Ro Ro passenger ferry safety: The capsizing of the Herald of Free Enterprise

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Executive summary: The unlearned safety lessons from the capsize of the Ro Ro passenger ferry the Herald of Free Enterprise at Zeebrugge in 1987 are explored. The key finding: safety is a "non-absolute entity" and closely integrated with impact assessment and a revolving management system. The generic design of safety management methodology is applicable universally.

Tags: transport, maritime, design for safety, safety management methodology, safety culture, corporate manslaughter law, complexity, system interfaces, damage stability, Belgium

Section 1: Background and introduction

The case study addresses the capsizing of the passenger Ro-Ro (Roll-on/Roll-off) ferry the Herald of Free Enterprise. In spite of a public inquiry and other studies carried out following this accident, there are still unlearned lessons, as is normal with accidents involving complex systems if examined under a different lens. There are many examples supporting this. For example, the Titanic accident was finally explained through a forensic study undertaken on the 100th anniversary of the disaster; the Estonia accident was explained by a Swedish Government-funded research project 10 years after the accident and following several investigations, reports and conspiracy theories; and the Derbyshire accident was eventually resolved 10 years later following a series of UK Government-funded research projects. The lens considered in this study relates to the nature of safety and its measurement. In particular, the lack of safety systems, which addresses quantitatively what we call 'safety level' by assigning risk credit to all contributions to safety and then informing decision makers of which actions to take cost-effectively in a consistent and rational manner. This applies to the safety of all complex systems. In this respect, safety is addressed though design (built-in safety) and operation (management of residual risk), targeting the requisite resilience to ensure a fail-safe system. A combination of these two approaches leads to what could generically be called, Design for Safety Management, so that life-cycle issues could be accounted for in a structured approach.

As such, fundamental features relevant to safety management involve the nature of safety, assessment of significant innovative concepts and the critical role of management per se. These topics are important because all related industries must meet challenging targets pertaining not only to safety of life onboard, but also encompassing environmental and financial hazards. As such, the experience from shipping can be shared widely. For example, the shipping industry is actively considering the use of Green House Gas (GHG)-less fuels, such as hydrogen and ammonia, as alternative marine fuels despite there being very little operational safety experience.

This case study highlights the complex nature of passenger ferry operations and examines the fundamental safety features. These were shared and discussed with colleagues in the profession via an internet questionnaire, leading to the conclusion that a Design for Safety Management methodology could assist in enhancing the safety of Ro-Ro ferry operations.

Ro-Ro passenger ferry operation as a complex system

The ferry operations have several key stakeholders, the principal ones being the passengers, the owner, the ship itself, port operators, regulatory bodies, suppliers and the wider public. The activities are dominated by human performance to meet a number of demanding and conflicting requirements, such as 52-7-24 operations under intense commercial pressure and international competition, bounded by national and international rules and regulations and served by multi-national and multi-cultural crews. At the same time, there is a need for good management, a positive attitude and behaviour, including effective communication, to ensure the ship operation is profitable venue.

The multifaceted interactions between the various activities are extremely complex and some are non-absolute entities where there is no unique right/correct or wrong/incorrect solution. This is not helped by the fact that safety itself is a non-absolute entity, thus introducing additional challenges.

About the accident

The vessel was operated by Townsend Car Ferries Limited (a subsidiary of P & O), and its normal routes were Dover-Calais and Dover-Zeebrugge. At 18:05 hours on 6 March 1987 she left the inner harbour at Zeebrugge, bound for Dover, with a crew of 80 on board plus 81 cars, 47 freight vehicles and approximate 460 passengers. There was a light easterly breeze, and the sea was calm. Four minutes after leaving the harbour, she capsized with complete sinking prevented by the fact that she was still in shallow seas. Water rapidly filled the vessel below the surface level, ending up with at least 150 passengers and 38 crew members losing their lives.

The capsizing was caused by several adverse factors acting together, the key ones being:

- Open bow door: The bow door must be closed when the ship is in motion, but there is a tendency to leave it open at the start of a journey to clear the fumes from the loaded vehicles. In this case, the bow door was left open as the person assigned this duty was asleep due to over work.
- Ship trim forward: This means that the vessel happened to have its bow immersed beyond level keel. This factor combined with the bow door being open meant that sea water rapidly entered the car deck. This triggered a reduction in the stability of the vessel, leading it to capsize.
- Ship was turning at high speed: The vessel quickly reached 14 knots and turned to port, thus introducing an additional heeling moment. The angle of lurch very quickly reached 30o and gradually increased to 90o until she was lying on her side.

