

Collisions at Sea: A Systems Analysis of Causal Factors and Countermeasures

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Abstract. Despite established and proven prescriptive safety legislation, accidents regularly occur across all sectors of shipping. Of particular concern is the number of collisions that continue to occur, even when experienced and trained officers are on board and modern navigation aids are in use. Using a systems approach, this paper will highlight common contributory factors, which can lead to collisions and then propose a set of countermeasures which can be used to reduce these types of shipping accidents.

Keywords. Shipping. Safety. HFACS. ACCIMAP.

1. Introduction

The expansion of the shipping fleet has placed enormous pressure on shipping companies to attract and retain trained and experienced sea-going staff and this has somewhat diluted the experience onboard. In addition to constantly investing in the recruitment and training of seafarers, there is now more pressure on the shore organization to monitor the shipboard operation for compliance, not only with international legislation, but also the company's own policies and procedures. The expansion of the fleet has also affected the recruitment of shore operational staff, these are traditionally drawn from a senior seagoing position such as Master or Chief Engineer and bring their skills and expertise to the shore-based organization. As the experienced pool of officers at sea and the experience of shore management staff decreases, the exposure to human error becomes more prevalent at sea, and organizational factors which may contribute to accidents (within the shore and ship environments), may also increase. By contrast, increased onboard automation and electronic navigation systems are becoming more commonplace and alongside investment in the training of ship and shore staff the risks of accidents at sea should be reducing.

Unfortunately, that does not seem to be the case. The shipping paper 'Tradewinds' reported for the period January to August 2016, a total of 26 collisions and 18 seafarer deaths.

In reviewing a number of selected accidents, using a systems approach, a set of accident reduction countermeasures will be developed which addresses the increasing likelihood of human error as accident causation in shipping accidents.

2. Methods

2.1.1 Sample

With an average of 300 collisions reported each year (Sea-web™, 2016), there is scope for much needed improvement in order to reduce year on year the number of collisions. For this study, four collisions with loss of life were analysed using Accimap and HFACS-Marine. These accidents were chosen because they had formal reports issued by maritime administrations which had not considered human and organisational factors as the accident causation.

2.2 Systemic Accident Analysis (SAA)

Human and organisational factors have only been researched to a limited extent within the shipping industry, however there are several generic models and frameworks for (SAA) that are established and could be applied to the shipping sector.

2.2.1 *Accimap*

The first SAA technique selected is the 'Accimap' method (Rasmussen, 1997). One of the advantages of Accimap is that it provides a graphical picture of the relationship between causal factors contributing to an accident, as well as details of how these factors interrelate and contribute to the accident. Accimap also provides details of external influences on the functioning of the system including regulatory and wider industry-related influences.

The Accimap method can be used to represent the high level system failures, decisions that were made and also actions by the actors that may have influenced the outcome. Accimap uses six levels to analyse; governmental policy and budgeting, regulatory bodies and associations, local area government planning and budgeting, technical and operational management, physical processes and actor activities and equipment and surroundings. These levels make the Accimap analysis adaptable to many industries.

2.2.2 *Human Factors Analysis and Classification (HFACS)*

The second SAA technique selected was Human Factors Analysis and Classification System (Wiegmann, D. A. and Shappell, S. 1997). HFACS was selected due to its established taxonomy which has already been modified for a number of industries including mining and rail industries. This technique can give an insight into accident causation by focusing on human error in organisational systems, something which is very relevant to the shipping industry.

The HFACS model was reviewed and modified as part of earlier work (Murray, 2012) in order to be relevant to the shipping industry. Compared to the standard HFACS model, HFACS-Marine includes the following changes: At the 'Preconditions for Unsafe Acts' level, 'Environmental Factors' has been added due to the influence of the environment. This category is then further split into two further categories; 'Physical Environment' and 'Technological Environment'. The physical environment category is a factor in an accident if the environmental phenomena affect the actions of the individuals involved and result in a human error or an unsafe situation. Technological environment is a factor when a design factor or an automation issue results in a human error or an unsafe situation. Other changes to this level include; 'Crew resource management' subcategory is changed to 'engine room or bridge resource management' to reflect terminology in the marine industry. This subcategory will cover human error associated with situational awareness, workload, leadership and culture when working as a team. 'Personal readiness' is changed to 'fitness for duty' to reflect ship board practices such as hours of rest periods and alcohol restrictions prior to duty. The hierarchy onboard the ship has a very steep authority gradient with the Captain having supreme command. Shipping companies also have very structured and hierarchal organisations for their day-to-day management of ships. Based on this, unsafe supervision has been changed to 'unsafe leadership' and the subcategory 'inadequate supervision' is changed to 'inadequate leadership' and 'supervisory violations' to 'leadership violations'. Patterson and Shappell (2010), suggest that there should be an additional tier to Reason's four main levels of failure called 'Outside factors'. These may be regulatory, political, social, environmental or economic. For HFACS-Marine, this tier is titled 'External Factors' to reflect decisions that are made remote from the ship and its operation that may affect safety.

