Using a design approach to re-analyse the Costa Concordia Incident

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The paper presents a systematic re-analysis of the Costa Concordia incident using the domains of Human Factors Integration (HFI) completed by undergraduate naval architects.
The importance of the human element in the passenger ship industry, from the design stage of a ship to the end of its operational life, has developed through time. Human element considerations are becoming increasingly significant as a tool for creating efficient and safe working environments in the shipping industry. The human element is particularly important for passenger ships due to the number of people, complexity of operations and the resulting complexity of human interaction with the ship and its systems.

The work was carried out in collaboration between Lloyd's Register and Southampton Marine and Maritime Institute of the University of Southampton. An applicable understanding of the human element topic was developed using textbooks, public bodies of information and EU project HCD training. Methodologies used by investigative bodies were explored to apply the human element to incidents particularly involving passenger ships. The Costa Concordia public report was reviewed to elicit an extensive event listing. These events were generalised into themes specific to the Costa Concordia incidents. The limitations of current statutory rules and regulations were highlighted against these themes and the domains of (HFI).
The results were analysed to identify regulatory shortfalls (gaps, inconsistencies, and limitations), and present the distribution of events and regulations under incident themes and HFI domains. The paper will report these findings.

Keywords: HFI, Costa Concordia, Human Factors Analysis, Human Element, Incident Investigation

1. Introduction

This paper presents the work done on re-analysing the Costa Concordia incident using human element investigative methods in a collaboration between Lloyd's Register and Southampton Marine and Maritime Institute of the University of Southampton. A range of bodies of knowledge were studied to acquire an applicable understanding of the Human Element (HE) (IMO Assembly, 2003). The different methodologies used by investigative bodies were explored to find an effective way to apply the gained knowledge of the human element to accidents, particularly those involving passenger ships.

Within the passenger ship industry it is important to recognise the significance of the reputation of a ship, and thus the company. In an age where news is able to communicate events in real time and also available to everyone through technology, it is important to find the root cause of the incident by investigating every aspect. Within passenger ships, because of a greater number of human and ship interactions, a broader range of topics needs to be analysed to find the underlying problem. Therefore, an approach that includes the human element in the analysis of an accident allows for a more comprehensive approach to understanding the issue and helps perceive the complexity resulting from having a large number of humans on a ship.

This paper reports the development of a tool to address this need by addressing human element design considerations into a forensic investigative framework which can be applied to real life incidents. For this paper the Costa Concordia incident has been used as a case study. The study was suggested by Richard Vie (retired VP Technical Development and Quality Assurance of Carnival Corporaton & Plc) after he noted that many events and issues within the Costa Concordia could be related to the Human Factor Integration (HFI) domains from the UK Ministry of Defence (MoD).

In applying a HFI framework to the Costa Concordia incident, human element issues and events were uncovered which contributed to the grounding and the management of the emergency evacuation post grounding. This led to the development of a means by which the findings of an incident can be described with respect to the human element.

2. Development of Human Element Incident Analysis Tools

There are different methods to go about investigating a maritime incident. As stated by the Maritime Accident Investigative Branch (MAIB), "The sole objective of the investigation of an accident under these regulations shall be the prevention of future accidents through ascertainment of its causes and circumstances" (Secretary of State for Transport, 2005). Within this quote, the main purpose of investigative bodies is unmistakably identified, and it is clear why it is important to analyse fully all accidents. However, different investigative bodies focus on different topics and facts. This paper demonstrates that an investigation should go beyond seeing human error as the cause of an incident, and has to use knowledge about human factors to understand why this error occurred and thus understand in what way it can be prevented in the future.

As is often mistaken, the human element should not only be regarded as the management of people and making sure they complete their duties on board a ship. The human element also refers to the interaction between the ship and the human and his environment. The skills, limitation and needs of the human have to be considered within the design of the ship and throughout the ship's operation. It is therefore necessary to apply the knowledge on all aspects of the human element within incident investigation methodologies to qualitatively measure shortfalls in the ship's design and operations. This will lead to the human error being the start of the investigation, rather than the end.

The IMO investigation framework adopted and further developed by the MAIB can be considered the most complete investigative method in operation. However, it is of a forensic nature and only analyses the event. When MAIB reports on an accident they use a timeline method to explore all the possible causes of the accident. In starting this timeline they look for a type of cause from the following; machinery failure, environmental (unpredictable event), properties of cargo and human error event. Then they look for the recovery mechanism. This line of event reporting assumes a narrow line of casualization for the event. However, many events could be the summation of multiple failures, suggesting a large variety of different lines which could need investigating.