Section 2: Analysis and insights

Analysis

The case study analyses the capsizing of the Ro- Ro passenger ferry Herald of Free Enterprise in 1987. It is not unreasonable to ask the following question:

> *The accident happened more than 34 years ago and, after a public inquiry and many studies, are there any lessons still to be learned?*

The argument presented in the introduction, namely that in the absence of a structured approach to addressing safety where all key contributing factors could be consistently measured and accounted for, leads to the following key observations:

1. Implication of safety as a non-absolute entity;
2. The use and limitations of a prescriptive regulatory approach to addressing safety;
3. Impact of significant innovations and the need to be assessed critically from a total system context;
4. The safety of complex systems is strongly affected by interfaces as they can disrupt continuity;
5. The role of management is critical to determining the quality of safety.

Implication of safety as a non-absolute entity

Safety is a word everyone knows, but how it is understood by various parties can differ. Safety is associated with meeting a goal, and this is best illustrated by an everyday example relating to crossing a busy road without being injured by the traffic. How this task is performed is dependent on personal perception of what is safe and not safe. Pedestrian A may stand at a traffic junction and wait for the green light before crossing and this can take a few minutes. Pedestrian B may decide to cross the same road at any point when he or she thinks traffic is clear. In fact, there is no correct or incorrect way of crossing a road. In other words, safety is NOT an absolute entity. When safety is addressed, by an individual, an organisation, a nation or an international body, for any situation it assumes that safety is a specific absolute entity, and the effectiveness would vary depending on its closeness to reality. To overcome this feature, it is essential for decision makers to continually re-assess the process via an iterative safety management system circuit while applying a combination of understanding, reviewing of available data, analytical assessment and practical insights.

In general, an organisation, such as a shipping company, would select a safety standard (or risk level) and train its staff to implement it in practice. The term 'risk' is used, unfortunately, by many people to mean both 'hazard' and 'risk' in an inter-changeable way. A hazard can be regarded as an obstacle that prevents the objective being met. Risk is a two-parameter term represented as the product of likelihood of a hazard becoming a reality and the level of its consequences. People working in the operation may not understand the theoretical background to deriving the magnitude of risk of a specific hazard, but instead make their risk judgement based on the guidelines given, personal experience and probability of occurrence because consequence is usually regarded as intolerable or undesirable. Sometimes individuals can misjudge the risk and that may lead to human errors.

The use and limitations of a prescriptive regulatory approach

In most situations, safety is assessed based on prescriptive regulations devised and implemented by a regulatory body. The prescriptive principle is illustrated by an everyday example involving buying a cheesecake from Marks & Spencer, see **Figure 1**.

As can be seen, both the requirement and the method of solution are prescribed. This is a familiar concept to everyone: in childhood, it is the parents at home, at school it is the teacher, etc. In life, there seems to always be someone who is prescribing what one has to do. This, in turn, has led to the belief that this is the way that everything, including safety, should be treated.

However, it has to be recognised that the regulatory approach assumes safety is an absolute entity for two main reasons:

- Firstly, the regulatory body needs a reference standard for users in practical applications. For example, it would be unsafe and unworkable in the present day to let car drivers decide what speed they should drive on public roads.
- Secondly, once the reference is established it will allow the regulatory body to enforce the regulations and also to achieve consistency.

This approach is workable under most circumstances if hazards are known, and their risk levels are fairly constant and readily predictable.

Unfortunately, there are situations where these conditions are not available. For example, hazards changing and their risk level being unpredictable, such as the Covid-19 variants known as Alpha and Delta that appeared in the UK and worldwide in 2020-21 and are now being actively monitored and examined.

Significant innovations need to be critically assessed in a 'total systems' context

In the 1960s the desire to take one's own car to the European continent across the English Channel required a very good reason and patience as the car was treated as cargo. On arriving at the quay side, the driver and other passengers went on board while the car was loaded. At the end of the crossing, they had to wait while the car was unloaded. Overall, the journey across the channel could take as long as half a day.

It was a significant innovation when the open deck concept was developed, and one or more decks became open spaces where cars and lorries could drive on and off with minimum delay. The process of driving onto the ferry (Rolling on) and driving from the ferry (Rolling off), was given the name Ro-Ro. The introduction of this concept of crossing the channel was most attractive, particularly so with the freight operators. For example, fresh fruits and vegetables could be loaded onto a lorry in the south of Spain and be available in the North of Scotland within 48 hours without any adjustment to the loads.