3 Results

3.1 Accimap Analysis

The Accimap output shows the factors across the different levels of the system relating to the failures involved in the accident. While the Accimap has six levels, in the case of analysing the four collisions, there was no failure associated with government policy and budgeting.

At the equipment and surroundings level there are several factors that may have contributed, including issues relating to the radars and also, in one accident, a factor may have been mechanical failure of the propulsion and/or steering systems. At the physical processes and actor activities level, various failures relating to the failure to follow navigation procedures as required by legislation and also the failure of the officers to follow best practices, particularly in restricted waters was evident. Given the lack of look out and poor communication or indeed no communication between the two ships involved, leads to the conclusion that the navigating team did not understand, or were unaware, of the hazard the ships were in. Other important factors to consider at this level include the Captain not being called in order to use his experience to assess the situation in good time and fatigue may have played a part in the decision making.

At the technical and operational management level, inadequate Company instructions, together with a lack of officer training, contributed to a lack of compliance with the most fundamental legislation relating to safe navigation; the Collision Regulations or ColRegs (IMO, 1972). This also had a direct influence on several factors at the physical processes and actor activities level. At this level, the Captain has to ensure his navigating team is directed appropriately and be aware of what is expected of them. Where English is not a first language, problems can arise in close quarter situations when the only option is to contact the other ship directly in order to prevent the collision after other means have failed. Failures relating to the shore management are also shown at this level; these include no processes for assessing the effectiveness of the navigation procedures or the compliance of the officers with same. Additionally, investigators highlighted in one official report that navigating officers had served for extended periods of time onboard the ship without a break.

The basic building block of shipping operations legislation is the International Safety Management Code (the safety management system) (IMO, 2002) and in several instances, failures were found because either there was not compliance with the Code or the ISM Code was inadequate. A lack of compliance with the Safety of Life at Sea (IMO, 1974) legislation was also highlighted in one collision, this is related to the requirement to have certain bridge equipment in operation when the ship is underway. At the regulatory bodies and associations level, a factor highlighted was the lack of a regime to test certain required bridge equipment after maintenance.

3.2 HFACS-Marine Analysis

The failures were classified across the levels of the HFACS tool. At the unsafe acts level, the analysis shows that there was a breakdown in effective watch keeping on two of the ships prior to the accident. Effective watch keeping is fundamental to the safe navigation of a ship, even more so when environmental factors contribute to the accident.

In one accident, the watchkeeper used the radar initially, but then made a decision not to pay further close attention to the ship as his perception of the track of the other ship was such that he 'felt certain' that the ships would pass at a safe distance. Only three minutes later the other ship was visually sighted only approximately 200 metres away and on course to collide. The HFACS output highlights that three out of the four accidents failed to use the navigation equipment correctly, including radar, which was available to them.

In one accident, also at the unsafe acts level, the Chief Officer's perception from navigating in open sea with very low marine traffic may have caused him to be lulled into a false sense of security and possibly caused him to misjudge the evolving situation. At the pre-conditions for

unsafe acts level, the environmental factors were only evident in one accident, the poor weather conditions requiring additional care to be taken when navigating and there was also an issue with the operation of the radar functions relating to the Automatic Radar Plotting Aid (ARPA) function. Poor communications were identified under substandard practice of operators in three collisions. While the correct application, by all parties, of the collision regulations should ensure safe navigation and avoid an accident, the investigators highlighted the lack or poor use of communications in good time, prior to the collision. Hours of work and rest periods are strictly controlled by legislation onboard ships, however it was identified by one of the investigations that the Captain may have failed to comply with the requirements due to the inexperience of one of his navigating officers which required him to be more available on the bridge in order to monitor the officer's watch performance.

Under unsafe leadership, all accidents reviewed had violations relating to the failure to comply with the ColRegs. This is seen as fundamental and the Captain, in command of the ship, has a responsibility under his leadership to ensure that his navigating officers are fully aware of the regulations and that they are implemented and followed correctly. This also highlights inadequate leadership relating to the limited experience of some of the navigating officers as officer of the watch. In addition, poor lookout was identified in two of the accidents, this being fundamental to resource management on the bridge particularly when there is restricted visibility or there is a risk of collision. At the unsafe leadership level, written instructions, whether a company policy or specific orders from a Captain, are required to be explicit and followed; in one instance this did not occur. The Captain's standing orders should give navigational instructions covering areas such as safe distances to be kept and also the requirements relating to this when a Captain should be called to the bridge in order to take control of the situation.

