accidents, the high number is in port stands out (Fig.10). One reason has already been mentioned: the large size of industrial installations.

It is noteworthy that there are a "balanced" number of accidents in coastal waters (only sailing a few hours a month in these waters). These ships have to slow down in advance (about 12 ') before reaching port. The slow approach speed will be one of the reasons for no more accidents.

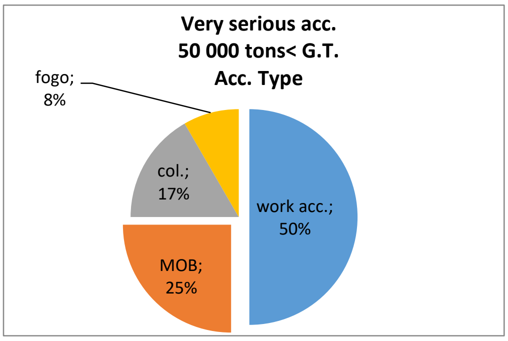

Figure 9 - Accident type distribution.

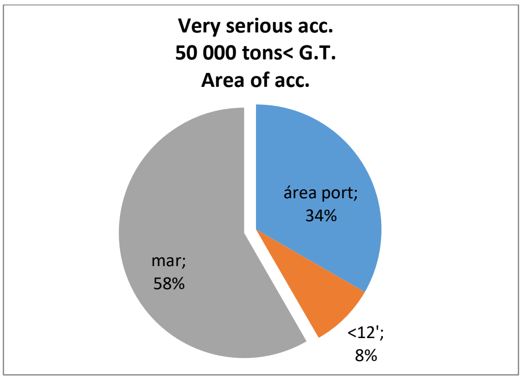

Figure 10 - Location of accident.

2.5 Ships accidents / ships number

Comparing the accidents distribution with the fleet distribution by classes, it's confirmed that the larger the ship, the lower the risk of a very serious accident (Fig.11 & 12).

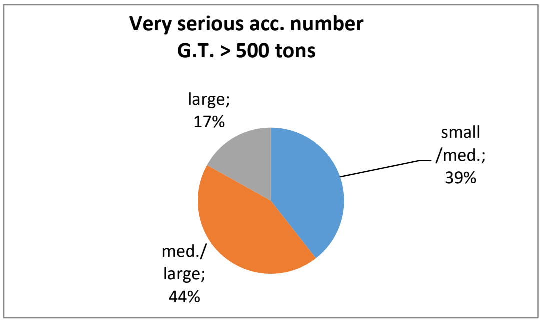

Figure 11 – Number of accidents.

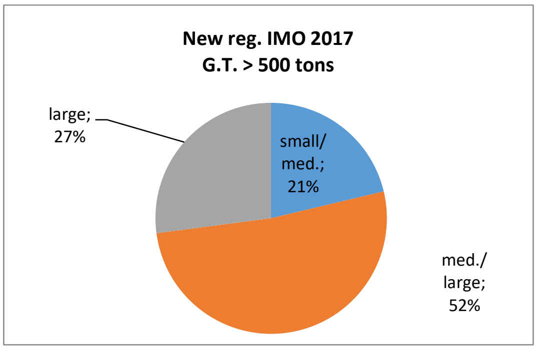

Figure 12 – Type of vessels operating.

Source IMO; GISIS; 2017. Samples: 100 accidents; 1000 flag registers.

3. CASUALTY ANALYSIS METHODOLOGY FOR MARITIME OPERATIONS

In the last decades several accident investigation methodologies together with appropriate taxonomies that provide the codification of the prevailing circumstances and contributing factors of accidents have been proposed. Among these methods is the CASMET (Casualty Analysis Methodology for Maritime Operations) methodology developed in a European research project (Caridis, 1999; Kristiansen et al. 1999). The approach consists of an analysis process that includes the initial data collection, identification and definition of the chain of events, the analysis of human and organizational factors (Caridis, 1999). In applying this methodology, data needed to explain a certain occurrence are collected and used to identified the sequence of accidental events, tasks, users and equipment involved, factors contributing to the occurrence and the root causes for each accidental event (Guedes Soares et al., 2000). The organization of information in a database requires a data coding structure directly related to the analysis process (Guedes Soares et al., 2000). The sequence of accidental events will be built for all events that are considered essential for the development of the accident. Thus, the events that are part of this sequence are essential, as if one had not occurred, the current would be interrupted, and the accident would not occur. These events are classified according to Kristiansen et al. (1999) as hazardous material, environmental effects, equipment failure, human error and other agent or ship; each have parameters associated with it for its characterization. A number of factors related to people, equipment, working conditions and management are then identified to code the causes of the accidental events. According to Kristiansen et al. (1999), the basic causal groups of the CASMET methodology include daily operations and management resources. The first relates to operational decisions: is related decisions and conditions on board for the management, individual behaviour, equipment and working conditions; while management and resources is related to the organizational culture, management class, buying ships or equipment, hiring and training employees – facts pertaining to the top management of the organization (Caridis, 1999).