However, like many situations in practice, there is a technical 'Achilles' heel' to the concept. If water found its way to the open deck, even a small quantity, the induced heeling moment could overcome the designed ship restoring capacity, normally determined by the ship weight (displacement) and the magnitude of the restoring lever, which is called GZ. **Figure 2** shows a vessel in various rolled positions (angles) against the values of GZ (intact ship). Regulations at the time did not account for the impact of water on deck These were enforced after the Estonia accident, in 1987, through what is known as the Stockholm Agreement, based on physical model experiments.

This means that the safety of a significant innovation must be assessed by a different method to that used traditionally via prescriptive regulations. In principle, a 'safety case' approach should be used to assess the safety implications of each innovation so that hazards with intolerable risk levels can be identified to ensure ferry operators give special attention to reduce the risk of any new feature. From a management point of view, there is also a need to understand any deficiencies and put appropriate measures in place to ensure that the residual risk from this 'Achilles' heel' is properly managed at all times.

Influences of safety interfaces on a complex system

It should be recognised that ferry operation is complex because

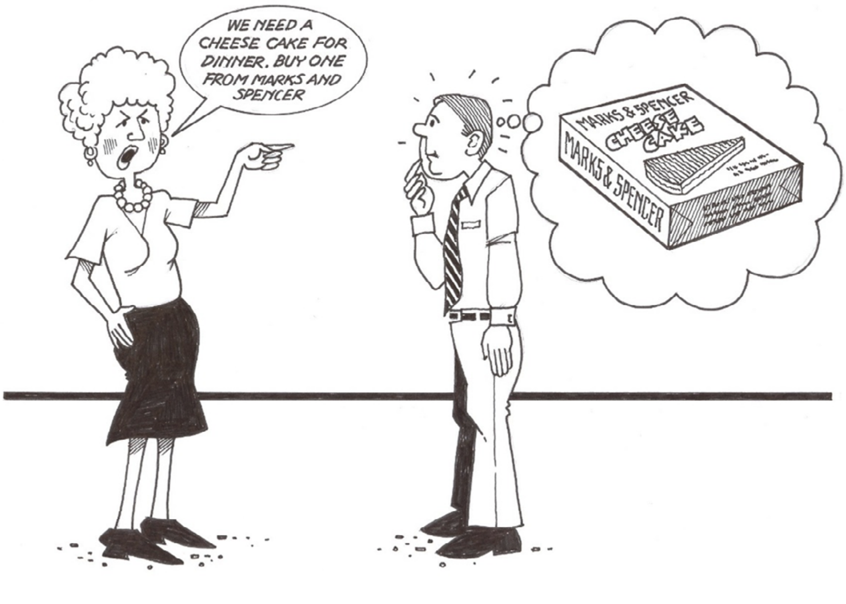

Figure 1: Buying a cheesecake for dinner.