Systemic Analysis

In January 2006 at the 'Learning from Marine Accidents III' RINA conference Vaughan Pomeroy and Brian Sherwood Jones presented a paper which set out a new way to look at accident analysis and reporting, it was called 'Learning from experience – Adopting a systems approach to the analysis of marine incidents' (Pomeroy and Jones 2006).

Their paper proposes that current analysis of accidents does not allow for any future development and implies that the only way the industry can move forward is through serious incidents. They proposed taking the basic accidents, then using a mind map flow diagram to think through the incident to find more general themes. Then to work forward to say what would have happened. If presented well this way of reporting means more people can understand what happened and help the industry as a whole move forward and find more industry-wide systemic failures. As seen in in their paper they have taken a loss of a vessel and then using different themes identified events to work towards the contributory factors to the incident under six general headings.

These six headings attributed to the different areas of the lifecycle of a ship allow the use of the mind map to assign the events to the different headings and thus to the different stake holders. This way of generalising events into broader themes to identify the stake holders and their responsibility in an incident addresses the larger scope of the incident and impact on all the parties involved. This way of generalizing events will be used below. Systemic analysis also focuses on the humans within the system, not the system itself like over methods.

Human Factors Integration

Later in 2006 the UK's Ministry of Defence's Sea Systems Group published Management and Technical guide to HFI. In these documents they set out a new way to develop and assess the procurement of parts for use in Military situations. They described a set of 6 domains, set out in Table 1, which could cover all aspects of the human integration with systems. They were set out in the Management guide (MAP-01-010) (MoD Sea Systems Group, 2006) with the goal of helping to achieve optimum operational performance.

A benefit of this framework is the use of the technical guide (MAP-01-011) provides in-depth information on the different areas to be covered and the different issues in each area. This allows anyone to see what they might have to consider and the technical specification associated with it, similar to Alert!'s "Tablemat" (Squire, 2006). These considerations can help planning at an early stage to find who they need to consult to properly consider all of the human-system issues and interactions.
They also see that there is no perfect system and that in the design stage certain trade-offs will have to be made with the overall balance in mind, they have highlighted the following;

- Reduction in manpower numbers vs the cost of increased automation.
- Reduction in manpower numbers vs increased personnel skill requirements
- The cost of simplification of the user interface vs increases in training time.
- Reduction in operator manpower vs increases in support manpower and skill requirements.

The generic HFI domains are have been marinised and elaborated into specific considerations in Alert!'s 'Tablemat' (Alert! 40). These considerations can help planning at an early stage to find who they need to consult to properly consider all of the human-system issues and interactions.

3. Incident Analysis Methodology

To better assess the human element within an incident the new method proposed within this paper combines investigative procedures to HFI design considerations. Re-analysing the accident from a human element perspective allows for particular observations to be made, which might have not been considered using other investigative methods. This method is displayed in Figure 1.

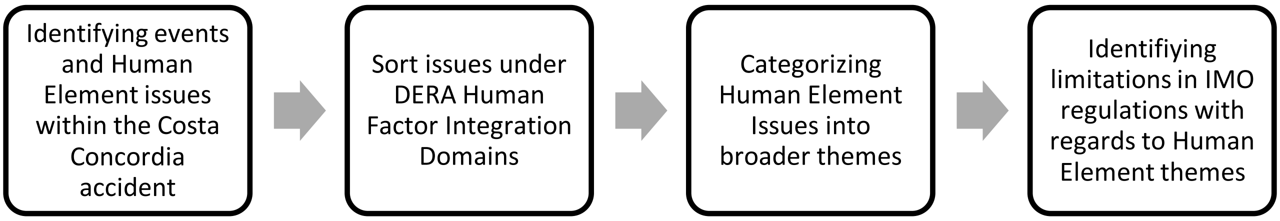

Figure 1 Flow diagram of methodology to consider the HE in incident analysis, and limitation s within the IMO regulatory documents.

Step 1: Every event and human element issue within the Costa Concordia incident was found from the investigative report. These were then sorted under the Human Factor Integration domains.

Step 2: These domains were used because they allow a better assessment of what aspect of the human element is being considered in the event, whether it is manpower, personnel, training, human factor engineering, system safety, or health hazards. These domains were used because they provide a more complete framework of looking at elements than the IMO's or Lloyd's Register's Alert! Human element considerations. The lack of a comprehensive human element structure in the commercial industry has meant that the optimum method of analysing the accident is using a framework which the industry does not have available. In addition to the six domains defined by MoD, and made to focus on the marine sector, an extra survivability domain was added. This human element domain is defined as any action taken or system available post casualty to decrease damage, loss of lives and facilitate evacuation.

