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The Contribution of Ship Bridge Design to Maritime Accidents

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ABSTRACT

Shipping is an industry where accidents have potential catastrophic effect on humans, the environment or material assets. The design of bridge equipment and the bridge layout has a significant impact on the human-technology interaction on a ship's bridge, hence design is important for safety of navigation. This paper presents a review of 28 accident investigation reports from the last decade where design of ship bridge equipment or bridge layout has been identified as contributing factors. Six categories of design issues were identified: 1) Bridge layout; 2) Not using available electronic equipment; 3) Unexpected use of electronic equipment; 4) Mode confusion; 5) Lack of information about system status; 6) Trust in electronic equipment. The corresponding investigation boards' safety recommendations and the shipowners' responses, mainly concerned revising the safety management system, revising or introducing procedures and checklists, as well as crew training. These responses place the responsibility for an improved human-technology interaction on the human operator. The few recommendations and actions that concerned improving design of technology where local fixes that do not contribute to learning on organizational or system level.

Keywords: Ship bridge design, Human-technology interaction, Accident investigation

INTRODUCTION

Shipping is an industry where organizational accidents occur. Reason (1997) describes organizational accidents as events that can have a catastrophic effect on humans, the environment or material assets. Further, organizational accidents occur within modern complex technologies, and they have multiple causes, involving many people at different levels in their organizations (Reason, 1997). Applying a systemic view on maritime accidents is not common, rather it is frequently reported that around 80% of maritime accidents are caused by human error. However, Wròbel (2021) could not find evidence for what he denotes the *80% myth*. Navigating a ship is a complex task that involves close interaction between the navigators and the technology and artefacts available on the ship's bridge. The design of the bridge equipment and the bridge layout has a significant impact on this interaction (Oltedal & Lützhöft, 2018). This is recognized by the International Maritime Organization (IMO) through the SOLAS V/15 regulation that requires human factors considerations in ship bridge design (IMO, 2002). However, lack of usability in the design of ship bridges and ship bridge equipment is a persistent challenge in the maritime industry (Costa & Lützhöft, 2014; Millar, 1980). This paper presents a review of 28 accident investigation reports from the last decade where design of ship bridge equipment or bridge layout has been identified as contributing factors. The objective of this review is to identify what kind of design issues the investigators recognize, as well as how these design issues have been followed up through the investigation boards' safety recommendations and the shipowners' response.

MARITIME ACCIDENT INVESTIGATION

Flag states are responsible for carrying out maritime accident investigations of accidents and incidents involving ships flying its flag or accidents occurring within its flag state territory (IMO, 2008). Human and organizational factors are included in the IMO guidelines to assist in the implementation of the Casualty Investigation Code (IMO, 2013). The accident investigation can be carried out by commissions or accident investigation boards within the flag state. The objectives of the investigations are to determine the accidents circumstances and causes, and to learn and prevent future accidents.

Studies of accident investigation reports have revealed design issues to be contributing factors to accidents. For example, Puisa (2018) analyzed accidents and incidents with passenger ships and found one of the prominent issues to be incomplete hazard analysis during design. Especially design issues that involve interactions between technology and people are either overlooked or not communicated to the operator (Puisa, 2018). Inadequate bridge design was also found to be one of the underlying factors in Sandhåland's (2015) study of accident reports from collisions between attendant vessels and offshore facilities in the North Sea.

In 2021, the Danish and the UK Maritime Accident Investigation Boards published a report from a study regarding the use of Electronic Chart Display and Information System (ECDIS). The study was issued due to the many investigations of groundings where a mismatch had been found between the way seafarers used ECDIS and the intention in performance standards and system design (MAIB & DMAIB, 2021). One of the reported challenges are difficulties in using some of the ECDIS safety features leading crew either to implement workarounds or ignoring the features. The report points towards structural flaws in the way new navigation technologies are designed and implemented and recommend that principles for human-centered design should be followed in the maritime industry (MAIB & DMAIB, 2021).

It is unquestionably valuable to study accidents in order to learn and to prevent future accidents. However, the causes found in an accident investigation reflects the underlying accident models used by the investigators, known as the 'What-You-Look-For-Is-What-You-Find' principle (Lundberg et al., 2009). This is followed by the 'What-You-Find-Is-What-You-Fix' principle, where the identified causes are turned into specific problems that can be resolved by implementing a solution (Lundberg et al., 2009). Maritime accident investigations are based on sequential accident causation models and tend to focus on technical components and pay less attention to how human, technological and organizational factors interact in sociotechnical systems

(Schröder-Hinrichs et al., 2011). Hindsight bias is a problem in accident investigations (Dekker, 2002), and so without applying a systems approach to investigations the possibility for learning may be limited even in preventing a similar accident. When human error is found to be the cause, only local responses like procedures and training is required, which is an impediment to learning on organization or system levels (Woods et al., 2010).