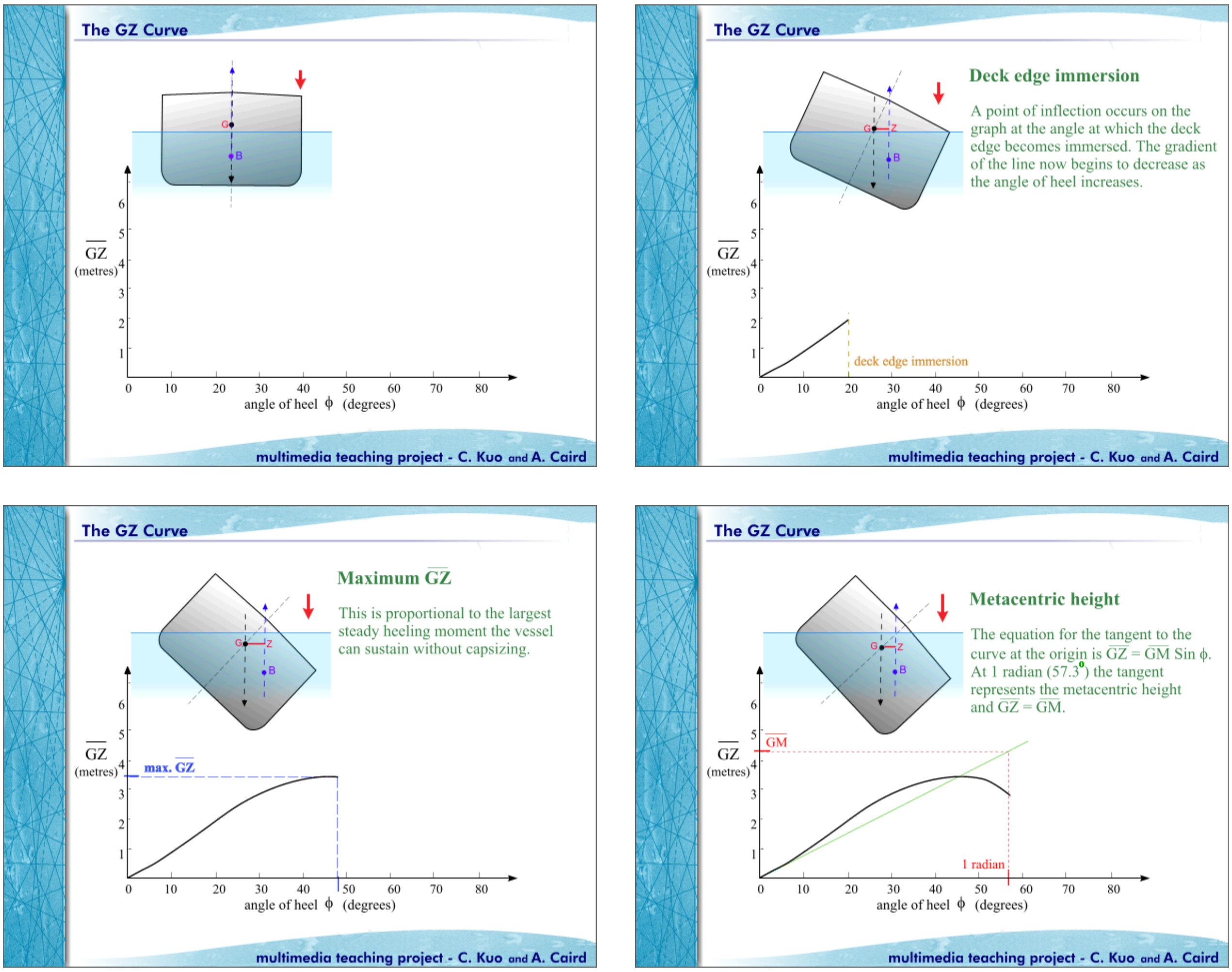

Figure 2: Animation to illustrate ship stability.

there are many system interfaces. This term is used here to mean interaction between different systems, including humans, while performing a task. The following are the main interfaces:

- Software-hardware: such as a prescribed process to be followed by equipment in performing operations;
- Software to software: the linking of two or more computer programs together into a larger software application;
- Hardware-hardware: combining the use of two supplied components in the design of equipment;
- Human-hardware: for example, the wearing of personal protection equipment when performing a hazardous activity;
- Human-software: when a human user implements a specific procedure in practice;
- Human-human: how a group of people work together or how two or more groups work together.

From experience, safety failures can usually be traced from these interfaces.

Interfaces in the following Ro-Ro ferry operations are relevant:

- Operating a novel design: It is assessed using the traditional marine safety regulatory approach, which does not take into account that new operations introduce new hazards with different risk levels.
- Commercial pressure: Ferry operations are very competitive because shipping is an international business. The demand for crossing the English Channel is very high, especially during the summer school holiday period.
- Operational procedure: For the reasons given in (b) above, the operational times are tight with rapid turnaround at ports. The short crossing route serves a large number of vehicles. In winter months, the schedules are affected by adverse weather conditions.
- Workload: The workload is high for the crew as the operation runs on a 52-7-24 schedule and key members are often heavily committed, leading to fatigue and, in turn, human errors.

- Crew communication: Ships are usually operated by crew from various countries with different cultural backgrounds and varying levels of language skills. This requires good communication between crew, especially during the busy periods.
- Politics: In any situation there can be problems with human-to-human interface and the term 'politics' is often used to describe the conflict of interest. These incidents can be unintentional as well as intentional. As an example, those operating onshore may not understand fully the working conditions of those working on board, leading to less co-ordinated operations.

The role of management in the quality of safety

As in any organisation, management plays a key role in all activities and, in particular, safety. It is the management team that decides on policies, development of organisational culture and makes decisions on a range of issues that include investment and commitment of funds. Safety has not been given top priority for many reasons. Two key reasons being:

Firstly, the boards of companies tend to focus their attention on short term issues, such as profit levels and investments for good return. Safety is regarded as an 'add on' expense, which should be minimised.