3.1 CASMET methodology criteria

This methodology follows requirements that were implemented namely (Caridis et al. 1999):

Reliability:

- Independent analyses should reach the same conclusions.
- The reliability and integrity of the information should not be affected by the investigator's understanding of the objectives and purposes of the accident database.
- Computerization (computer processing) of information should not affect the reliability of human factor data.

Validation:

- The causes found must be true and predictable causes.
- Computerization (computer processing) of information shall not affect the validity (or omission) of human factor data.
- The collection of human factors should not be negligent or simplified in investigations.
- Taxonomy or classification scheme should not affect the collection and description of information.

Discernment:

- Distinguish between events and cause of event.
- Temporal sequencing and relating the consequences.
- Identify a cause relationship between different levels of explanation.
- Distinguish between human error, technical failure and surrounding environment.
- Relate faults with the basic system modules: technician, human-machine relationship, operator, procedures, support organization and environment.
- Identify tasks or operations not performed.
- Identify poorly performing tasks or operations.

Quantification:

- Allow to gather results of many accidents.

Practicability:

- Enable cost-effective study.
- Independence of specializations.

Meaning:

- Identify preventive measures.
- Identify consequences reduction measures.
- Formulation of prevention recommendations.
-Formulation of consequences reduction recommendations.

Analysis process:

The accident approach is based on two factors, the analysis method and a coded information database, summarizing:

- Collection of initial information.
- Identification and reconstruction of events.
- Analysis of human factors.
- Systems, hazardous materials and environment.
- Summary of cause relationships.

3.2 Accident analysis using the CASMET

The following 3 accidents have been analysed and coded using the CASMET.

Grounding of the N / M “Islay Trader” on the Thames, 2017 (MAIB 9/2018).

In October 2017, N / M “Islay Trader” ran aground in Margate, Kent, U.K.

Summary of HF found in this case:

<u>The tasks in which human error influenced this accident were:</u>

Ship was at anchor with few shackles in the water.
Lack of instruction in the bridge.
The Mate didn't realize he was dragging.
The Master was not informed of the situation.
The Mate did not control the movement of the ship.

<u>The main causes related to daily operations were:</u>

Supervision, inadequate instructions.
Manning, long working hours, too much extra time, too high workload.
Personal, lack of skill, low physical / psychological ability.

<u>The main causes related to management and resources were:</u>

Organization & general management, undercut, unclear rules and responsibilities, lack of coordination and communication.
Sea management, perform non-compliance, improvement of work instructions, safety assessment, risk analysis.

<u>Unresolved Issues:</u>

There is not enough information (in the report) to make any statements, but the ship owner increased the rest time and recruited one more bridge officer for the ship.

<u>Considerations:</u>

This accident results from fatigue and "low" judgment caused by night.

The ship owner (from this "rich" and developed country) decided to increase the ship's crew by 1 pilot thus exceeding the safe manning of the ship.

It is the opinion of many of the maritime professionals and entities that the implementation of STCW in 2014 with the reduction of working hours to 13 hours per day has improved fatigue.

I disagree because I do not see any ships stopping because their crew has reached 13 hours a day, nor that they reach 20, 30, etc. (At sea the days may be longer until the task is completed).

Port authorities authorize loading / unloading operations 24 hours a day, but know that (small) ships do not have crew to divide into shifts.

Collision of M/V "Privocean" with M/V "Bravo" and tug "Texas" in Mississippi, 2015 (NTSB / MAB 2016/08).

In April 2015 M/V "Privocean" broke the mooring at the Convent Marine terminal on the Mississippi River. It drifted and collided with the tanker M/V "Bravo" and the tug M/V "Texas" watching the "Privocean".

Summary of HF found in this case.

The tasks in which human error influenced this accident were**:**

The River Pilot did not recommend using the ship's propulsion equipment.
The Master took too long to request the 3rd tug.
The Mate just dropped one anchor.
The Master did not use the ship's main engine or manoeuvring aids.
The Master did not avoid the 2 collisions with the "Bravo" or the tug.

