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Hazards and Risks of Automated Passenger Ferry Operations in Norway

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ABSTRACT

This paper describes the hazards and mitigation of risks for operating automated ferries in sheltered waters in Norway. Two cases have been explored, one with max 25Pax (persons on board) close to shore, and another involving fjord crossing with max 130Pax. The approach is based on the formal safety assessment FSA framework specified by IMO (International Maritime Organization). The first step has been a Hazard Identification-HAZID in collaboration with key stakeholders (manufacturers, maritime authority, operators, and researchers), based on action research, building on experience and risk perception of the stakeholders. The HAZIDs have been based on prior incidents, safety critical task analysis, and hazards that may impact personnel safety and security. We have identified key areas of concern: Fire, Collision/Grounding, Man Overboard, Evacuation, or Ferry capsizes. We have suggested design approaches/measures to reduce probabilities of hazards occurrence and/or mitigate consequences. Challenges of non-failsafe situations must be handled through emergency response centres, and mobilization of passengers.

Keywords: Maritime automation, Fail safe, Human factors, Hazards, Minimum risk condition, Barriers

INTRODUCTION

Automation is increasing in many transport areas. Unmanned metro trains have been successfully operated (without significant incidents) in several cities since 1980, Johnsen et al. (2019). Automated marine operations have been prioritized - doing surveys, mappings/charting, for example, through remote operated vehicles (ROV). Industry use of ROVs has increased, avoiding dangerous, dirty or difficult sub-sea operations. Automated ferry operations for person transport have been of great interest, due to possibilities of increased efficiency and positive environmental impacts. We have explored two cases, in a research project called AutoSafe, financed by the Norwegian research council. The two cases are one small ferry, operating close to shore with max 25Pax (persons on board) going from one professional seafarer to remote operations. In the future, the goal is to operate the small ferry as an "elevator", with no manning using an emergency "push-button" to get help.

A larger and faster ferry involving fjord crossing with max 130Pax is discussed, with the crew being reduced from three to two or one seafarers with support from remote operations.

We have based our approach on IMO (2018), for formal safety assessment (FSA). The FSA is a systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, i.e., HSE (Health, Safety and Environment). Automated and autonomous ferries are governed by the Interim guidelines for MASS (Maritime Autonomous Surface Ship) trials IMO (2019), and Guidelines for unmanned operations IMO (2013). The Guidelines IMO (2013) describes the process for assuring that an alternative solution is as safe as an equivalent conventional solution. The Norwegian Maritime Authority (NMA) adopted these guidelines on a national level NMA (2020). The guidelines require risk and hazard assessments for alternative solutions (such as automated functionalities), to document the equivalent safety. One challenge lies in determining the current risk level of a similar system Thieme et al. (2019), when regulations are prescriptive and not functional.

The risks of automated shipping were discussed in Wrobel et al. (2017) based on an evaluation of 100 prior accidents exploring risks and consequences based on "what-if" the operations were automated. The analysis suggested that the probability of unwanted incidents may be reduced by automation, but the consequences may increase due to the absence of competent personnel involved in operation. During operations, there is a need to go to a fail-safe condition. However a "non-failsafe" conditions such as fire or sinking of the ship/ferry must also be handled, and the ferry must go to a minimum risk condition.

The first step of our analysis has been to perform a HAZID (hazard identification) in collaboration with key stakeholders based on action research, building on experience and risk perception of the stakeholders. The HAZIDs have been based on prior incidents, safety critical task analysis and hazards that affect personal safety and security.

This article describes the findings of the HAZID and implications for the human-machine interaction, user and passenger involvement, and collaboration with emergency services. The paper focuses on how the whole system's design, i.e., technological solutions and involvement of passengers and control facilities, may contribute to the prevention or mitigation of accidents and handling of "non-failsafe" events. This has been addressed to a little degree in the existing literature, Thieme et al. (2019), and thereby represents a novel contribution to the design of automated ferries. To limit the scope the operational domain has been limited to areas close to shore. For the case studies, the Norwegian domains, Domain1 (completely enclosed waters, lakes and rivers, inland parts of fjords and waters where there is calm waters); and Domain2 (protected waters from waves and wind from the open sea, as well as all within inland waters) were used. The methods and findings used are described in more detail in Fjørtoft et al. (2022) tailored to industry.

This paper starts with this introduction, a description of the two cases and a description of our approach, what is the result in combination with a

Table 1. Table representation of a "bow-tie", with the example fire ignition.