Secondly, there is a lack of understanding of the importance of safety and the critical responsibilities for safety assurance. This was identified in the public inquiry conducted under Justice Sheen.

However, there was a special change to the law in the UK for addressing safety as a result of the Herald of Free Enterprise accident that is often not recognised generally. It is concerned with the introduction of corporate manslaughter into the legal framework relating to safety. The effort was promoted by the Disaster Action charity, which was formed after the Zeebrugge ferry accident. Yet, it took 20 years before this became law. In the simplest terms, this law stipulates that instead of putting blame only on the actual person(s) responsible for the root cause of the failure and fining the board, the fault should also be attributed to the Board of Directors and that those responsible for safety may be jailed in the case of a fatality. The passing of this law in 2007 ensured a concentration of minds on safety at board level.

Insights

Seeking the views of colleagues in the profession

Having identified unlearned safety lessons, it was decided to seek the views of colleagues in the maritime safety profession by designing a special questionnaire and circulated it to those with responsibility for safety, or those involved in related safety projects. An example of the latter includes those who have been actively involved and participating in the STAB conferences, which are held every three years at different locations around the world.

The results of the questionnaire are given in the Appendix whilst key findings are highlighted in **Table 1**.

Main findings of the investigation

A summary of the main findings can be considered under the following headings:

- What went wrong? There are several aspects, and these include: The status of the bow door was not readily observable, and, in this case, it was left open due to human error when the ship departed from the port. Available draft gauges giving the loading conditions were not accurate enough. The location of the ship's centre of gravity was uncertain – it is a key stability parameter and was obtained by experiment when the ship was built, but over the years modifications were made and extra facilities added that changed the location. The company's management team was described as 'rotten to the core' in the public inquiry and it was unclear who was

Item	Issue considered	Agreement level
1	Safety is a non-absolute entity	70%
2	Management features involved in marine accidents	93%
3	Better understanding: safety factors	73%
4	Greater awareness of the management role	74%
5	Insufficient attention given to near misses	76%
6	Lessons: Higher safety for new GHG-less fuels	75%
7	Better awareness of management and management systems	78%

Table 1: Summary of key findings from the questionnaire responses of maritime safety professionals

responsible for the safety of the vessel.

- What aspects would improve safety? Firstly, a recognition by more people that safety is not only a technological matter but must consider other features such as human factors relating to attitude, behaviour, performance etc. and hence the complex nature of the system. Secondly, a "good level" of safety can only achieved when it is properly managed or, in other words, the need for good management at all levels.
- What potentially worse outcomes were avoided? These include the following: firstly, the ship capsized close to shore and in shallow waters, making emergency rescue operations more readily available and effective. The ship was busy, but not at its peak or running during the busiest operating times where there could have been more fatalities.

A design for safety management methodology

In the offshore oil and gas industry the treatment of safety was changed from using a prescriptive regulatory approach to a goal-based approach, namely the safety case approach, after the explosion of the Piper Alpha installation on 8 July 1988. The report from the public inquiry, popularly known as the Cullen report, made 108 recommendations and these included the use of a safety case approach. The methodology is based on system engineering when the safety of a system is examined by asking the following set of questions: What aspect can go wrong (or hazard identification); how likely that would be (probability of occurrence); and how serious are the likely outcomes (consequences), with the product of the latter two giving a risk estimation. In addition, it includes what to do when 'things' go wrong (emergency preparedness and response). These tasks are then managed by a linear safety management system. There is no doubt that this is an enhancement. Since safety involves both technical and management aspects, research has led to design for safety management that can integrate technical and management features. This thinking and method could be used widely, for example to examine the safety of ships using GHG-less fuels, such as hydrogen and ammonia.

Section 3: Discussion and transferable learnings

Overall lessons learned

The lessons for general safety derived from this case study can be summarised as follows:

- The safety of significant innovative ideas and solutions should be assessed in the total system context and by a systems engineering approach so that hazards with intolerable risk are identified and appropriate mitigation steps taken.
- The accident could have been prevented if management had given safety higher priority, thus ensuring there was a positive safety culture within the whole organisation, including attention to safety procedures such as closing the bow door before the ship sets sail.
- In the light of this accident and many investigations and research studies, there are now fresh guidelines and regulations on passenger Ro-Ro ferry operations plus greater safety awareness that would reduce the probability of similar accidents occurring, including enhanced resilience leading to a 'fail safe' system.

