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Human and organisational factors in maritime accidents: Analysis of collisions at sea using the HFACS

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ABSTRACT

Over the last decade, the shipping industry has implemented a number of measures aimed at improving its safety level (such as new regulations or new forms of team training). Despite this evolution, shipping accidents, and particularly collisions, remain a major concern. This paper presents a modified version of the Human Factors Analysis and Classification System, which has been adapted to the maritime context and used to analyse human and organisational factors in collisions reported by the Marine Accident and Investigation Branch (UK) and the Transportation Safety Board (Canada).

The analysis shows that most collisions are due to decision errors. At the precondition level, it highlights the importance of the following factors: poor visibility and misuse of instruments (environmental factors), loss of situation awareness or deficit of attention (conditions of operators), deficits in inter-ship communications or Bridge Resource Management (personnel factors). At the leadership level, the analysis reveals the frequent planning of inappropriate operations and non-compliance with the Safety Management System (SMS). The Multiple Accident Analysis provides an important finding concerning three classes of accidents. Inter-ship communications problems and Bridge Resource Management deficiencies are closely linked to collisions occurring in restricted waters and involving pilot-carrying vessels. Another class of collisions is associated with situations of poor visibility, in open sea, and shows deficiencies at every level of the socio-technical system (technical environment, condition of operators, leadership level, and organisational level). The third class is characterised by non-compliance with the SMS.

This study shows the importance of Bridge Resource Management for situations of navigation with a pilot on board in restricted waters. It also points out the necessity to investigate, for situations of navigation in open sea, the masters' decisions in critical conditions as well as the causes of non-compliance with SMS.

1. Introduction

Around 90% of world trading is carried out by the shipping industry. Shipping is considered as a safe, economical, and environmentally benign form of commercial transport. Although increasing mediatisation draws public attention to accidents, the statistics show a slow but steady decline in maritime accidents over the past 10 years (Allianz Global Corporate & Speciality, 2013). This decade follows the general shipping safety improvement trend that took place over the 20th century. Records showed a rate of loss of 1% a year in 1910; this rate has improved to the figure of about one ship in every 670 in 2010 (Allianz Global Corporate and Speciality, 2012).

Shipping is also a highly regulated domain, and regulations have been reinforced in the last two decades. The main principles underlying shipping regulations are harmonized national rules based on international conventions and resolutions given by the International Maritime Organisation (IMO) (Kristiansen, 2008).

Among those regulations, the SOLAS[1] convention is seen as the most important of all international treaties concerning the safety of merchant ships. Its main objective is to specify minimum standards for the construction, equipment, and operation of ships. It is divided into 12 chapters. In response to the capsizing of the ferry Herald of Free Enterprise in March 1987, IMO adopted in 1993 the

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[1] SOLAS: International Convention for the Safety of Life at Sea, 1974, as amended.

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International Safety Management (ISM) code through its resolution A.741 (18). The ISM code was added in 1994 as chapter IX of SOLAS, "*Management of the Safe Operation of Ships*". This chapter requires a Safety Management System to be established by the shipowner or any person in charge of a ship. According to Kristiansen (2008), this requirement represents a dramatic departure in regulatory thinking on the part of the IMO since it acknowledges that detailed prescriptive rules for design and manning have serious limitations and stimulates safety consciousness, both ashore and on board. With the ISM code, the shipping industry is slowly moving from an idea of safety as front line operator training and the use of check-lists to an industrial safety culture involving everybody in the trade, from the AB seaman[2] to the general manager of the company. The ISM code became mandatory for passenger and dangerous cargo ships in 1998, then for the rest of the fleet in 2002.

At the same time, the IMO's international convention on Standards of Training, Certification and Watchkeeping (STCW) for seafarers, in its 1995 revised version, adds in section B-VIII/2 recommendations on proper "Bridge Resource Management", that is to say, the correct allocation and use of all resources available on the bridge. The Manila amendments[3] to the STCW code, which came into force on January 1st, 2012, go a step further towards mastering the human factor by bringing Bridge Resource Management into the mandatory A section of the code, as well as a new Engine-room Resource Management competency. It also explicitly asks for leadership and teamwork skills both at the operational and at the management level.

This paper presents an analysis of maritime accidents that are posterior to 1998, i.e., posterior to the ISM code and the STCW95 advent. It deals with collisions at sea and uses a systemic approach to analyse the role of human and organisational factors in these recent events. Whereas collisions are the main cause of only 12% of total losses (Allianz Global Corporate and Speciality, 2012), they appear to be one of the three primary causes of "serious casualties" (Graham, 2012). Moreover, they account for some 50% of the total risk in busy waterways (Min Mou et al., 2010). Thus, collision and grounding represent 71% of accidents in European waters; it was reported in 2010 that the largest number of vessels involved in accidents (45%) were involved in collisions and contacts with infrastructure (EMSA, 2011).

Several studies have pointed out the role of human and organisational factors in maritime safety (Chauvin, 2011; Hetherington et al., 2006; Schröder-Hinrichs, 2010). The role of those factors is a central issue in collisions. In fact, "collisions should theoretically be avoided if every vessel abided by the International Rules for the Prevention of Collisions at Sea 1972, which came into force in 1977" (MAIB, 2004, p. 15). Studies dealing with collisions pointed out the role of the following factors: "poor lookout", "poor use of radar", "improper manning", "the poor employment of ratings on the bridge", "lack of competency", "communication or teamwork on the bridge", or "inter-ship communications". These studies yielded interesting findings, but they often put emphasis on some of these factors and did not provide a systemic approach of those accidents. Furthermore, they concerned events that were anterior to or occurred just after the introduction of the ISM code and the STCW95.

A MAIB report (MAIB, 2004), based on the analysis of 33 collisions involving 41 vessels during the period 1994–2003, showed that the most common contributory factors were poor lookout (for 65% of the vessels) and poor use of radar (73%). On 19% of the vessels involved in collisions, Officers Of the Watch (OOWs) were completely unaware of the other vessel until the collision, or in some cases even after the collision. In a further 24% of collisions, officers became aware of the other vessel's proximity only when it was too late for any avoiding action to be successful. Poor lookout itself might be linked to an improper manning, the poor employment of ratings on the bridge, or to incompetence. This study did not include vessels under pilotage.

In contrast, a TSB report (TSB, 1995) dealt with 273 occurrences involving vessels under the conduct of a pilot in Canadian pilotage waters between February 1981 and May 1992. Among these occurrences, there were 43 collisions with another vessel underway. The report pointed out that breakdowns in communication or teamwork on the bridge appeared to be implicated in many of these marine occurrences.