Step 3: Because of the large amount of events and HE issues, these were categorized into broader HE topics that would convey the principal themes of these issues. The human element themes defined are given in Table 2. The category about the cooperation procedures between the ship and SAR was formulated because of the reporting method of the Marine Casualty Investigative Body that works together with the Italian coast guard.

Step 4: The IMO regulations, codes, resolutions, circulars, and guidelines are analysed to assess to what extent they cover the human element themes defined in this report. These regulations and documents were found using Lloyd's Register Rulefinder 9.23 (January 2015) – Statutory Documents program. Key word searching was used, on top of previous knowledge of the structure of regulation. Also, a guidance note on human element publications from the IMO (Lloyd's Register Marine Product Development , 2010) was used to direct the search for circulars and resolutions.

The layout of the final matrix is shown in Table 3. The principal vertical column shows the HE themes, and the principal horizontal row represents the HFI domains. Within each HFI domain there are two columns for stating the IMO publications and beside it the limitations or comments that have come up when reading the documents.

4. Analyses of Results

4.1 Distribution of Events and Regulation

To understand the matrix which was discussed in the previous section one view of the results is through a look at the numerical distribution of regulations, events, and Human Element issues within the different domains. This analysis gives an overview of the varying approaches by the industry, and even how effective they might have been in this case. However, it should be stated that this is purely based on numbers of regulations and events, not quality. This will be discussed in the following section.

A summation across the different domains for events and regulations with the difference between the regulations and events were calculated, this is displayed in Figure 2.

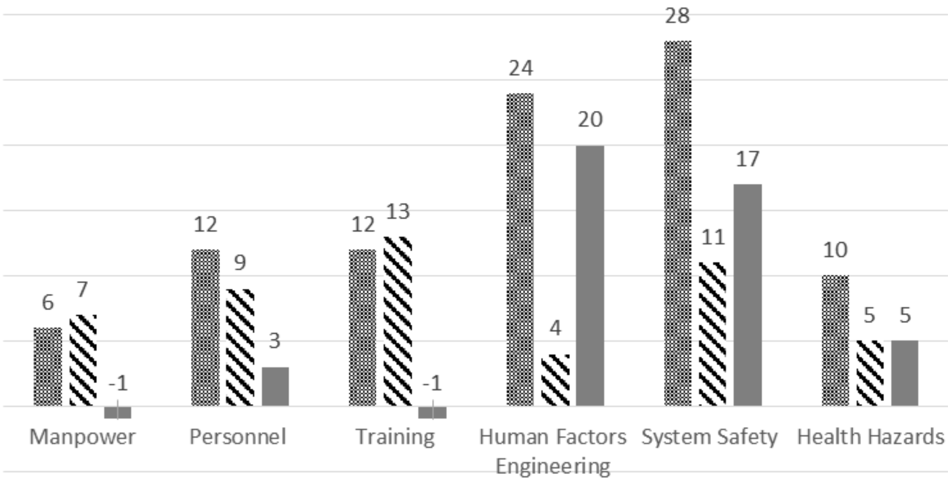

Figure 2 Distribution of Events and Human Element Issues, Regulations, and the difference between them.

Three cases were found: firstly, where there are large number of regulations and events (small difference), secondly being where there are more events than regulations (negative difference), and finally high regulations and few events (large difference). In the first case, as seen in ‘Health Hazards and ‘Personnel’, this could point to regulation which is not implemented correctly or poorly written. For the second case there are again two examples, ‘Manpower’ and ‘Training’. These both have many regulations meaning the issues may arise again from bad implementation in the industry, or the low number of regulations coming from the fact that a large document with high coverage is counted only once. The final case has again a large documentation background, but in very technically specific area. This could be a sign of ‘over-regulation’, but did still allow for some events to occur in the incident.

4.2 Findings - Regulations

This analysis identified issues in the incident that should have been covered by IMO regulations. It found that existing protocols are limited in their coverage of the HE, resulting in regulations which do not fully act as preventing measures for incidents. A topic which has arisen from the analysis of the incident is the assumption of perfect human performance in the regulations. Regulations such as MSC.1/Circ1251 ‘Guideline on the control of ships in an emergency’ (Maritime Safety Committee, 2007) assume that the master of a ship will remain in control of the vessel and will tell the SAR authorities everything they need to know. In reality however, as has been shown from the Costa Concordia incident, this is not always the case. This resilience on the human in an emergency situation to perform advanced procedures seems to be unrealistic.