The main causes related to daily operations were:

Supervision, inadequate work preparation, lack of resources.
"Manning", wrong person assigned
Personal, lack of expertise, lack of knowledge.

Workplace conditions, dimensions:

Tools, inadequate tool.
Emergency preparedness, absence and emergency response initiative.

The main causes related to management and resources were:

Economic environment, economic conditions.
Operations management, pressure to maintain schedule and costs, improper procedures.
Sea management, analysis, incident reporting, safety assessment, risk analysis.
Personnel management, selection / hiring policy, selection of officers.
Design (design), difference from appropriate.
Emergency preparedness, emergency procedures.

Unresolved Issues:

The terminal continued to receive ships that were too long even when the current was exceptionally strong.

The bollards are the same. Recommend 2 bow moorings for strong current, when the terminal knows the cables will jump and the recommendation cannot be executed.

None of the entities mentions the use of the ship's main engine or manoeuvring aids.

Considerations:

This accident results from the sum of different failures and errors.

Extreme environmental conditions (river current), coupled with the ship being too large for the terminal and human judgment without being able to resolve the situation safely.

The omission of the use of the propulsive means of the ship and auxiliary manoeuvre. Everybody from the river Pilot who docked the ship to the final report, to many entities involved for several days in the problems of the stay, ignored the lack of use of the ship's steering gear.

The use of ship propulsion systems is a normal practice in Europe as part of our maritime culture.

Grounding of the M/V "Damia Desgagnés" on the St. Lawrence River, 2017 (TSBC 2018) M17C0108.

In June 2017 the tanker M/V "Damia Desgagnés" ran aground in Morrisbourg, Ontario.

Summary of HF found in this case:

The tasks in which human error influenced this accident were:

The owner of the ship owner accepted the bridge automation system that did not comply with BV regulations. The crew could not operate part of the bridge systems.

The main causes related to daily operations were:

Supervision, inadequate task preparation.
Personal, lack of knowledge
Workplace conditions, lack of information, inappropriate information, screen design, controls.

The main causes related to management and resources were:

Operations management, training.
Sea management, safety assessment, risk analysis.
Personnel management, inadequate training program.
Design (design), wrong design.

Unresolved Issues:

The Ship owner took 8 months trying to solve the problem before replacing the dangerous equipment.

Considerations

This accident was due to the use on board of badly designed equipment.

Only after the ship was in operation did the Ship owner begin to realize collateral problems and equipment malfunctions. After a few months, without the crews to adapt to the problems of the equipment, they were removed from the fleet.

4. SAFETY I AND SAFETY II

In this area the main objective is to ensure that the system works as intended. It is also important to consider the ways in which the system may fail.

These analyses are normal in complex technical systems such as fault tree, cause-consequence analysis, event tree and many more.

One of most important concepts is the barriers. A barrier is an obstacle, obstruction or difficulties. In the safety analysis context, a barrier can prevent, an action to be taken or an event to occur or consequences lessen their impact.

A barrier serves to slow down or prevent an uncontrollable release of matter or energy by limiting the consequences range or diminishing them. They are important for understanding and preventing accidents.

If there was an accident, it means that you do not hear barriers or that they have failed and did not serve their intended purpose.

Nowadays our civilization surrounds us with barriers, even if we do not notice them. They can be materials if prevent an event from occurring or the consequences from spreading. Functional if they need to be triggered to function and set logical requirements or time relationships before they act. Symbolic if they need proper interpretation and knowledge of their way of acting. Immaterial if they are not physically present or related to the situation.

The barrier function of is how the barrier achieves its purpose. They will be preventive or protective, depending on whether they work before or after the occurrence. The barrier system is the set in which it is integrated, namely the structure and organization of which it is part.

Identification of barriers in accident analysis and choice of barriers for system design are the most commonly used methodologies.

A methodology for analyzing the accidents causes and selecting safety interventions can be made by human factors levels. The most important is the lowest, policies and culture, management policies and organizational culture that promote a human Safety environment, because they influence all upper levels. Next levels are: workplace design, environment control, manpower requirements, personal selection, training, job aids, only influence upper levels. The upper level is fitness for duty is influenced by all levels doesn't influence them and is the aim of this methodology.

The purpose of accident investigations is to identify the causes and factors that contributed to adverse events and the risk assessment aims to determine its probability. Both approaches try to eliminate the causes or improve the barriers or both.

In the past, when production requirements were lower, systems were simpler and more independent. It was assumed that systems could be fragmented and that their components worked binomially: good or bad. Thus, the systems are stable and allow to be detailed to look for the causes and correct the problems.