Considering the organisational influences, one accident investigated had issues relating to manning. This was due to the officers onboard not being relieved in time, with their time onboard coming to an end but having to extend their contract. Extended onboard time can lead to complacency, fatigue and a general lack of motivation. Only one accident investigation directly identified company procedures as being inadequate.

4 Discussion and Conclusions

The accident reports used for this study recommended updating procedures or management systems instead of researching the reasons behind the failures of the navigating officers to comply with legislation such as the ColRegs. This paper demonstrates the potential for a system-based approach which facilitates lessons to be learned and for regulatory bodies and shipping companies to take a proactive stance when reviewing any incidents or indeed audit observations, when results could be categorised using one of the tools. System based approaches have already been proposed for analysing events in other industries which have the potential for human error. Shorrock and Kirwan (2002) proposed several techniques for both the retrospective and predictive analysis of cognitive errors within the air traffic control sector. The shipping industry faces similar challenges and therefore a systems approach is appropriate. For this study, Accimap and HFACS were the system based tools selected and the approach to applying each is quite different. Salmon et al. (2012) compared the use of Accimap with HFACS and his analysis also found similar conclusions which are briefly described below.

4.1 Accimap vs. HFACS

The Accimap analysis is conducted without any taxonomy as guidance. It allows all the contributory factors to be assessed and also the interactions between them to be considered.

However, one of the issues with the Accimap analysis is that it is very subjective as the failures can be described in different ways by the person conducting the analysis. HFACS, by contrast, is more structured and has a taxonomy associated with the tool. This gives more guidance to the analysis relating to the error and contributory classification being considered. HFACS also worked well when considering a number of accidents together as in this case. However, one of the problem areas associated with the HFACS study and, as identified by Salmon et al (2012), is that the tool is heavily associated with the aviation industry and many of the error and failure modes are industry specific. This was addressed in this study by the use of HFACS-Marine. Considering ship accident investigation, the HFACS-Marine tool may be used by non-professional safety practitioners in the safety departments of shipping companies. This would allow shipping companies to analyse their near misses, incidents and accidents relating them to human and organisational factors within the company, thus allowing root causes to be identified, corrected and prevented.

4.2 Conclusion

The legislative process in shipping is not a revolutionary step change. Rather, it is evolving as new practices and tools become accepted generally first in other industries, followed by being accepted in the shipping sector. Certainly in the case of collisions, the basis for avoiding them are already in place and proven but there is still something going wrong based on the accident data assessed in this study. The systems approach allows a new focus to be introduced in order to reduce the number of collisions and near misses.

Furthermore, focusing on collisions specifically, several actors and organisations in shipping companies have a role to play in reducing the frequency of such accidents. Shipping is complicated as there is not only a shore management structure, but there are also a number of remote satellite offices (the ships) that require to be monitored and measured against company's policies, procedures and other requirements. In addition, the shipping industry has a transient workforce as seafarers are usually only employed on a contract basis. As a result, and more so than other industries, establishing a safety culture on a ship can prove challenging due to its remoteness from the shore structure. The following is therefore a description of measures that could be introduced in order to reduce the contributing factors to collisions and secondly, a proposal for further research.

The ISM Code (Section 12, Company Verification, Review and Evaluation) requires 'internal safety audits on board and ashore at intervals not exceeding twelve months to verify whether safety and pollution-prevention activities comply with its safety management system'. However, both analyses show that there is a lack of compliance with the required legislations (the STCW and ColRegs) as a factor in all of the collisions. This does raise the issue of the adequacy of internal audits. In the case of ensuring safe navigation of their ships, some companies do not consider internal audits adequate and therefore use external contractors to conduct additional audits. The introduction of this requirement for an additional external auditing function is something that may be considered in an effort to improve onboard compliance with regulations and procedures. From 2017, navigating officers will have to complete a Bridge Resource Management training course and while this training may address some of the issues raised in the analyses such as communication and the authority gradient, the BRM training is not conducted onboard with the actual team working together. Therefore, as part of the external auditing suggested above, an onboard 'bridge resource assessment' should be carried out by an auditor. This assessment will be required on a regular basis due to the changing personnel onboard. Additionally, BRM training does not include ratings which may interact with the officers both as a lookout and as a helmsmen. The onboard bridge resource assessment would also be able to assess this relationship.

Both analyses highlighted the failure of the watch keeping officers to comply with the ColRegs something very fundamental to a navigating officer's skill set. There is currently no

refresher training required for these important regulations. Therefore, navigating officers should be required to undergo formalised repeat training and assessment of the ColRegs. Taking this one step further, and as is common in some other industries, a Competence Management System could be introduced. The purpose of such a system relating to individuals is fourfold; it will make the individuals aware of the required competencies required for their role, ensure that they receive the correct training, assessment and development, that they have the appropriate experience and importantly in this instance; maintain or improve their competence over time.