Several studies have investigated coordination and communication between vessels. The detailed analysis of several collision cases led Perrow (1999) to point out that difficulties of coordination (between two or more vessels or between members of the same crew) are the main causes of accidents. Perrow called these accidents "disconcerting" as the officers on board both vessels had perceived the risk of collision, and, in some of the cases, they had even communicated and agreed upon the manoeuvre needed. After analysing 59 collisions between merchant vessels, Pourzanjani (2001) observed a frequent lack of communication of manoeuvring intentions. Pourzanjani noted that 46% of the officers involved had not clearly indicated their intention to manoeuvre and that 23% of the officers had not detected or correctly interpreted the signal although it had been correctly given. One potential cause of these failures could be that different systems of rules exist: formal rules (collision regulations) on the one hand and informal rules shared between certain types of vessels and specific to certain zones of navigation on the other hand (Chauvin and Lardjane, 2008). In situations of interaction between people who do not know each other, the co-existence of formal and informal rules is, more often than not, a source of difficulties, uncertainty, and misunderstanding; the co-existence of two systems of different rules can, in fact, be the origin of accidents when two players or two groups of players interact while each referring to a different system.

This paper presents a systemic and multifactorial analysis of collision at sea, aimed at identifying different types of accidents, i.e., accidents characterised by different patterns of human and organisational factors. The analysis relies on a tool based upon Reason's model: the Human Factor Analysis and Classification System (HFACS). This tool is used to classify and analyse factors that are mentioned in accidents reports for 39 vessels involved in 27 collisions that occurred between 1998 and 2012. One objective of the study is to compare the causes of these recent accidents with accident causes identified in previous studies.

2. Theoretical framework

2.1. The need to choose a relevant accident model

Since the end of the 1990s, it has been acknowledged that accident analysis must rely on systemic and organisational models (Rasmussen, 1997; Reason, 1997) that are adapted to the context of the study, even if they still represent a simplified view of reality. Simple linear accident models (e.g., cause-effect models) can be used in specific contexts but remain limited when the structure of the socio-technical systems is complex. Complex linear accident models such as the "Swiss cheese" model (Reason, 1997) and systemic non-linear models such as FRAM (Hollnagel, 2004) have the

[2] Able-Bodied Seaman ("AB or ABS") is a qualified and trained merchant seaman who is certified so by a training authority.

[3] Final Act of the Conference of Parties to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, Manila, The Philippines, 21–25 June 2010.

advantage that they provide a better capture of the complexity of the socio-technical systems and therefore enable a greater understanding of the factors that lead to the genesis of an accident or disaster.

According to Hollnagel (2004), the choice of a model to analyse an accident is crucial because it will determine the analyst's perspective and therefore guide the conclusions of the investigations and the preventive measures resulting from these conclusions. Similarly, methods and tools used for data collection and analysis will depend directly on the model selected. In other words, accident analysis is guided by the well-known "What-You-Look-For-Is-What-You-Find" principle (Hollnagel, 2008; Lundberg et al., 2009). Thus, the model provides a specific framework of observation and analysis. It is therefore essential to choose a model before starting the investigations, according to the characteristics of the system and the nature of the accident. The investigation of the accident of Alaska Airlines Flight 261 (Dekker, 2004) showed that analysts were guided by sequential models (simple linear accident models) that did not enable the identification of systemic factors responsible for the erosion of safety margins. Generally, when the object of investigation relates to complex socio-technical systems, models other than simple linear models provide a more appropriate answer than a simple search of cause and effect relationships.

The choice of an accident model is also decisive regarding the investigation manuals since "What-We-Find" relies on "What-We-Look-For" and "What-We-Look-For" relies on the model itself. Therefore, the structure and contents of these manuals also depend on the selected model. Moreover, when accident analyses are carried out from one or several investigation reports that were developed from an investigation manual based on a non-relevant model, then an analysis bias appears (Lundberg et al., 2010). Indeed, even if the accident investigations rely increasingly on the complex linear models (Lundberg et al., 2009), some reports may not contain all the elements that are useful for a comprehensive and thorough understanding of the accident. The ideal of "What-You-Look-For-Is-What-You-Find" cannot always be reached for this reason.

In this study, we analysed investigation reports realised by the Marine Accident Investigation Branch of the United Kingdom and by the Transportation Safety Board of Canada. Because they are based on Reason's "Swiss cheese" model of accident causation (Rothblum et al., 2002), we used the HFACS tool, which stems from this model.

2.2. The HFACS framework: a tool built from the "Swiss cheese" model

Reason (1997) emphasised the organisational dimension of major accidents by proposing the "Swiss cheese" model of accident causation. Through this model, active failures and latent conditions are clearly distinguished. Active failures are the unsafe acts (errors and violations) committed at the "sharp end" of the system (pilots, ships' crews, etc.) that have a direct and immediate impact on the safety of the system. They are seen as the consequences of deeper causes or latent conditions. Latent conditions are comparable to resident pathogenic agents (Reason, 1988). They can exist in a system for a very long time without causing harmful consequences. In fact, they need to be combined with a local trigger element and active failures to cause an accident. They arise from strategic and top-level decisions made by governments, regulators, manufacturers, designers, and organisational managers. Like Rasmussen (1997), Reason focused on the idea of propagation when he explained that "The impact of these decisions spreads throughout the organisation, shaping a distinctive corporate culture and creating error-producing factors within the individual workplaces" (Reason, 1997, p. 10).

As for the models, the methods and tools of analysis must also be adapted to the context under study. Drawing upon Reason's concept of latent and active failures, the Human Factor Analysis and Classification System was designed to facilitate human factors accident investigation as well as the analysis of the underlying causes of human error (Shappell and Wiegmann, 2000, 2001). The HFACS describes human error at each of four levels of failure: (a) unsafe acts of operators, (b) preconditions for unsafe acts, (c) unsafe supervision, and (d) organisational influences. Originally designed for the military aviation domain, it has since been applied to the classification and analysis of civil aviation accident data (Shappell et al., 2007) but also in the railway industry (Reinach and Viale, 2006) and the mining industry (Patterson and Shappell, 2010). Quite early, Rothblum et al. (2002) proposed to use it during the investigation of maritime incidents. Recently, it has also been used in the shipping industry by several authors. Celik and Cebi (2009) proposed to generate an analytical HFACS based on a Fuzzy Analytical Hierarchy Process. Xi et al. (2010) used the HFACS to analyse marine accidents and mishaps that occurred in the south-east coastal area of China. Recently, Schröder-Hinrichs et al. (2011) adapted this tool to the maritime domain and, more precisely, to the machinery spaces on ships (HFACS-MSS). Our tool is very close to the HFACS-MSS, although it includes some aspects that are specific to the collision avoidance activity and to the vessels bridge space.