Threat (Initiating event)	Reduce probabilities	Hazard (Top event)	Reduce consequences
Battery overload/ overheating	Robust design; Battery maintenance; Monitoring of battery;	Ignition (Fire)	Deluge; Go to shore

discussion, a short exploration of the reliability of the research followed by conclusions.

APPROACH, METHOD AND SCOPE

The identification of risk reduction measures was based on an adapted safety critical task analysis as described in Smith & Roels (2020) i.e., identifying unwanted incidents through the HAZID, then perform a task analysis and discuss hazards that may lead to HSE consequences when operating the ferry. The HAZID and identification are based on structured brain-storming and group discussion. As input hazard lists, a pre-prepared review of similar system HAZIDS, and system information (drawings, operational description etc.) are used. The scope has been the operational domain, the automated ferry and the surrounding infrastructure, with data support through radar/wind measurements, control systems, including a remote operations center (ROC), and emergency response (ERC).

The chosen approach involves users and key actors in a collaborative environment based on action research Greenwood & Levin (2006), learning through implementation and reflection. Key actors have been the maritime authority, ship designers, ship builders, suppliers delivering new technology, seafarers aboard existing ferries and researchers. To structure the discussion of risk reduction measures, we explored the identified hazards using a bow-tie to identify threats, top events and consequences. A hazard is defined as "a condition or situation which has the potential to create harm to people, property, or the environment" IPENZ (1983). A threat is a generic way to describe danger, whether the danger has actualized or not, and is used on the left side of a bow-tie model. A hazard (top event) has a potential to create harm "before" the harm occurred.

In a bow-tie we identify the 'top event' as a step in the direction of an accident, i.e., the moment when control is lost over the hazard and just before events start causing actual damage (i.e., to a large extent a subjective and pragmatic choice based on expert evaluations.) Based on each identified top event, we identified risk reducing measures (proactive barriers) for each threat and measures reducing possible consequences (i.e., reactive barriers), illustrated in Table 1. The benefit of a bow-tie diagram is that it gives a simple, visual explanation of accidental scenarios and risk. It thus helps support a systematic exploration of proactive and reactive risk reduction measures.

In the example, Table 1, ignition of flammable material is the hazard. Fire is the top event. It can be caused by the ignition of the battery due to heavy load (threat), while damage to the ferry and exposure of the passengers are the consequences.

Case Study Description

The two cases are a ferry in Florø close to shore with max 25Pax and a ferry performing fjord crossing in the Trondheimsfjord with max 130Pax. Both ferry cases are using an electric propulsion system with a battery-based energy storage on board the ferries. The following tasks were identified for both case studies:

- Planning and preparing for an automated trip
- The boarding of passengers, and preparation, i.e., instructing passengers for the voyage and emergencies
- Starting the trip away from the quay
- Going across open water, navigating to the destination (and handling emergencies)
- Arriving at the destination and disembarking of passengers
- Maintenance and preparation for next trip (or for a longer break).

The first case is a commuting ferry between Florø and the Fjordbase (offshore supply base), approximately 2.6 km apart. Due to the proximity to shore, the ferry will sail with a maximum speed of 5 knots, resulting in a journey time of 20 min. The route is in shel-tered water close to land. It was assumed that one operator is required on board of the ferry initially, who is supported through a ROC. The tasks during emergency situations need to be defined with the input from the HAZIDS summarized in this paper. It is assumed that the operator can be replaced by the ROC.

The second case is based on the existing express ferry between Trondheim and Vanvikan. The ferry is sailing with 23 knots 16 km across the open fjord. The fjord can be subject to strong currents and waves, however there is little traffic to be expected. The terminal areas are small, and some traffic (sailing boats and kayaks) is to be expected. Today three people form the crew; the captain, the engineer and the mate. It was assumed that operations are automated needing one or two persons on the ferry. A ROC is available for the captain on board experts.

RESULTS AND DISCUSSION

Our aim was to identify hazards with significant impact on passenger safety and the environment. Automation may contribute to the risks. Summary of challenges from automation is listed in NAS (2021), i.e., “brittleness” (automation will only be capable of performing well in situations that are covered by its programming or training data) and “perceptual limitations” (detection algorithms continue to struggle with reliable and accurate object recognition). Main human challenges of automation are “Poor Situational Awareness (SA) and out-of-the-loop performance degradation” (slower to understand a problem resulting in serious consequences in unexpected situations) and "Degradation of manual skills" (skills can atrophy if they are not used in automation).

Identified Hazards

Three workshops with key stakeholders were arranged, i.e., ferry operator, ship designer, developer/supplier, research institute, and from the maritime safety authority. The HAZID workshops resulted in both an increased knowledge among the participants and a list of prioritized hazards, see below. The hazards were used to identify threats, proactive risk reduction barriers and barriers to reduce the consequences.