Together, the introduction of required refresher training and a competence management system will contribute to ensuring that all navigating officers have current and comprehensive knowledge of their fundamental tools for navigating, even those that have been in rank for an extended period. Adding external auditing of onboard navigation skills and a bridge resource assessment should ensure that the number of collisions reduces over time. This will also impact the other categories of accidents positively, such as grounding or foundering, when poor navigation has had a part to play in the accident.

4.2 Study Limitations and Future Work

While the sample size of the study was small, based on the author's experience of ship operations, the factors leading to the collisions are consistent with observations that relate to navigation when ships are audited by either external or internal inspectors.

It was also interesting to note that in none of the reports reviewed did the investigators consider the shore influence on the operation and safe navigation of the ships. This would include closely checking a company's safety management system for compliance with the legislation, the auditing of the system (which is required by the ISM Code to be conducted both ashore and onboard), the role of the shore-based staff and ensuring that once an officer has been trained his standard of navigation is measured and re-assessed as necessary.

Despite the limitations discussed above, the authors believe that the findings of this study offer a basis for future work and research in the area of accident causation in the shipping sector.

Both shore and sea staff work in a very hierarchical manner, with vertical integration, and this may limit the advantages that a systems approach may bring. Therefore, further research needs to consider this and approach the problem of unsafe navigation as a contributor, while also recognising the specific problems of shipboard management of people, this includes considering the workload and the work pattern of the seafarer to prevent cognitive overload and the effects of fatigue. Further, there is scope for analysing the work system on board using macroergonomics, this focuses on the organization-system interaction.

Macroergonomics can be applied when the work system comprises two or more people working together, as in the case of a bridge navigating team, and they interact with technology within an organizational system that is characterized by an internal physical and cultural environment (Kleiner, 2006). Using this technique, technological and personnel systems can be assessed to consider how they are designed with respect to each other and also considering the demands of the external environment on the work system in order to achieve a harmonized work system.

Applying the systems approach not only to collisions, but to other accident causations, will benefit the shipping sector. This is especially true where the causation factors are similar.

This research has showed that accident investigations in the shipping sector do not routinely consider human and organisational factors as contributors. They tend to mainly look at the physical factors, but not the underlying reasons why the factors occurred. The systems approach can consider these underlying reasons and apply corrective and preventative actions to prevent re-occurrence. In addition, adopting a systemic perspective, apart from its

application to accident investigation, can also be used to review operational practices, before an incident occurs.

References

- Chang, A. Schyve, P.M. Croteau, R.J. O’Leary, D.S. & Loeb, J.M. (2005). The JCAHO patient safety event taxonomy: a standardised terminology and clasificatiob schema for near misses and adverse events. *International Journal for Quality in Health Care*, Volume 17, Number 2, pp 95 – 105.
- International Maritime Organisation. (1977). *Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs)*. London. International Maritime Organisation.
- International Maritime Organisation. (2002). *International Safety Management Code*. London: International Maritime Organisation.
- International Maritime Organisation. (1974). International Convention for the Safety at Sea (SOLAS), 1974. Retrieved 15th September, 2016, from [www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-\(SOLAS\),-1974.aspx](http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx)
- Murray, S. (2012). A Proposed Technique to Identify Human and Organisational Factors in Accident Investigations in the Marine Industry. Heriot Watt University. Edinburgh.
- Patterson, J. and Shappell, S.A. (2010). *Operator error and system deficiencies: Analysis of 508 mining incidents and accidents from Queensland, Australia using HFACS*. *Accident Analysis and Prevention*, 42(2): 1379-1385. Elsevier.
- Rasmussen, J. (1997). *Risk Management in a Dynamic Society*. Swedish Rescue Services Agency. Karlsted, Sweden.
- Salmon, P. Cornelissen, M. and Trotter, M. (2012). Systems-based Accident Analysis Methods: A Comparison of Accimap, HFACS, and Stamp. *Safety Science* 50 pp. 1158 – 1170. Elsevier.
- Sea-web™ online. Retrieved 5th September, 2016, from http://maritime.ihs.com/Areas/Seaweb/authenticated/authenticated_handler.aspx?control=casualtysearch&bp=1&type=clear
- Tradewinds online. Retrieved 20th September, 2016, from www.tradewinds.no
- Wiegmann, D. A. and Shappell, S. (1997). *Human Factors Analysis of Post-Accident Data: Applying Theoretical Taxonomies of Human Error*. *International Journal of Aviation Psychology* 7, 67-81.