The target audience for this case study

There are many target audiences for the outcome of this case study:

- The prime target audience is the maritime and offshore industries. In the former, the focus is on maritime transport, which is responsible for 90% of bulk goods, and great effort is being devoted to the use of GHG-less fuel such as hydrogen and ammonia. Presently there is little operational safety experience. It is also relevant for those involved in generating offshore renewable marine energy where efforts are focused on floating systems where safety must meet both maritime and offshore regulatory requirements.
- Another target audience is land-based industries where safety is critical, such as the nuclear industry and the car industry developing autonomous vehicles. The lessons from this case study are fundamental and could be applied to addressing similar problems faced by these industries.
- Generally speaking, where safety of a complex system is concerned, the arguments presented, and the lessons learned are directly relevant and readily transferable.

Looking to the future

To achieve safer operations in a complex system, a number of suggestions are outlined here.

Firstly, it must be recognised that safety must be managed to achieve a desirable standard and this needs to be done at all levels. Top management has many responsibilities and a crucial one is the development of a positive safety culture within the organisation.

Secondly, there is a need for greater safety awareness by all stakeholders. One method of achieving this goal is conducting a number of focused active interactive workshops for the wider spectrum of stakeholders in order to improve communication and understanding. These should include addressing fundamental safety issues and its management as well as providing experience via simplified group exercises.

Design for safety management as a transferable methodology

This case study has shown the roles of technology and management and their interdependence. There is, therefore, a need to integrate these factors. An effective method would be to adopt the concept of design for safety management that can combine the advances made in design for safety with the application of management techniques to provide an effective and transferable methodology.

Appendix – results from the questionnaire

a) About the responders: There is a wide range of organisations with ship operations (28%) and consultancy (18%) being the largest groups (**Figure 3**).

b) Over 83% of the responders have either good or very good knowledge on safety

c) There is a general agreement (around 70%) relating to the impact on the non-absolute nature of safety; the regulatory approach assumes safety is absolute as a reference standard and enforcement, while the prescriptive regulatory approach would be unsuitable for complex safety systems (**Figure 4**).

d) The attitude of people is regarded (by 27%) as contributing most significantly to marine accidents and this is followed by the wrong procedure, lack of information and communication breakdown, with poor management

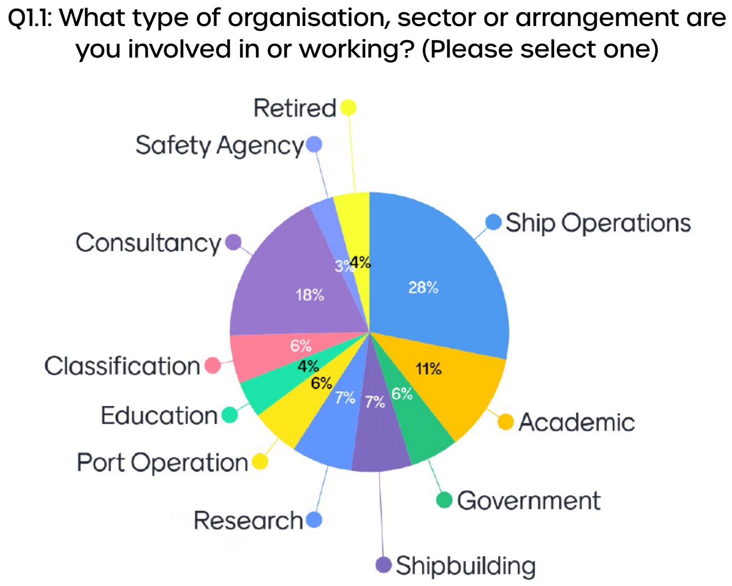

Figure 3: Background of the responders to the questionnaire.