1. Fire – fire may start in the engine room, passenger salon, or battery room
2. Collision or grounding – a collision with other vessels, objects or grounding
3. Man overboard – passenger falls from the ferry, or person drifts in the water
4. Evacuation – due to fire, collision, engine stop
5. Ferry capsizes – Ferry capsizes /overturns due to overload
6. Passenger emergencies – Personal injuries, medical conditions, vandalism

Risk Reduction - Reduction of Probabilities and Consequences

In the following we have documented the main risk reduction measures to reduce probabilities or consequences associated with the hazards. Measures should include human, technical or organizational elements. In addition, safe states were defined if possible.

Fire: A fire can start in the passenger area (from smoking, overheated personal devices, or from equipment used to make food/coffee), in the machine room or in the batteries. Initiating events discussed are smoking onboard, failure/short in equipment (used in kitchen), overload/overheating of batteries.

Main actions to reduce probabilities: Physical design (i.e. using non-flammable materials, compartmentalization of batteries, isolating sources; installing approved/certified equipment with high reliability; Sensors that detect danger before fire; Safety information before boarding (no smoking); Inspection of equipment.

Main actions to reduce consequences: Fire retardant material, Fire extinguisher/ deluge, Fire alarm, Emergency procedures, Visible cues to passengers (lights in the floor/around doors); Camera (information to and from ROC); Rapid/safe return to port procedure; Drop battery in the sea; Safe evacuation (Life jackets, life raft); Emergency response from fire department (required 5 min response time).

A fire is a "non-failsafe" condition, evacuation may increase risks, one minimum risk condition is to move rapidly to closest shore.

Collision or grounding: This can happen due to sensor failure (navigation/ maneuvering) or poor automation "sense of self", i.e., own perception of size and position; Objects difficult to observe; Challenging weather conditions (fog, spray, dirt); Too high speed; Loss of propulsion; Navigation Error (onboard or ROC); Unpredictable navigation from another ship.

Main actions to reduce probabilities: Redundant sensors (diverse types of sensors, supporting information from infrastructure, e.g., shore-based radar/positioning systems); Operational procedures in poor weather (Involvement human operator); Adapt speed to conditions (increased traffic, visibility, distance to shore); Signal to others ships that the ferry is automated; Select and mark routes for automated ships; Automated operation in challenging situation where automation is superior.

Main actions to reduce consequences: Design ship to avoid sinking (with separate compartments, increase buoyance, inflatable fenders); Redundant propulsion (go to closest shore/ emergency port); Determine extent of damage (system/sensors); Notify emergency services; Get help from stand by vessel; Evacuation (if this is the safest way); Robust emergency towing; Rescue capsule as an integral part of the ferry.

A sinking ship is a "non-failsafe" condition, evacuation may increase risk, one minimum risk condition is to egress to shore (i.e., move to closest shore).

Man overboard (MOB): This can happen due to poor design (i.e., low railing on sun deck, boarding way, harbor infrastructure); Passengers not being careful (or choosing to jump into the sea); Accident/impact, i.e., collision/grounding.

Main actions to reduce probabilities: Design ferry and boarding area such that access to the sea is difficult (i.e., Physical barriers to prevent falling into the sea).

Main actions to reduce consequences: Uncomplicated alarm to contact ROC/ERC (with information on location, status, weather conditions, etc.); Camera that can detect MOB (e.g., via temperature); Easy to dispatch rescue devices (i.e., rescue drone); Protective guard for propellers to avoid cut damage.

Risk to MOB is reduced if discovered, and received lifebuoy, raft or line.

Evacuation: Evacuation may be necessary due to Fire, Water intrusion, Lost Stability, Collision or Engine stop (these issues has been explored earlier).

Main actions to reduce probabilities: Avoid evacuation through system and operational design, since evacuation creates significant risks for passengers; Design safety systems based on user centric design and extensive testing to ensure failsafe operations; Provide clear safety information before boarding and on board, (I.e., on rescue routes, and rescue procedures).

Main actions to reduce consequences: Involve emergency rescue services (I.e., tow the ferry away or to go to a safe state or minimum risk condition); Communicate openly and continuously (I.e., via video) among ferry, ROC and ERC, to ensure that necessary information is available for the evacuation situation.

Ferry Capsizes: One known serious accident with an unmanned (cable) ferry in Norway is due to too many people boarding the ferry late at night. The operator (Brønnøya Vel) was held responsible for the incident Giørtz(2017).