3. Method

The original HFACS framework (Shappell and Wiegmann, 2000) has been enriched by Reinach and Viale (2006), who introduced a fifth top-most level named "outside factors" in order to optimise its relevance to the railroad industry. Outside factors include the regulatory environment as well as the economic/political/social/legal environments. This category is justified, because – as shown by Rasmussen (1997) and Reason (1997) – decisions taken at this upper level represent constraints for actors situated at the other levels: company, management, and staff. This level has also been taken into account in the HFACS-MSS. Other minor changes were made by different authors in order to adapt the HFACS tool to the features of a particular domain. Thus, this paper proposes a HFACS-Coll (Fig. 1, Table 1).

3.1. HFACS-Coll

3.1.1. Collision reports

The collision reports used in this analysis were obtained from two separate sources: 6 investigation reports set up by the Transport Safety Board (TSB) of Canada and 21 investigation reports written by the Marine Accident Investigation Branch (MAIB) of the UK. As previously explained, TSB and MAIB investigators take human and organisational factors into account, but they have their own investigative methodologies and do not use HFACS.

A total of 27 accidents, from 1998 to 2012, were therefore considered. They involved collisions between two merchant vessels or between a merchant vessel and a fishing vessel.

3.2. Coding process

The coding process concerned 39 vessels involved in these 27 collisions. They were merchant vessels of over 500 GT only, for which the ISM code is mandatory. Two experts familiar with the HFACS carried out coding separately. In case of disagreement, a discussion took place in order to reach consensus. Only those

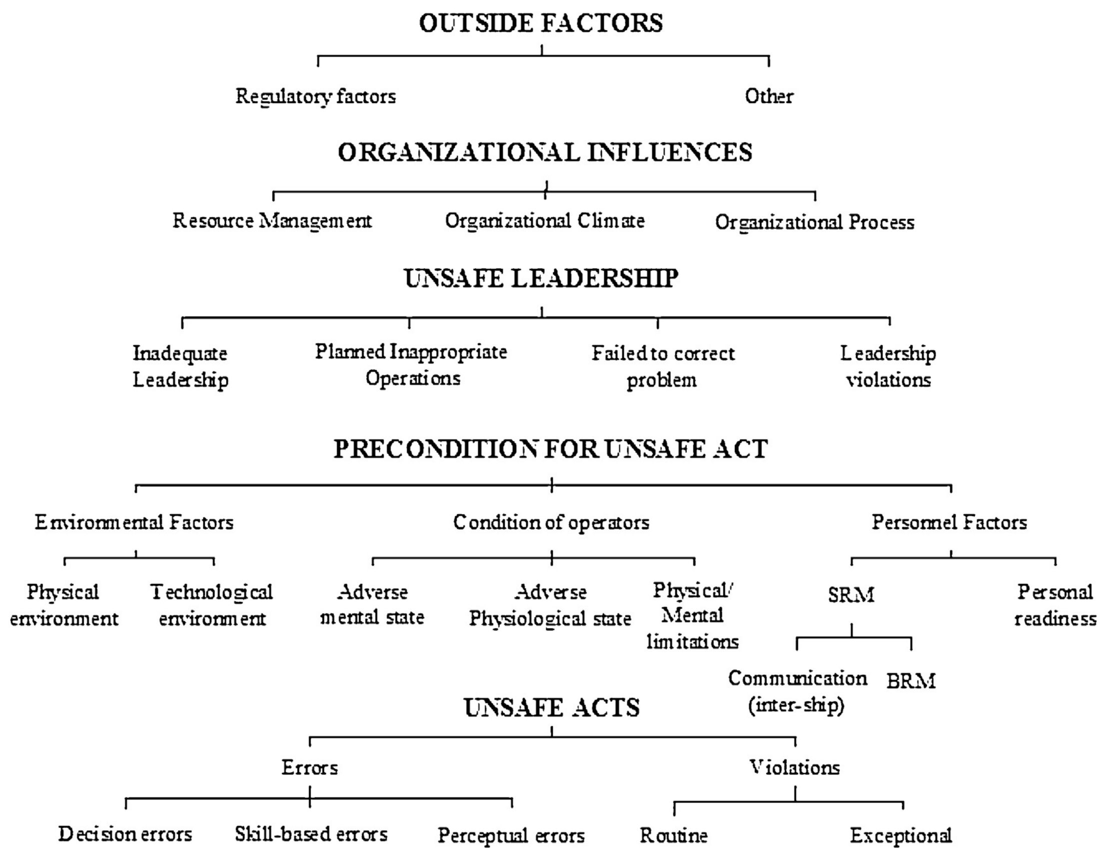

Fig. 1. HFACS-Coll.

factors that were explicitly mentioned in the reports were considered and classified following the HFACS so as to avoid any subjective interpretations.

3.3. Statistical analysis

A chi-square test was used to identify any significant link between factors considered two by two. Multiple Correspondence Analysis (MCA) was performed to detect patterns of contributory factors explaining collisions. It was completed with a Hierarchical Clustering, aiming at creating different classes of vessels, and a Classification Tree.

Multiple Correspondence Analysis is a geometric data analysis technique that is the counterpart of Principal Component Analysis for categorical data. It is used to detect underlying structures in a data set by representing data as points in low-dimensional Euclidean spaces. It is particularly adapted to the analysis of data sets with a moderate number of individuals and a comparatively important number of variables (Burt, 1950; Greenacre and Blasius, 2006; Le Roux and Rouanet, 2004).

Hierarchical Clustering is a clustering technique that seeks to classify statistical units in a hierarchy of clusters (Hastie et al., 2009).

Classification Tree learning is a standard data mining method. It seeks to predict the class to which the data belong, based on several input variables (Hastie et al., 2009).

The MCA, the HC, and the CT analyses presented in the paper were conducted using the R packages FactoMineR (Agrocampus Rennes Applied Math Department, 2008) and Rpart (The R Development Core Team, 2012).

4. Results

Vessels involved in collisions were general cargos (9), containers (9), tankers (8), passengers' vessels (6), and bulk carriers (5). Most of them (87%) were of medium size (from 500 to 24999 Gross Tonnage). Of the 39 vessels involved, 21 vessels (54%) were navigated in open seas (coastal waters, Traffic Separation Scheme – TSS –, or high seas). All collisions in open seas were investigated by the MAIB. The remaining 18 vessels (46%) were navigated in restricted waters (rivers or fairways), and 11 of those were under the conduct of a pilot. For 9 of these vessels, the accident was investigated by the TSB and for the other 9 by the MAIB. Table 2 shows the number of cases where each class of factors and each factor are mentioned.

4.1. Unsafe acts

Unsafe acts are divided into two main categories: decision (82%) and perception (15%). Decision errors may appear at the different stages of the decision process: during the diagnosis or during the planning phase.