METHOD

The accident investigation reports were obtained by searching through the publicly available reports issued by the Accident Investigation Board Norway (AIBN), the German Federal Bureau of Maritime Casualty Investigation (BSU), the Danish Maritime Accident Investigation Board (DMAIB) and the UKs Marine Accident Investigation Branch (MAIB). According to UNCTAD (2022) these are the countries with the largest merchant fleet in North and West Europe by country of beneficial ownership. The search was limited to accidents occurring in the period 2010-2020. The investigation reports that had identified and reported design issues as contributing factors to the accidents were included. An overview of the selected reports is given in Table 1.

The reported design issues, as well as the safety recommendations and the shipowner's response were identified in each investigation report and grouped according to their themes. The resulting themes are presented and discussed in the following sections.

RESULTS

Design Issues Identified in the Investigation Reports

The design issues described in the accident investigation reports was grouped into six themes. It should be noted that the investigations often found several of the categories contributing to the same accident, e.g., in the report regarding the *Commodore Clipper* grounding, both bridge layout and unexpected use of equipment was registered. Also, reports investigating collisions may have reported design issues on board both ships involved.

1. **Bridge layout** was a design issue reported for 13 ships (*MF Bognes, Steinbock, Stena Nautica, Victoria, Express 1, World Bora, Raba, Ice Rose, Arrow, Red Falcon, City of Rotterdam, Commodore Clipper, MV Finnarrow*). There were three ways bridge layout could be a contributing factor to the accidents: a) The bridge layout hindered access to operate or use equipment. For example, on board *Red Falcon* the Electronic Chart System (ECS) and radar placement were not compatible with the natural manoeuvring position during single person operation; b) The bridge layout hindered visual overview. For example, on *Steinbock* it was not possible to have an all-round view from the helm as the funnel covered a significant part of the view astern; c) The bridge was designed to accommodate several functions. For example, on board *Express 1* the bridge

Table 1. The accident investigation reports included in this study.

Name of vessel (s)	Year of Accident	Accident Type	Accident Investigation Board
MV Godafoss	2011	Grounding	AIBN
MF Godfjord	2015	Grounding	AIBN
MF Bognes	2016	Grounding	AIBN
Aurora Explorer	2018	Allision	AIBN
Steinbock and MV Minerva	2010	Collision	BSU
MV Beluga Revolution	2010	Grounding	BSU
Nils Holgersson and Urd	2012	Collision	BSU
MV Fransisca and MV RMS Bremen	2014	Collision	BSU
Wes Janine and Stenberg	2014	Collision	BSU
Pazifik	2018	Grounding	BSU
Stena Nautica	2014	Allision	DMAIB
Victoria	2017	Grounding	DMAIB
Express 1 and Baltic Condor	2019	Collision	DMAIB
World Bora and Raba	2019	Collision	DMAIB
Ice Rose and Kazanets	2020	Collision	DMAIB
MV Finnarrow	2013	Allision	MAIB
Ovit	2013	Grounding	MAIB
Commodore Clipper	2014	Grounding	MAIB
City of Rotterdam and Primula Seaways	2015	Collision	MAIB
Muros	2016	Grounding	MAIB
Royal Iris of the Mersey	2016	Grounding	MAIB
CMA CGM Vasco de Gama	2016	Grounding	MAIB
Celtic Hav	2018	Grounding	MAIB
Priscilla	2018	Grounding	MAIB
Red Falcon and Greylag	2018	Collision	MAIB
Seatruck Performance	2019	Grounding	MAIB
Kaami	2020	Grounding	MAIB
Arrow	2020	Grounding	MAIB

had been designed as a combination of bridge, office and rest room which was very disturbing for the navigators.

2. **Not using available electronic equipment** to assist in navigation was reported for 10 of the ships (*MV Godafoss, MF Bognes, Steinbock, MV Beluga Revolution, Wes Janine, Stenberg, Seatruck Performance, Priscilla, Cetica Hav, Royal Iris of the Mersey*). For example, it was reported that before *MV Godafoss* grounded the voyage was performed visually with hardly any use of available navigational aids. The reason for not using the ECDIS was that the master knew that the passage marked on the electronic chart system was not accurate enough to be used as a navigational aid in the applicable waters.
3. **Unexpected use of electronic equipment** was reported for eight of the ships (*MV Beluga Revolution, Kaami, Seatruck Performance, Priscilla, Muros, CMA CGM Vasco de Gama, Commodore Clipper, Ovit*). For *MV Beluga Revolution* the unexpected use concerned the GPS receiver,

echo sounder and ECS. All the other cases concern the use of ECDIS. One typical example of this was the grounding of *Muros* where the track was not planned or checked on an appropriate scale chart, audible alarms and the guard zone function were disabled, the use of 'standard' chart view limited the information displayed. The term 'unexpected use' is inspired by the following quote from the *Muros* investigation report: "The ECDIS on board *Muros* had not been used as expected by the regulators or equipment manufacturers." (MAIB, 2017).