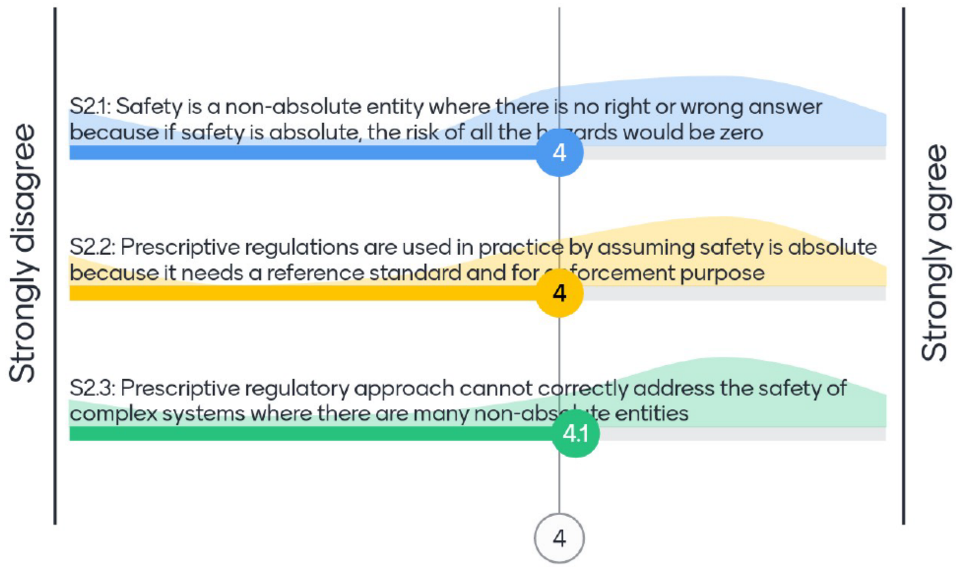

Figure 4: Findings of views on the non-absolute nature of safety.

receiving 17%. Yet, all the previous four factors are dependent on management. The total represents 93% (**Figure 5**).

e) General agreement on the lessons learnt from the Ro-Ro ferry accident, with more attention given to near misses (77%), better understanding of the role of management, better understanding of factors influencing safety and reduction in potential future accidents sharing equal scores (**Figure 6**).

f) The most significant benefits from the investigation were considered to be improved safety understanding and greater safety awareness in the industry (52%) (**Figure 7**).

g) Safety lessons for general application led to high agreement on the need for GHG-less fuels aiming to achieve a safety standard as high as reasonably practicable (78%) and technical people could benefit from some understanding of management and management system (78%) (**Figure 8**).

All industries could learn from maritime accidents for the following key reasons: understanding human factors, grasp of the non-absolute nature of safety and the important role of management.