Many production systems are not stable and are constantly evolving. Its complexity and evolution does not work binomially, but almost always performance has to change and adapt to changing and changing needs.

The safety I point of view does not explain why almost always goes well. Almost permanent good performance is not due to compliance with rules and regulations but to human flexibility in adapting to the changing and evolving world. As production systems develop, human adaptability is increasingly important for performance and success.

The challenge for safety is knowing why everything usually goes well. Under Safety II, instead of ensuring a minimum of bad events, the aim is to ensure a maximum of good events. The question is why the system succeeds when conditions vary. The human being is seen as a necessity for the flexibility and resilience of the system. Management is geared to anticipating developments and events (proactive, reactive at Safety I).

The purpose of accident investigation is to understand why everything is usually OK and occasionally there are bad occurrences. Risk assessment attempts to understand conditions where performance variation may be difficult or impossible to verify and control.

Given the increasing complexity of production systems the safety approach has to adapt. For now, there are still bad events where the Safety I approach resolves without serious consequences, but there are a growing number of occurrences that this approach does not resolve. In the future there is a need to develop Safety II that will fill the gaps in Safety I. The transition to Safety II will add new practices to looking for what is right, focused on the vast majority of everyday events, but remaining sensitive to the possibility of going wrong.

CONCLUSIONS

Maritime safety is a very wide subject that has undergone important developments in recent decades, namely in the way accidents are analyzed and in codifying the influence of human and organizational factors, which are the two main themes of the dissertation.

The dissertation presents an overview of the evolution of maritime accidents, despite the difficulties resulting from the dispersion of information. For this purpose, information from IMO and its GISIS database was used. It has been found that vast areas of the world do not collaborate in accident reporting, notably Africa and South America, and that major countries such as the United States and the United Kingdom have their own databases and analysis methodologies.

Instead of following the generic approach taken in previous studies that does not allow practical conclusions to be drawn, a study was conducted that divided the world fleet into 4 classes by GRT. In each class, values above (or below) the average have been analysed, in the type of vessel, type of accident and place of accident, based on the knowledge of 40 years of the Portuguese fishing and shipping tradition and my personal experience in the maritime sector.

CASMET has historical importance as a precursor to the marine accident coding taxonomy developed by EMSA. The implementation of EMCIP enables regional numerical studies (Europe) and, briefly, the improvement of maritime safety in the region.

Analyzing accident reports with this methodology has some difficulties mainly related with the development of the step diagram as it does not provide a compact view of the sequence of events that resulted in the accident. EMSA reports are very complete, partially solving the problem of lack of technical information, which is common in many reports consulted.

Barrier analysis is a “simple” solution to prevent, avoid, limit or mitigate the consequences of accidents. They are part of all projects but can be modified and improved individually or together. Combined with event tree and cost-benefit studies one can calculate the cost of safety and the benefit in terms of risk reduction. The Hollnagel & Leonhardt's white paper discusses an evolving world, where human variability is the solution to solving all challenges. The examples mentioned in this dissertation intended to alert to the side effects (or causes) existing in maritime activity. Complex and multidimensional events; many entities involved; hard environment; psychic, social and socio-technological behaviour are some factors mentioned.

REFERENCES

Caridis, P. 1999. Casualty analysis methodology for maritime operations. In Final Report of the European Research Project CASMET.: National Technical University of Athens.

Guedes Soares, C.; Teixeira, A. & Antão, P. 2000. Accounting for human factors in the analysis of maritime accidents. *Foresight and precaution*, 521-528.

Holling, C. S. 1973, Resilience and Stability of Ecological Systems, *Annual Review of Ecology and Systematics,* Vol. 4, pp. 1-23.

Hollnagel, E. & Leonardt, J. 2013. ‘From Safety-I to Safety-II: A white paper’. Eurocontrol. CEE.

Kristiansen, S.; Koster, E., Schmidt; W., Olofson, M.; Guedes Soares, C. & Caridis, P. 1999. ‘A New Methodology for Marine Casualty Analysis Accounting for Human and Organisational Factors. *Proc. of Int. Conf. on Learning from Marine Incidents.* London.

MAIB, 2018, Investigation Report 09-2018.

NTSB, 2016, DCA15LM019. National Transportation Safety Board. US.

NTSB, 2016, Marine accidents investigation branch. UK., Marine Accident Brief

TSBC, 2018, Marine Transportation Safety Investigation Report M17C0108 2018. Transportation safety board of Canada.