4. **Mode confusion** contributed to three of the accidents (*MF Godfjord, Aurora Explorer, Nils Holgersson*). For example, to limit unwanted vibrations due to a incorrectly adjusted port drivelines propeller pitch on *Aurora Explorer*, it was decided to operate the vessel in combinator mode during docking, and in back-up mode to reach cruising speed between destinations. The most likely cause of the accident was forgetting to re-engage to combinator mode before arrival to dock. This caused the vessel to increase its speed ahead as the port side maneuver handle was pulled astern, and the vessel collided with the quay.
5. **Lack of information about system status.** Systems not providing information about the system status to the navigators was found to be contributing in two of the accidents (*MV Finnarrow, Stena Nautica*). For example, on board *Stena Nautica* the steering arrangement allowed the switch from one control station to another to be performed without the watchkeeping crew having full knowledge of the helm and rudder positions. The design of the centre hand steering wheel was such that its position was not clearly indicated, especially at night.
6. **Trust in electronic equipment.** Not verifying the position displayed on the chart with other means like radar or visual bearings was reported to be contributing to the collision between *MV Fransisca* and *MV RMS Bremen*. The investigation found there had been a GPS error. On both vessels the officer in charge relied on the positions displayed on the electronic chart and did not verify the satellite positions displayed with another system, such as radar or visual bearings. This is the opposite issue as those reported in category 2 where navigation was performed visually, and electronic aids were not used.

Electronic charts, ECDIS or ECS, were the equipment type most frequently occurring in the reported human-technology issues - they occurred in 14 of the investigation reports. Several of the reports have limited descriptions of the design issue. In some cases, it was reported that certain equipment has not been used, but the reason for not using it was not addressed. It should also be noted that typical for organisational accidents, the design issues were not the sole contributing factors found by the investigators. Other contributing factors were the cooperation between pilot and crew, bridge resource management (BRM), fatigue, manning and external factors (fog or other vessels in the vicinity).

Safety Recommendations

The safety recommendations issued by the accident investigation boards were in most cases directed to the shipowner or ship operator. Safety recommendations were in some cases also directed to harbor commissions, maritime and coastguard agencies, pilot associations, the Vessel Traffic Service (VTS) and coastal administrations. In ten of the reports no safety recommendations were issued due to actions already taken by the involved parties. In several reports the investigation issued by MAIB and DMAIB (2021) was the reason for not issuing further safety recommendations. 17 of the safety recommendations directed to shipowners or operators advised a revision of the safety management system (SMS), procedures or checklists. Four reports recommended ECDIS or BRM training. Five reports had safety recommendations addressing the design issues:

- The owner of the *Aurora Explorer* was recommended to carry out and document risk assessments of operational changes.
- The owner of the *City of Rotterdam* was recommended to inform the crew and pilots about the risk of spatial distortion occurring due to the unusual shape of the bridge, particularly when standing away from the centreline or a navigation station.
- The owner of *MV Finnarrow* was recommended to ensure the status of the fin stabilisers had sufficient procedural and visual checks to prevent them being left deployed when the vessel enters port.
- The owner of *Red Falcon* was recommended to review the method of determining the orientation of the vessel displayed on the ship's electronic chart system and to ensure that the system was not solely reliant on the operation of a toggle switch.
- The investigation report regarding the grounding of *Ovit* was the only report having a safety recommendation to an equipment manufacturer. They were advised to improve the management of safety critical information in their ECDIS system.

Shipowners' Response

The shipowner's actions taken after the accidents were reported in 25 of the 28 accident investigation reports. In most cases the response was a combination of several actions. The solution used in most cases (19 reports) were revising existing or introducing new procedures and checklists. Performing BRM training or ECDIS training was reported in 13 reports. Distributing a circular, report or safety bulletin about the accident was reported in 12 investigation reports. In eight cases the shipowners reported doing a change or upgrade of bridge equipment or bridge layout (in addition to training, circulars and procedures):

- *Arrow*: The ECS system was upgraded.
- *Aurora Explorer*: The setup of the manoeuvring system was changed and the pitch on the propeller was adjusted back to system supplier's recommendations.