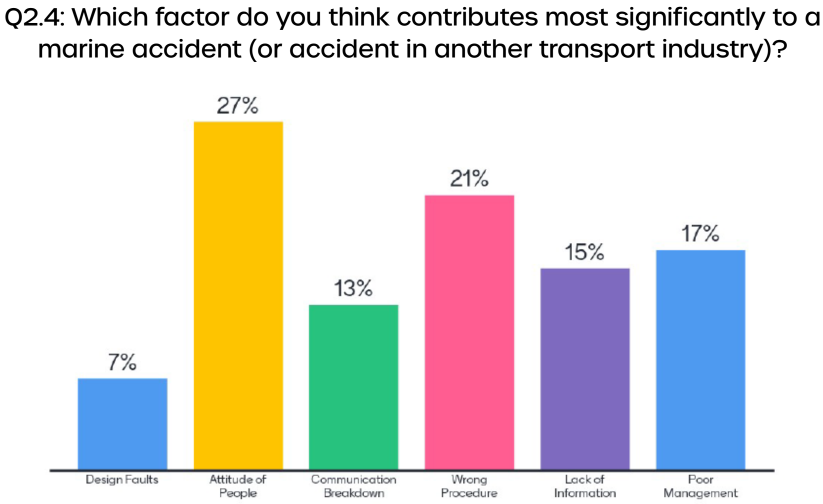

Figure 5: The factors that contribute to marine accidents

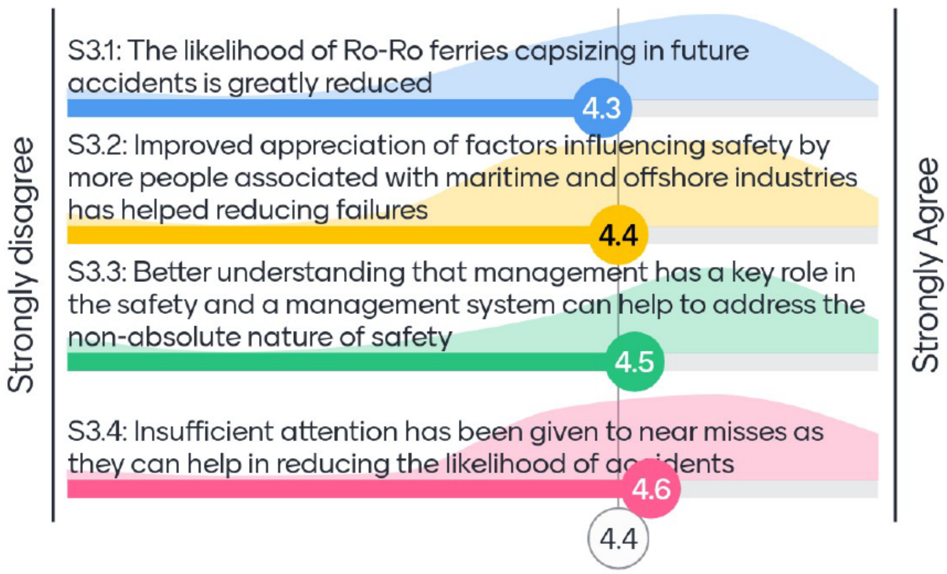

Figure 6: Lessons learned from Ro-Ro ferry accidents

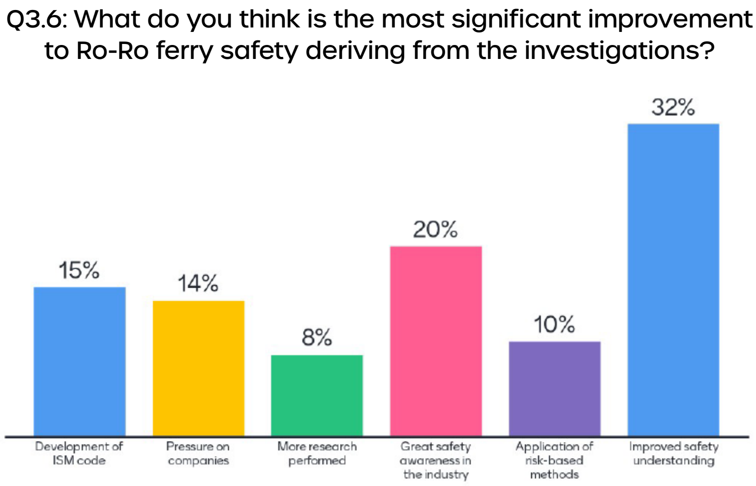

Figure 7: Factors contributing to improvements in Ro-Ro ferry safety

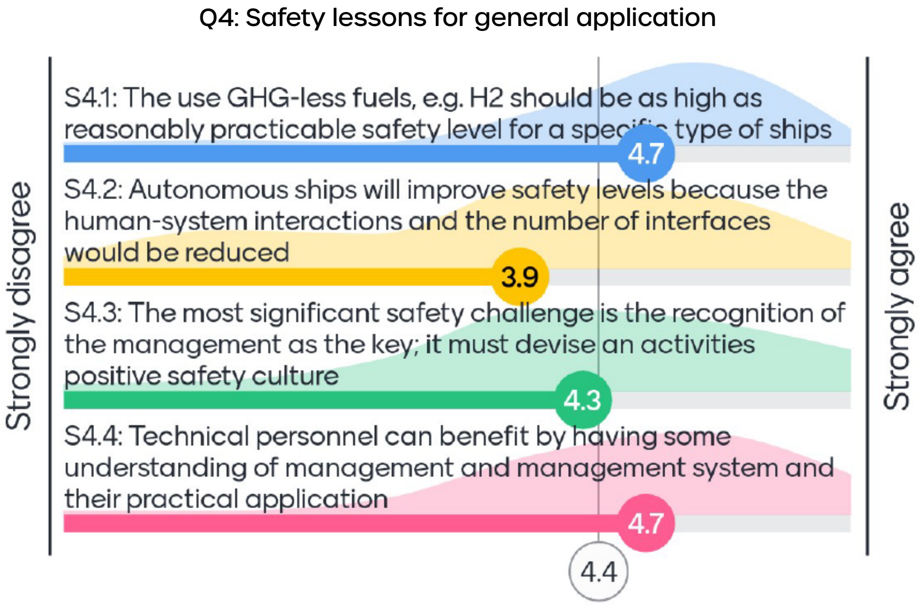

Figure 8: Findings of safety lessons for general application

In summary, the findings of the questionnaire have provided good guidance on how safety management can be adopted in practice and how safety lessons learned from Ro-Ro passenger ferry accidents can assist in enhancing the safety of complex systems.

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