As shown earlier (Cf. Table 1), "error of perception" means that the crewmembers on board one vessel did not perceive the other vessel or perceived it very late (TCPA[4] $\leq$ 1 min). Skill-based errors are absent; they would be related to the execution of skills or procedures that have become so well-learned that they are performed almost automatically. One violation occurred on board a chemical

[4] TCPA: Time to Closest Point of Approach.

Table 1
Description of the HFACS-Coll causal categories.

Causal categories	Description
Outside factors	*Regulatory factors* in the shipping industry are mainly: the COLREG (COLlision REGulations) and the International Code of Safety Management (ISM). *Other factors*: decisions, actions, and products coming from outside actors (designers, administration, port authorities) and informal rules.
Organisational influences	*Resource management*: management, allocation, and maintenance of organisational resources, including human resource management (selection, training, staffing), monetary safety budgets, and equipment design. *Organisational climate:* the notion includes: the command structure (chain of command, delegation or authority and responsibility, communication channels, formal accountability for actions), policies (official guidelines that direct management decisions about hiring and firing, promotion, retention, raises, sick leave, drugs and alcohol, overtime, accident investigations, and the use of safety requirement), and culture (unofficial or unspoken rules, values, attitudes, and beliefs and customs of an organisation). *Operational process* refers to formal processes (operational tempo, time pressures, production quotas, incentive systems, schedules, etc.), procedures (performance standards, objectives, documentation, etc.), and oversight within the organisation (organisational self-study, risk management, establishment and use of safety programmes). In the shipping industry, this category includes the Safety Management System (SMS). According to the ISM code, every company should in fact develop, implement, and maintain a Safety Management System which includes the following functional requirements: (a) a safety and environmental protection policy, (b) instructions and procedures to ensure the safe operation of ships and protection of the environment in compliance with relevant international and flag State legislation; (c) defined levels of authority and lines of communication between, and amongst, shore and shipboard personnel; (d) procedures for reporting accidents and non-conformities with the provisions of this Code; (e) procedures to prepare for and respond to emergency situations; and (f) procedures for international audits and management reviews.
Unsafe leadership	Supervising authorities must provide guidance, training opportunities, leadership, and motivation. In the shipping industry, supervision refers to two different hierarchical levels: (a) the persons ashore who have, according to the ISM code, the responsibility and authority to monitor the safety and pollution-prevention aspects of the operation of each ship and to ensure that adequate resources and shore-based support are applied, as required; (b) the master who has the responsibility on board to implement the safety and environmental protection policy of the company and to motivate the crew in the observation of that policy. *Inadequate leadership* includes failure to provide guidance, failure to provide operational doctrine, failure to provide oversight, failure to provide training, failure to track qualifications, failure to track performance. *Planned inappropriate operations* refer to improper or inappropriate crew scheduling and operational planning (crew paring, crew rest). The supervisor failed to provide correct data or to provide adequate briefing time. The mission is not defined in accordance with the rules (the speed, for example, may be excessive with regard to the environmental conditions). The manning may be insufficient regarding these conditions. *Failure to correct known problems* occurs when deficiencies among individuals, equipment, training, or other related areas are “known” to the supervisor, yet are allowed to go on uncorrected. *Leadership violations* are instances when existing rules, regulations, instructions, or standard operating procedures are wilfully disregarded by supervisors during the course of their duties.
Preconditions for unsafe acts	*Environmental factors* refer to the features of the physical and technological environment. Regarding the physical environment, they are: visibility, lighting, the presence of hydrodynamic phenomena (such as the bank suction effect in a river). The category of technological environment includes failures in the bridge design, the bridge instrumentation (presence or absence of ARPA radar), or in the use of instruments. *Adverse mental states* account for mental conditions that adversely affect performance: loss of situation awareness, mental fatigue, attention deficit, circadian dysrhythmia, complacency, and misplaced motivation. *Adverse physiological* states refer to physiological, pharmacological, and medical abnormalities known to affect performance. *Physical and/or mental limitations*. This category includes instances when individuals do not have the knowledge, aptitude, skill, or time to deal safely with information. *Substandard practices of the operator*. Ship Resource Mismanagement (SRM) includes the failures of both inter- and intra-bridge communication as well as communication with or between pilots and with shore personnel. This category also includes those instances when crew members do not work together as a team or when individuals directly responsible for the conduct of operations fail to coordinate activities. *Personal readiness failures* occur when individuals fail to prepare physically or mentally for duty: violations of crew rest requirements, excessive physical training, self-medicating, and being under the influence of alcohol.
Unsafe acts	At the active level, the active failures, which include operator actions and decisions, directly influence the occurrence of accidents. They are classified in two categories: violations and errors. Errors are divided in three sub-categories: decision errors, skill-based errors, and perceptual errors. *Violations* are behaviours that show wilful disregard for the rules and regulations. For example, a merchant vessel that is navigating in the wrong direction in a Traffic Separation Scheme. *Decision errors* account for conscious, goal-intended behaviour that proceeds as designed; yet, the plan proves inadequate or inappropriate for the situation. *Skill-based errors* occur with little or no conscious thought. They are related to automatic behaviour. Onboard a vessel, an example could be an inadvertent activation of the rudder. *Perceptual errors* occur when sensory input is degraded. In collision cases, these errors are related to the fact that the crewmembers on board one vessel did not perceive the other vessel or perceived it very late (Time to Closest Point of Approach $\leq$1 min).

tanker because the watch officer had left the bridge and gone to his cabin.

4.2. Preconditions for unsafe acts

The preconditions for unsafe acts include three main factors: environmental ones, individual ones (conditions of individuals), and personnel factors. 36 reports (92.30%) mentioned at least one of those factors.

4.3. Environmental factors

Environmental factors are related to the physical but also to the technological environment. In this category, two factors are predominant: visibility (56.51%) – visibility impaired either by fog or

Table 2
Number and percentage of cases for each factor.