Main actions to reduce probabilities: Count number of passengers entering; Sensors to check weight to ensure that no embarkation is done with too many passengers.

Main actions to reduce consequences: Design self-righting boat; Automatic emergency alarm when ferry has capsized.

Passenger emergencies: Passenger emergencies can happen due to being crushed as doors/entry are opening/closing during de-/boarding; unforeseen medical needs (cardiac arrest, seizures and loss of consciousness, etc.); unpredictable behavior.

Main actions to reduce probabilities: Design entry/exit area and doors to avoid crushing damages; Remote overview of exit/entry; Store emergency equipment (defibrillators).

Main actions to reduce consequences: Emergency response equipment onboard; Possibility of calling for emergency response with short response time.

Safety Measures to Address Hazards

The summary above shows the need for qualified and rapid emergency response. A key challenge for automated ferries is the reduced crew on board in case of an unwanted incident. With only one operator on board or only support from ROC the concept for guiding and handling passengers in a crisis needs to be rethought, i.e.:

- Assessment of mental and physical workload in an emergency.
- Design of emergency support and response, through ship design, and rapid and targeted involvement of ROC and ERC in emergencies.
- Training, guidance and information systems for the passengers (and crew).
- Involvement of passengers in emergencies.

A user centered design approach is required to develop the necessary capabilities for guiding and involving passengers, which also addresses the design of crisis intervention through ROC and ERC. This must be designed, including tasks and responsibilities between onboard operator, passengers, the ROC and ERC. Scenario analysis of crisis intervention can assist in this, Aas et al. (2009). Today's crew size is often based on required emergency response ability. Through well designed solutions key tasks could be executed from the ROC, aiding the on-board operators to keep a high level of situational aware-ness. This design must be based on workload assessment (mental and physical) of emergency crew. ROC operators must be able to address and involve passengers when no crew is on board (I.e., in medical emergency situations or evacuation). Regarding guidance of passengers, they must be able to obtain necessary information of the ferry's status, predicted state in the future, and needed actions they must carry out.

Interaction with ERC is seen as vital, as they will be able to quickly aid the ferry and become an integral part of the emergency handling. This requires situational overview of ferry's status (visual, position, and status of speed, environment, sensors, emergency information). The ROC must have robust and resilient communication with the users, with backup through governmental emergency services (ERC).

Technology can help to reduce risks, but it cannot handle decisions, it must give decision support and situational awareness to the operators. Further risk reduction can be achieved by design of the ferry or simplification of the operational domain (I.e., sailing close to shore, safe retreat zones).

RELIABILITY, CREDIBILITY AND TRANSFERABILITY

Reliability is the extent to which another researcher would find the same answer and describes the consistency or repeatability of the research that has been performed. Thus, the results are considered reliable if our measurements would give us the same result. We have seen that similar results have been identified by other researchers in the referenced literature. Credibility has been checked by member checks with the stakeholders (as the most important technique testing hypothesis and interpretations), prolonged engagement, progressive subjectivity, persistent observations, peer debriefing with a disinterested peer and negative case analysis. Transferability has been checked by exploring experiences from other transportation domains, i.e. Johnsen et al. (2019).

CONCLUSIONS AND FURTHER WORK

Today's safety solutions are based on prescriptive regulations (size of the vessel, no. of passengers, and type of propulsion). This limits the possibility of adopting novel solutions for passenger ferries. At present, there is little guidance on how to show equivalence of safety design. The current prescriptive rules should be adjusted or interpreted as functional rules, to build regulations supporting automation.

To establish safe automated ferry operations, we see the need to base the design on a risk-based approach of the whole system. A system approach ensures that we include the operational domain, the ferry, and needed infrastructure (sensors, ROC, emergency response). The identified hazards and vulnerabilities point towards the need for assessing and designing emergency assistance, through human intervention and if needed human improvisation. Some hazards can be mitigated through going to a failsafe condition or minimum risk condition. However, there is a need to handle "non-failsafe" conditions through human intervention, i.e., fire or capsizing. There is a need to plan mitigation through human centered design to achieve a safe, reliable and resilient operation for the people involved. There is a need to define the role of personnel involved in the operation under all conditions including emergencies (including the passengers) and design/specify the needs of remote emergency services through collaboration with the actors involved. Based on a risk-based design of the operational domain, the ferry, supporting infrastructure and operational procedures – (partly) automated ferry operations should be safe and efficient, and an advancement in relation to the present operations. However, there is a need to perform extensive testing and trials of operations to build knowledge and statistical data as a basis for more quantifiable assessments.

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