Another finding was whether the deaths in the incident occurred, and whether they were passengers or crew members. This distribution lead us to investigate the use of the elevator as a means of escape. In SOLAS Chapter II-1- Part D- Regulation 42 – “Emergency Source of Electrical Power in Passenger Ships,” it states that the emergency source of electrical power shall be sufficient to supply all those services that are essential for safety in an emergency, and has to bring the lift car to deck level (International Maritime Orgnaization, 1980). Also, SOLAS regulation II-2/28.4 states that in no case should lifts be considered as forming one of the required means of escape. However, the Maritime Safety Committee (MSC) at its sixty-ninth session, approved guidelines on human element considerations for the design and management of emergency escape arrangements on passenger ships. These guidelines, recognized within MSC Circular 846, state that “in emergencies, lifts may be used as an additional means of escape, provided they are controlled by the assigned member of the crew and are supplied from the ship’s emergency source of electrical power. Members of the crew should be assigned to manually operate each lift designated for use in emergencies, and to clear and shut down lifts which are not to be used” (Maritime Safety Committee, 1998). Unfortunately, MSC Circular 846 provides a loophole for the use of elevators in an emergency.

As seen within the Costa Concordia incident, although the lifts are meant to attach to the emergency source of electrical power, if the electrical power does not run smoothly, or the emergency generator has difficulty in connecting to the emergency switchboard, the elevators will not function effectively, leading to people being trapped within them.

4.3 Findings – Analysis Tool

This tool was also able to determine that within the industry there are many well written and easy to follow regulations. However, because of the limitations of these regulations in addressing the HE, this tool supports the IMO resolution A.947 (23) “Human Element Vision, Principles and Goals for the Organization” (IMO Assembly, 2003) in combination with Resolution MSC.287 (87) “Adoption of the International Goal-Based Ship Construction Standards for Bulk Carriers and Oil Tankers” (IMO , 2010) to develop a new approach to tackle the role of the HE in regulation. This approach should be goal based, rather than traditional prescription.

It was found that there are traces of goal based standards in existing regulation, mostly within guidelines and circulars. The "Guidelines for Engine-Room Layout, Design and Arrangement" (Maritime Safety Committee, 1998) are a mixture of the usual checklist approach and goal based standards. The first section on lighting level is a series of check boxes, which on one hand can be used as a reference for a basic level of operational effectiveness, but on the other hand results in limited innovation for new design systems. The section on ergonomics uses goal based standards, as given in this example. "A noise-protected communication station should be installed in the general area that most maintenance and watchkeeping activities take place, such as the engine-room lower level or pump flat, and outside the control room, when a control room is provided." Within this regulation it allows for different designs of engine rooms and systems that may be used. It allows a designer to think about the use and situation it is in.

Similarly, a resolution which can and should be developed into a goal based regulation for considering the human element in ship design and ship operations is MSC-MEPC.7/Circular.3 – "Framework for IMO Consideration of Ergonomics and Work Environment." The circular recognizes that the seafarer is the "ship's primary protector of maritime safety and security" (MSC & MEPC, 2006). The circular states that the IMO should have five main key considerations for ergonomics on board ships to reduce P&I claims and human error. These are: manual valve operation access, location and orientation, stairs, vertical ladders, ramps, walkways and walk platforms, inspection and maintenance considerations, and the application of ergonomics to design. With the definitions of these considerations within the circular, goal base standards can be developed for ships in operation and for new builds.

5. Concluding Remarks

A better, human-centred approach to incident analysis and ship design is needed to create a more pre-emptive culture as the industry advances. Investigative methods to analyse major accidents are well developed and implemented in the maritime industry. However, as discussed in this paper, a post analysis of an incident is a useful tool to evaluate less familiar perspectives which can highlight previously unseen root causes.

By re-analysing the Costa Concordia incident we identified Human Element issues which contributed to the grounding and also to post grounding events. Because of the complexity of passenger ships, the impact of human factors in the emergency procedures was more significant to the overall casualty than the human element issues leading up to the grounding. As observed from this paper the majority of the IMO's statutory documents are concerned primarily with operational limitations to maintain safety and ship systems within emergency procedures. However, the effectiveness of these regulations is restricted because of their limitations in addressing the human element.