	Number of reports where the factor is mentioned and percentage (%) $N = 39$	Restricted waters $N = 18$	TSS and open seas $N = 21$
1 Unsafe acts	39	18	21
Errors			
• Skill-based errors	0		
• Decision errors	32 (82.05)	17	15
• Perceptual errors	6 (15.38)	1	5
Violations			
• Routine violations	1 (2.56)		1
• Exceptional violations			
2 Preconditions for unsafe acts	36 (92.30)	18	18
2–1 Environmental factors	32 (82.05)	15	17
• Physical environment			
○ Hydrodynamic phenomena	5 (12.82)	5	0
○ Visibility or lighting	22 (56.41)	12	10
• Technological environment			
○ Ship building/bridge design	4 (10.25)	2	2
○ Non use or misuse of instruments	19 (48.71)	5	14
○ Radar failure	2 (5.12)	0	2
2–2 Conditions of operators	24 (61.54)	12	12
• Adverse mental state			
○ Loss of SA	13 (33.33)	6	7
○ Attention deficit/workload	12 (30.77)	6	6
○ Complacency	6 (15.38)	2	4
• Adverse physiological state			
○ Fatigue	5 (12.82)	0	5
• Physical/mental limitations			
○ Medical abnormalities	1 (2.56)		
○ Knowledge or skill limitations	8 (20.51)	5	3
2–3 Personnel factors	23 (58.97)	17	6
• SRM			
○ Inter-ship communication	19 (48.71)	14	5
○ BRM	15 (38.46)	12	3
• Personal readiness			
○ Alcohol	1 (2.56)	1	
3 Unsafe leadership	23 (58.97)	6	17
• Inadequate leadership	2 (5.12)		2
• Planned inappropriate operations	20 (51.28)	6	14
• Failed to correct problem			
• Leadership violations (non compliance with Safety Management System SMS)	13 (33.33)	3	10
4- Organisational influences	21 (53.85)	8	13
• Resource management	6 (15.38)	3	3
• Organisational climate			
• Organisational process			
○ Incomplete SMS	14 (36.84)	7	7
○ Perfectible Audit	4 (10.25)		4
5 Outside factors	6 (15.38)	3	3

by an external lighting – and the use (non-use or misuse) of the main instruments (48.71%). Hydrodynamic phenomena are always linked with collisions occurring in restricted waters, as well as with the presence of a pilot on board.

4.4. Conditions of operators

The main factors are inappropriate situation awareness (33.33%), attention deficit (30.77%), and knowledge limitations (20.51%).

Situation awareness is formally defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1995, p. 36). Applied to collision activities, it should cover – once the other vessel has been seen – the perception of its trajectory (course and speed), the comprehension of the situation (is it an overtaking situation, a head-on situation, or a crossing situation), the risk evaluation, the target identification, and the prediction of the future manoeuvre of the other ship (Chauvin et al., 2008). It is worth noticing that this notion is used with a more restrictive acceptation by accidents investigators. In collision reports, this notion covers only the comprehension of the situation. Loss of situation awareness refers to cases in which the master or the OOW had an incorrect comprehension of the situation, as explicitly stated in the reports: "he did not have a good appreciation of the other vessel's position or movements", "he lost awareness of the vessel's relative position and speed", "he didn't have a complete situational awareness of the rapidly developing close quarters situation", "he had misinterpreted the meeting of the two vessels as an overtaking one".

4.5. Personnel factors

This category is divided into two important sub-factors: inter-ship communications (48.71%) and Bridge Resource Management (38.46%). Personal readiness failure (namely being under the influence of alcohol) appears in one case only.

Inter-ship communication may involve two bridge teams, or two pilots, or a bridge team (with or without pilot) and the vessel traffic service (VTS). Problems are mainly related to ambiguities or misunderstandings or to an absence of relevant communication between two pilots throughout a developing situation. They may be related also to the use of mobile phones between two pilots; such devices do not allow the shipmasters to be aware of what is being said.

Bridge resource mismanagement includes problems of coordination and problems of communication between crewmembers. BRM failures are related to poor shared mental models and shared situation awareness in the bridge team. According to Salas et al. (2007), shared mental models consist in knowledge that allows a closed-loop communication, mutual performance monitoring, and adaptive and supportive behaviour. BRM failures relate to those four aspects:

- Absence of closed-loop communication, as in the following example: "The Filipino lookout was on the bridge, but it was not customary for the watchkeeping officers to talk to the lookouts. When the lookout reported a red light to starboard, and then advised that he was leaving the bridge to undertake safety rounds, the chief officer made no comment. As this was not abnormal, the lookout was unaware that the chief officer had not registered his report".
- Absence of mutual performance monitoring, especially between master and pilot.
- Inadequate task allocation considering the workload of each crew member.
- Absence of supportive behaviour from the team members, especially when a pilot is on board; for example, "the pilot was not proactive in requiring support, and neither the master nor OOW was proactive in providing support to the pilot, thereby unnecessarily increasing the pilot's workload".

Shared situation awareness is about the current situation, current plans and goals but also the roles and responsibilities of each team member. It requires communicating about all of these aspects. BRM failures cover the following:

- Insufficient communication about the salient features of the current situation (during the watch but also during the hand-over); salient features may be, for example, decreasing visibility or the use of unusual amount of helm to maintain the desired heading. This information must be given by the watch officer to the master, or by the helmsman to the bridge team. The pilot must also inform the master so that the latter can have a full appraisal of the situation.
- Insufficient briefing and discussion about the master's and the pilot's roles, about who is in charge of the con.

There is a link between accident localisation and BRM deficiencies, $\chi 2$ (1, 39 = 10.58, $p < .01$) as well as between inter-ship communications and accident localisation, $\chi 2$ (1, 39 = 10.55, $p < .01$). Both factors are more often involved in collision occurring in restricted waters than in open sea.

There is also a strong relationship between the presence of a pilot on board and BRM factor, $\chi 2$ (1, 39 = 11.06, $p < .001$) as well as between the presence of a pilot on board and the inter-ship communications factor, $\chi 2$ (1, 39 = 9.8, $p < .001$).

4.6. *Unsafe leadership*

In the maritime field, the level of leadership (or supervision) must be divided into different sub-levels. The direct leader of the crew is the master, but the master himself receives orders and resources from supervisors located ashore. However, in accident reports, unsafe supervision appears to be related to the captain's choices. It mainly concerns the planning of inappropriate operations (51.28%): manning is not sufficient, or speed is too high considering the environmental conditions (visibility or traffic). In 33.33% of cases, these choices are made regardless of the existing rules or the company Safety Management System (SMS). Inadequate supervision appears in two cases: a master who did not sufficiently motivate the second officer to follow the company's navigational procedures and a master who did not leave night orders.

There is a link between inappropriate operations and collision localisations, $\chi 2$ (1, 39 = 5.11, $p < .03$), as well as between non-compliance with SMS and collision localisations, $\chi 2$ (1, 39 = 4.68, $p < .05$. Both factors are more often involved in collisions in open sea than in restricted waters. There is also a relationship between inappropriate operations and non-compliance with SMS, $\chi 2$ (1, 39 = 4.67, $p < .05$).

4.7. *Organisational influences*

Several collision reports make mention of organisational influences. These factors are related to:

- Resource management (6 cases), when the vessel's manning is not sufficient (1 case), when the company failed to provide adequate training or refresher training for its masters or deck officers (3 cases) or when the company had no formal system in place to monitor or appraise the performance of its masters (2 cases).
- Operational process (18 cases), when the SMS is incomplete or the audit process carried out to assess the SMS may prove to have been inefficient.