- *City of Rotterdam*: A bow tip marker on the centreline immediately ahead of the centre bridge window was installed to provide a reference point from any position on the bridge. The length of the VHF handset wires was increased to enable the radios to be used from the forward centreline conning position. Notices warning of relative motion illusion was posted in several positions.
- *Commodore Clipper*: An ECDIS repeater display was fitted at the chief officer's position.
- *Express 1*: Equipment was moved, and workspaces re-arranged so only navigation is performed on the bridge.
- *Nils Holgersson*: The button for triggering the automated crash stop sequence was made bigger and apart from other buttons.
- *Red Falcon*: The positioning of the radar units was adjusted on all 'Raptor' class vessels so that they are more visible to the person conning the vessel from the side of the forward and aft manoeuvring consoles.
- *Stena Nautica*: The old hand steering wheel was placed on top of the new one. A counterweight was placed on the wheel to force it to neutral position and a fixing hook was added to keep wheel centred.

DISCUSSION

Human and organizational factors are part of the IMO guidelines for maritime accident investigations (IMO, 2013). Design of technology is an important part of the ship bridge sociotechnical system. As such, the identification of design issues in maritime accident investigations are an important step towards improving and managing this risks in the sociotechnical system. The question remains of what can be learned from these investigation reports. The review of the 28 reports in this study resulted in six categories of human-technology cooperation issues. These issues are consistent with design issues previously found in maritime as well as other high-risk industries (Oltedal & Lützhöft, 2018; Woods et al., 2010). For category 2 and 3, not using or unexpected use of electronic equipment, ECDIS was by far the most frequently occurring equipment. The recently published study report by MAIB and DMAIB (2021) regarding the use of ECDIS, pointed at several challenges faced by navigators due to the inadequate design of ECDIS. The report found that these challenges led the users to implement workarounds and a minimalist approach, seen in the investigation reports as non-use or unexpected use of equipment. The report by MAIB and DMAIB points towards structural flaws in the way new navigation technologies are designed and implemented and recommend that principles for human-centered design should be followed in the maritime industry. This conclusion is valid also for the other design issue categories identified in the investigation reports. The underlying common theme for all six categories is that those who design, purchase and install ship bridge equipment does not have a sufficient understanding of the navigator's work tasks and work context, i.e., the end-user needs.

The accident investigation boards' safety recommendations and the shipowners' response to the accidents were mainly revising the SMS, revising or introducing procedures and checklists, as well as crew training. These responses put the responsibility for an improved human-technology interaction on the human operator. The assumed solution is that the human should adapt better to the technology rather than adapting technology to better support the human.

Safety recommendations that addressed the identified design issue from the point of view that design of technology should be changed or reviewed, were found in five of the 28 investigation reports. Shipowners addressing the design issue by doing something with the design or bridge equipment was reported in eight of the investigation reports. However, both the safety recommendations and the actions by shipowners were local fixes to make sure the exact same accident will not happen again. For example, installing a bow tip marker on the centerline and posting notes to warn about the possibility of relative motion illusion on board the *City of Rotterdam*, or placing a counterweight on the wheel to force it into neutral position and adding a fixing hook to keep wheel centred on *Stena Nautica*. Such local fixes will not prevent other potential design flaws to combine with other events and create new accidents in the future. The only report explicitly recommending improving design was the *Ovit* investigation report, where the equipment manufacturer was recommended to improve their ECDIS design.

For the maritime industry to learn from accidents and improve future bridge design, it is important that design issues are not only identified by the investigators, but they should also be described and investigated in more detail. In addition, applying a systems approach to accident investigations may contribute to investigate beyond the cause 'human error' and recommend solutions and lessons learned on an organizational or system level. The lessons to be learned should be fed back in a useful way to the relevant stakeholders, like regulators, designers, purchasers and installers, so new designs can possibly become more human-centered. Human-centred design may add value for both seafarers and shipowners (Costa & Lützhöft, 2014) and design considerations should be part of managing risk in any company.

CONCLUSION

This paper reviewed maritime accident investigations where design issues have been identified as contributing factors. The design issues were categorised in six categories: 1) Bridge layout; 2) Not using available electronic equipment; 3) Unexpected use of electronic equipment; 4) Mode confusion; 5) Lack of information about system status; 6) Trust in electronic equipment. The investigation boards' safety recommendations and the shipowners' responses mainly concerned revising the SMS, revising or introducing procedures and checklists, as well as crew training. The few recommendations and actions that concerned improving design of technology were local fixes that do not contribute to learning on organizational or system level.

The increasing instrumentation and digitalization of ship bridges during the last decades has changed the work environment of navigators considerably. These relatively rapid changes in ship technology does not seem to have been accompanied with usability concerns at the same pace, and the operational consequences of new ship bridge design are thus being shouldered by the navigators.

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