When the tool developed in this paper is applied to an incident it highlights limitations and deficiencies in statutory IMO documents. The paper supports the development of goal based standards in regulation to cover the human element. This study did not include Class Rules. Gaps related to regulation and the event that could be addressed by class are not described in this report. However, this gap could be suggestions for new areas improving the rules to a more human element focus system.

To conclude, analysing incidents from a human element perspective can allow for a better understanding of how the ship is used and where danger areas are. The approach described in this paper is a useful tool to identify human element issues for designers, operators, ship owners, surveyors, maritime accident investigators and also students.

6. Acknowledgements

This paper would not have been possible without the initial momentum from Richard Vie, the investigative insights from David Wheal at the MAIB, the enthusiasm of Brian Sherwood Jones with his work in the CyClaDes project and the supervision of Dr Jonathan Earthy at Lloyd's Register and Dr Dominic Taunton at the University of Southampton.

Knowledge of the quoted incidents within this paper originates from publicly sourced reports by the Italian Ministry of Infrastructure and Transport Marine Casualties Investigation Body as well as UK's Marine Accident Investigative Body. The analysis done was not in any way intended to be critical and its sole purpose was to expand the knowledge of the human element within maritime incidents.

7. References

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8. Appendix

Table 1 HFI Domains as set out in MAP-01-010 *(MoD Sea Systems Group, 2006)*

Manpower	Concerns the number of men and women, military and civilian, required and available to operate and maintain the system under consideration.	
Personnel	Considers the aptitudes, experience, and other human characteristics, including body size and strength, necessary to achieve optimum system performance.	
Training	Embraces the specification and evaluation of the optimum combination of: instructional systems; education; and on-the-job training required to develop the knowledge, skills and abilities needed by the available personnel to operate and maintain systems to a specified level of effectiveness under the full range of operating conditions.	
Human Factors Engineering (HFE)	Covers the comprehensive integration of human characteristics into product and system design, including all aspects of workstation and workspace design. For vessels it also considers accommodation and habitability issues.	
System Safety	The process of applying Human Factors expertise to minimise safety risks occurring as a result of the system being operated or functioning in either a normal or an abnormal manner. The objective is to reduce to 'as low as reasonably practicable' (ALARP), the risk of injury to service personnel (non-service persons under some circumstances) and damage to equipment. Often, engineering solutions are called for. In some cases, changes to interface design, personnel selection criteria, training requirements, manning or operating procedures may provide a cost-effective alternative.	
Health Hazard Assessment	As part of System Safety considerations, this process seeks to identify and address conditions inherent in the operation or use of a product that may cause death, injury, illness, and disability or reduce the performance of personnel (e.g. vibration, toxic fumes, radiation, noise, shock, recoil).	

Table 2 Human Element Themes Definitions.

Human Element Topic	Definition
Seafarer within Emergency Procedures	The reliance of the emergency procedure on the number of crew available and the performance of the crew.
Ship's Detection System	How well the ship is able to assess the condition of the ship and relate information to the sea farer
Competence of Senior Officers	Whether the officers in charge are capable of making decisions in emergency situation with the correct support
Working Systems of Compartments within a Ship	The interrelationship of compartments and systems within compartments including the workability of the environment.
Evacuation Systems	The evacuation and escape arrangements for passengers and crew.
Actions in navigational procedures	How much of the navigation relies on active participation of the seafarer and his presence.
Inadequacy in Communication	How the ship's crew communicates with each other and with the bridge and vice versa.
Cooperation procedures between the Ship and SAR	The process of the ship collaborating with the SAR, assuring the safety of passengers, cargo, ship, environment and crew
Operational Limitations to maintain safety	How well systems are integrated to provide continuous safety in normal and abnormal operations
Weakness in Company Requirements	The Company's responsibility to consider the human element within operations and emergency procedures
Ship Systems within emergency procedures	Socio-technical integration of ship systems in emergency procedures.

Table 3 Example Final Matrix Layout.

Category	HFI Domains													
	Manpower		Personnel		Training		Human Factor Engineering		System Safety		Health Hazrds		Suriviability	
	Regulation	Limitation	Regulation	Limitation	Regulation	Limitation	Regulation	Limitation	Regulation	Limitation	Regulation	Limitation	Regulation	Limitation
Seafarer within Emergency Procedures														
Ship Detection System														
Senior Officers Competence														
Subdivision of ship -bulkheads, and spaces														
Evacuation Plan														
Limitations too Navigational Procedures														
Inadequacy in Communication														
SAR procedures														
Operational Limitations														
Weakness in Company Requirments														
Ship Systems within emergency procedures														