4.8. *Outside factors*

Outside factors appear very seldom and are heterogeneous. The investigation reports did not make any reference to loopholes in existing regulations. Outside factors concern:

- Administration. One report mentioned that the failure of administrations to check the downward movement of manning levels had resulted in "safe manning" levels becoming "unsafe".
- Informal rules prevailing within the external environment. In certain areas, "unwritten rules" exist concerning the vessels' actions. These rules create expectations. In the Dover Strait TSS, an "unwritten rule" exists concerning ferries or high-speed craft (HSC) manoeuvres (Chauvin and Lardjane, 2008); in particular, it is expected that HSC will keep clear in all instances. Obeying this rule, watch officers may fail to take action in compliance with the formal rule. One report mentioned these rules.
- Convergent practices. MAIB investigators showed that dangerous situations arise in the southwest lane of the Dover Strait TSS because vessels of markedly different speeds are travelling in coincidental tracks. These tracks are GPS pre-programmed ones. The use of the same software creates a high and dangerous traffic concentration. This factor appears to be a central one in one of the 27 collisions.
- Use of incorrect publications for passage planning. These publications are harbour notices sent to mariners and marine navigational charts.
- The Port Marine Safety Code, when there is no national standard for qualifying trips/training of Pilotage Exemption Certificate (PEC) holders.

4.9. *Patterns of causes*

In order to point out patterns of contributory factors, a Multiple Correspondence Analysis (MCA) was carried out. This analysis

Table 3
Variables used in the MCA.

Variable	Signification	Level
vis	Visibility	Pre-condition
ins	Non use or misuse of instruments	Pre-condition
com	Inter-ship communication problems	Pre-condition
brm	Bridge Resource Management deficiencies	Pre-condition
awa	Loss of situation awareness	Pre-condition
att	Attention deficit	Pre-condition
op	Inappropriate operations	Leadership
sms	Non-compliance with SMS	Leadership
inc	Incomplete SMS	Organisational
pil	Pilot on board	Other
loc	Localisation	Other

was conducted with the main variables (variables with more than 10 observations per modality): visibility (bad, correct), misuse of instruments (yes, no), loss of situation awareness (yes, no), attention deficit (yes, no), inter-ship communication problems (yes, no), BRM (yes, no), planned inappropriate operations (yes, no), supervisory violations (yes, no), incomplete SMS (yes, no).

Two situational variables were added: localisation and presence/absence of a pilot. The case involving a violation was excluded from this analysis. MCA was, therefore, carried out on 38 cases.

All the variables used in the analysis are summarised in Table 3.

Axis 1 explains 28.10% of the inertia. It is determined by loc, pil, brm, com, sms, op, and ins. It opposes:

- The modalities: sms (no), localisation (restricted waters), pilot (yes), brm (yes), com (yes), op (no), ins (no), on the positive side, to
- The opposite modalities on the negative side.

As far as individuals (vessels) are concerned, it opposes:

- Vessels experiencing a collision in restricted waters, with a pilot on board, having problems of inter-ship communication, BRM deficiency, with a good use of instruments, appropriate operations and compliance with SMS, to
- Vessels experiencing a collision in open sea, without a pilot on board, with inappropriate operations, no use or misuse of instruments and non-compliance with SMS.

This axis opposes communication and coordination factors to operational factors (personnel to leadership causes).

Axis 2 explains 18.35% of the inertia. It is determined by the following variables: ins (no use or misuse of instruments), op (inappropriate operations), att (attention deficit), vis (visibility) and inc (incomplete SMS). It opposes:

- The modalities inc (yes), att (yes), vis (yes), ins (yes), op (yes) on the positive side, to
- The opposite modalities on the negative side.

As far as individuals are concerned, it opposes:

- Vessels experiencing a collision under conditions of poor visibility, where instruments were not used or misused, where the choices related to speed and/or manning were inappropriate regarding the current conditions, where the OOW's attention was not focused on the lookout and where the SMS was incomplete, to
- Vessels experiencing a collision under the opposite conditions.

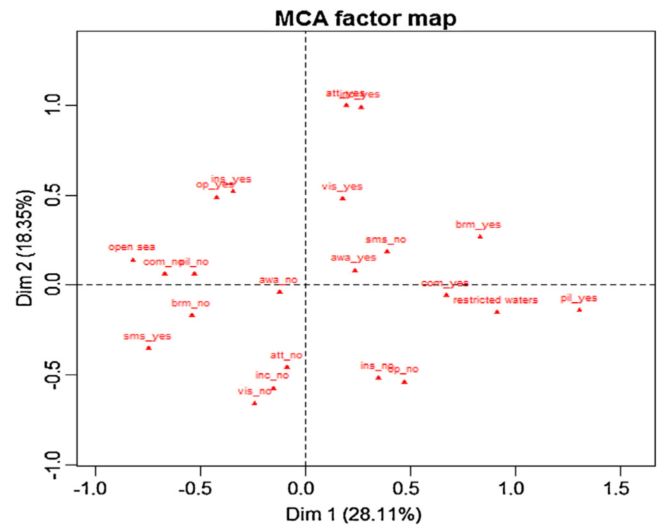

Fig. 2. MCA on the database main variables.

This axis quantifies the intensity of lookout, operational, and organisational problems.

Together, these two axes explain more than 46% of the data variability (see Fig. 2).

A hierarchical clustering was carried out from the coordinates of individuals on all the axes. The analysis shows three different classes of accidents (see Fig. 3a and b).

Class 1 ("Personnel accidents") refers to vessels experiencing a collision in restricted waters, with a pilot on board and rather poor visibility, where communication and coordination problems were observed, with no leadership problems. It is strongly linked to Axis 1 and is made up of 16 individuals. It distinguishes 16 vessels where factors linked to leadership problems did not play a role but where communication and coordination problems were the main causes of the accident.

Class 2 ("Leadership accidents") refers to vessels colliding in open sea, with no pilot on board, with good visibility. At the bridge of these vessels, there were no communication or coordination problems and no problems of attention. The SMS was complete but was not complied with. This class is strongly linked to Axes 1 and 2 and is made up of 13 individuals.

It distinguishes 13 vessels where non-compliance with the SMS was the main cause of the accident in otherwise good operational conditions.

Class 3 ("Operational accidents") refers to vessels colliding in open sea, with no pilot on board, under conditions of poor visibility. On board those vessels, SMS was incomplete, instruments were misused or not used at all, and inappropriate operations were observed. This class is strongly linked to Axis 2 and distinguishes 9 vessels where misuses of instruments and operational problems are important.

A classification tree (see Fig. 4) shows the variables that best explain vessel allocation to the different classes among awa, brm, com, sms, inc, op, att, and ins. They are: brm and inc (incomplete SMS). Each tree leaf matches with a class. The left side of each branch corresponds to a "yes" to the question in the root, whereas the right side corresponds to a "no". Under each leaf, the number of elements of each class in the leaf appears; 12/1/2 means that there are 12 accidents belonging to the first class, 1 belonging to the second class and 2 of the third class. The presence of BRM deficiencies appears to be a characteristic of the first class. Class 2 is well characterised by the absence of BRM deficiencies and the presence of a complete SMS, which was not complied with. Class 3 is reasonably

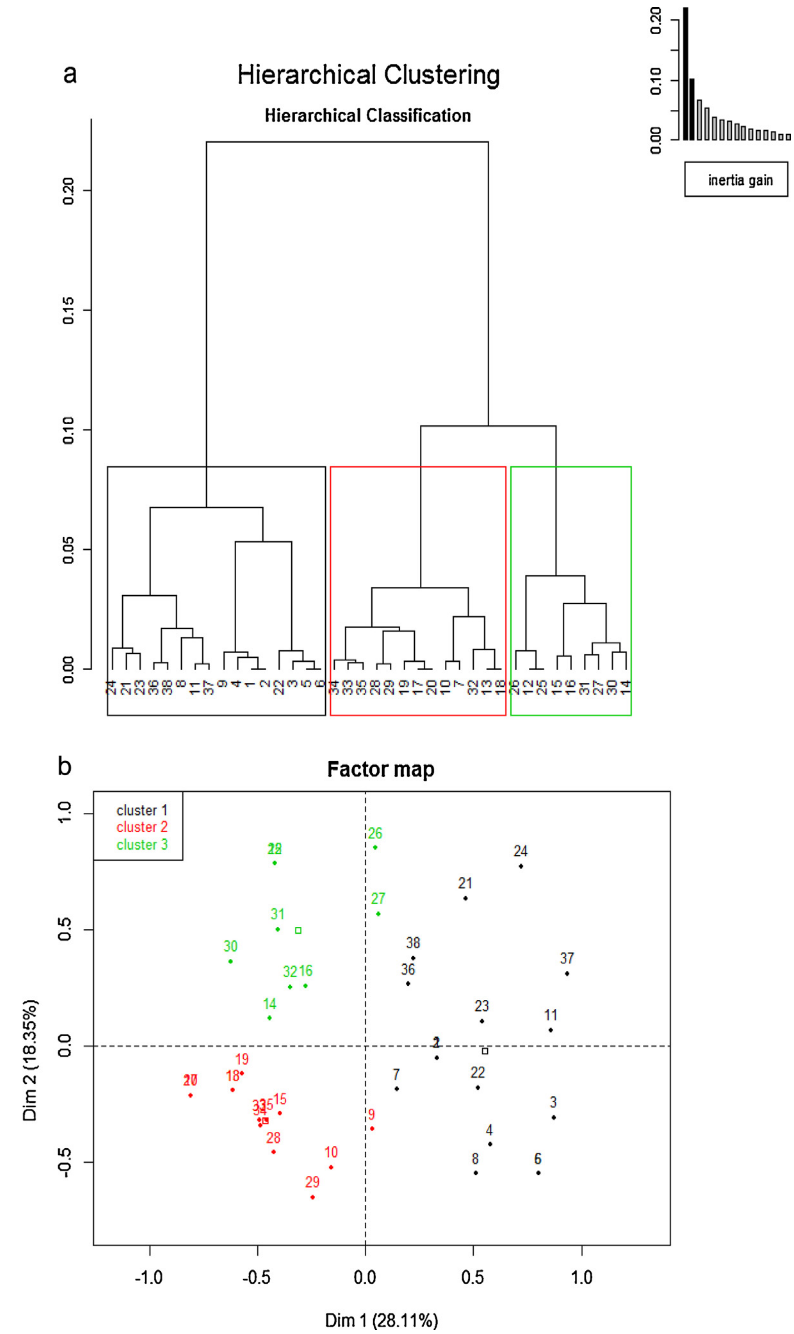

Fig. 3. (a) Hierarchical clustering. (b) Clusters projected on the factorial plan.

characterised by the absence of BRM deficiency and by the presence of an incomplete SMS.

5. Discussion and conclusion

This paper presents an analysis of 27 recent collisions cases involving 39 vessels, using the HFACS tool. Using the HFACS-Coll to analyse collisions at sea has provided significant findings concerning the main contributory factors of those accidents and the existence of patterns of contributory factors. These results confirm findings obtained in other studies dealing with the same topic. This study has limitations. It also has practical implications. In particular, it opens the way for further research dealing with the impact of organisational and safety culture on the decisions made by the master in critical situations.

5.1. *The main contributory factors*

Considering the first level, one may notice that skill-based errors are absent and that violations are exceptional. Unsafe acts are mainly related to decision-making (85%) while non-perception of the other vessel concerns 15% of the vessels involved in the 27 collisions. At the level of preconditions, the analysis brings out poor visibility and the misuse of instruments as the main environmental factors. Visual conditions (poor visibility and inadequate lighting) appear also to be major contributing factors in train accidents (Reinach and Viale, 2006) as well as in commercial aviation accidents (Shappell et al., 2007). The MAIB report emphasised the role of improper or poor use of radar in collisions, since it appeared in 73% of the cases being investigated (MAIB, 2004).

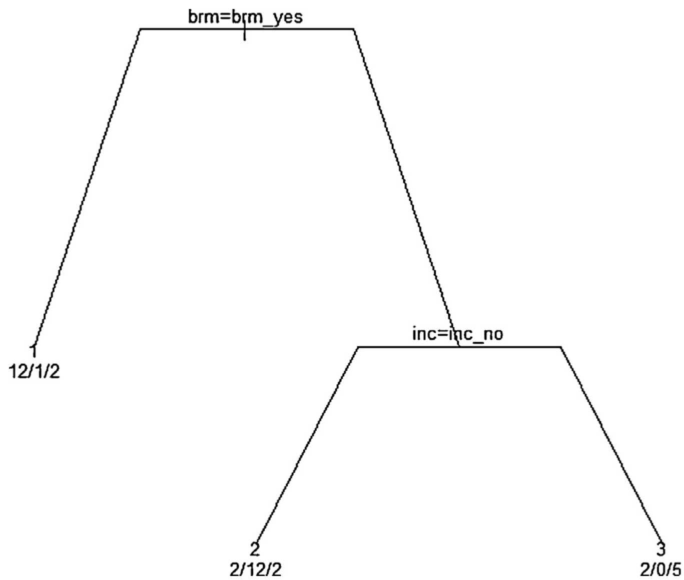

Fig. 4. Classification tree.

As far as conditions of operators are concerned, situation awareness and deficit of attention appear to be major elements. Inappropriate situation awareness is often the precursor of a poor decision. Deficit of attention is synonymous with an inefficient lookout. In turn, poor lookout occurs because several tasks are often carried out on the bridge: navigation and collision avoidance but also administrative tasks. Previous studies showed that poor lookout is a major cause in collisions (MAIB, Ibid).

Two personnel factors are crucial elements: inter-ship communications and Bridge Resource Management. They both deal with coordination, communication, and shared situation awareness. Failures in BRM are involved in more than 1 out of every 3 collisions investigated. BRM is a contributory factor of accidents when it does not play its role as a "barrier" to prevent accidents.

At the leadership level, the analysis reveals the frequent planning of inappropriate operations. In other words, instructions given to the bridge team were inappropriate, given the situation requirements (poor visibility or heavy traffic). They may have been in direct contradiction with the SMS. In that case, they also constitute supervisory violations. They may reveal some difficulty for leaders to adapt their instructions to a changing situation. They may also reveal a poor safety culture.

At the organisational level, failure in the SMS or failure in the audit process carried out on board vessels concerned 47% of the vessels involved in collision. SMS and audit are fairly new in the maritime field, unlike the commercial airlines domain where monitoring on the flight deck has been part of the landscape since the 1990s. The Line Operations Safety Audit (LOSA) programme is a response to the Crew Resource Management (CRM) training implemented in the 1980s, aimed at improving safety and providing an insight into *why* the crew did what they did (Helmreich, 2002). Flight experts (airline captains) accompany the crew during the whole flight and collect data from cockpit observation. This observation of operational activity is much more valuable than process auditing (checking papers stating what the activity is supposed to be), as investigations sometimes show a considerable discrepancy between the company's quality system wishful thinking and real life.

At the highest level, few outside factors are related. They are, nevertheless, highly significant since they influence important decisions made at the lower levels: decisions made by the company concerning the manning levels and decisions made by the bridge team concerning route or manoeuvre choices.

Finally, it must be emphasised that all levels are not equally represented. Investigation reports contain more items belonging to the lowest level (preconditions for unsafe acts are mentioned in 92.30% of the cases) than items relative to leadership or organisation; organisational climate and safety culture, in particular, are never mentioned. Schröder-Hinrichs et al. (2011) obtained the same result as the outcome of their review of 41 reports of accident investigations of fires and explosions in machinery spaces using the HFACS.

We could ask the same question that Shappell et al. (2007) already asked: "Does the current accident data reflect the scope of the organisational/supervisory problem or is it possible that issues associated with middle- and upper-level management are underreported?" (p. 236).

5.2. Three typical patterns of causes

This analysis reveals three different patterns of collision causes.

The first pattern (Axis 1 of MCA, Class 1 of HC) is typical for collisions occurring in restricted waters and involving vessels that carried a licensed pilot. It includes two personal factors: inter-ship communication problems and BRM deficiencies (personnel factors). It confirms results obtained in the TSB study of operational relationships between ship masters/watchkeeping officers and marine pilots (TSB, 1995). This study showed, in fact, the importance of inadequate interpersonal communications among the bridge team, leading to misunderstanding, lack of adequate information exchange, incomplete understanding of the intended manoeuvres, loss of situational awareness, absence of monitoring of the ship's progress, etc. It concluded that such factors suggested deficiencies in the effectiveness of current bridge team management practices in compulsory pilotage areas.

The second pattern (Axis 2 of MCA, Class 3 of HC) includes factors belonging to different levels: visibility and misuse or non-use of instruments (pre-condition level), attention deficit (conditions of operators), inappropriate operations (leadership level), and incomplete SMS (organisational level). This pattern illustrates Reason's Swiss cheese model; each level of the socio-technical system has weaknesses (called voids) caused by latent and active failures. These voids are similar to the holes in slices of Swiss cheese. A hole may allow a problem to pass through one layer, but in the next layer, the problem may be stopped if the holes are in different places. However, when the holes are aligned, they create a "window of opportunity" for an accident chain to continue moving forward. The pattern confirms one result obtained in the MAIB study on bridge watchkeeping, which showed a link between poor visual lookout and the poor employment of ratings on the bridge.

These two patterns of factors, which were identified in the MAIB and TSB studies, thus account for a considerable number of collisions, despite the advent and development of BRM on the one hand and of the ISM code on the other.

Furthermore, a new pattern appears (Axes 1 and 2 of MCA, Class 2 of HC) characterised by non-compliance with SMS, although the latter is complete.

5.3. Limitations

The main limitation of this study is related to the low number of collisions studied. As the statistical base is small, it is difficult to identify more than three main patterns of contributory factors. The comparatively low number of collisions and the high number of variables do not allow one to use stochastic modelling; this is the reason why a geometrical descriptive has been used in this paper.

5.4. Implications and future research

This study confirms the importance of Bridge Resource Management for situations of navigation with a pilot on board. BRM has always dealt with those situations, as evidenced by Swift's (1993) practical guide. Nevertheless, the organisations involved in the global delivery of BRM training went further in 2003, when they decided to rebrand the course from BRM to Maritime Resource Management (MRM) and to broaden the target of MRM to ships' officers, engineers, maritime pilots, and shore-based personnel (Hayward and Lowe, 2010).

This study also stresses the necessity to investigate the masters' decisions in critical conditions. These decisions concern bridge manning and vessel speed. Combined with misuse of instruments and attention deficit, they may lead to accidents. These decisions relate to the notion of Efficiency-Thoroughness-Trade-Offs addressed by Hollnagel (2009), but such principles have not yet been discussed in the maritime context (Schröder-Hinrichs, 2010). These decisions also relate to SMS, ISM and, more generally, to the company safety culture. In fact, some recent studies have called the efficiency of the ISM into question. Battacharya (2012) explained that "seafarers experienced implementation of the ISM Code as an imposition. To them it was a managerial tool, which merely required compliance from them and not participation in the true sense of the word. This undermined their professional seafaring skills and thus led to its rejection" (p. 533). Battacharya added that "research voyages showed that seafarers applied other measures to safeguard themselves. The safe working skills, which seafarers claimed to have learnt through experience, were put to use for day-to-day management of shipboard safety" (p. 533). At the organisational level, the dimension of safety culture might appear, therefore, as relevant as the notion of SMS completeness. Studies dealing with safety culture and safety climate in the maritime field are numerous (see, for example, Ek and Akselsson, 2005; Håvold, 2005, 2010; Lu and Tsai, 2010; Lu and Yang, 2011). Some of them have shown that safety climate is, indeed, an important factor influencing safety behaviour (Lu and Tsai, 2010; Lu and Yang, 2011).

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