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Analysing the Need for Safety Crew Onboard Autonomous Passenger Ships – A Case Study on Urban Passenger Transport in Norwegian Waters.

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Today, the number of crew required to operate small, conventional passenger ships is often equal to the number of safety crew required to ensure passenger safety in emergency situations. This paper investigate whether it is possible to realize autonomous passenger ships and still maintain passenger safety as the number of safety crew is reduced towards zero. An important role of the safety crew is to manage emergency situations, and by that comply to the crew safety instructions in such situations. The safety instructions of two use cases have been analysed in terms of which tasks that is possible automate, and by that reduce the need for onboard crew. The analysis resulted in a classification of safety tasks that can be automated and those who appear more difficult and needs to be managed either by onboard safety crew or by a remote control centre operator. We argue that given the current technology gaps and short-term expected developments, there will still be a need for safety crew onboard autonomous passenger ships. We propose a definition for a safety responsible officer. Requirements are also derived for new developments of safety equipment that will be needed with reduced safety crew. The results of the study provide input to ongoing regulatory discussions where distribution of tasks between automation systems and humans on ship and in remote control centres are relevant.

Keywords: Ship autonomy, passenger safety, safety crew, automation, remote control center.

1. Introduction

Autonomous ships are commonly associated to be crewless, able to navigate by themselves based on a combination of novel technologies (Rødseth, 2018). Autonomous passenger ships, as opposed to cargo ships, come with the added complexity that is to ensure passenger safety in all operational scenarios. So far, systems and solutions enabling safe navigation have been the main focus area towards realisation of autonomous ships (Fjørtoft, et al., 2022; Utne et al., 2020). However, until procedures and solutions assuring passenger safety are developed and adapted to operations with reduced or no crew, these solutions alone will not yield a viable business case for autonomous passenger ships.

Today, the number of crew required to secure daily operation of a small conventional passenger ship (e.g. navigation, manoeuvring, machinery watch), is very often equal to the number of crew required to maintain a necessary passenger safety level in case an abnormal situation should occur (e.g. man overboard, fire, flooding, grounding, collision and evacuation), (Holte and Wennersberg, 2021). Any reduction in crew compared to the requirements in the current regulatory framework, must be approved by the relevant authorities using a risk-based approach, where one need to prove that the ship design in combination with work procedures and installed technology meet the requirements assuring passenger safety, both in normal and abnormal situations.

An important input for such an approval is the crew safety instructions. Based on the technical solutions and safety equipment installed on board, the instructions specify how tasks and responsibilities are distributed across the defined roles, and ultimately what the different crew members are expected to carry out in abnormal situations. We have analysed the safety instructions for two conceptual use-cases with the purpose of determining which of the crew tasks that either can be automated or shifted to a remote control centre operator, and furthermore analysed how this influence the number of safety crew that is needed onboard the ship. The analysis is carried out with certain presumptions in expected technology development.

The purpose of this paper is thus to analyse the need for safety crew onboard autonomous passenger ships, and to what extent tasks as defined in the safety instructions can be automated or not. We also propose a general definition of a safety responsible officer.

2. Method and study limitations

The research method and approach for this work was two-fold, in which the first stage was based on a qualitative analysis of publicly available documents and research literature. This was supported with information gathered from semi-structured interviews with key industry actors across the maritime value chain. The semi-structured approach, based on open-ended questions, was chosen to facilitate an open conversation and discussion (Edwards and Holland, 2013). The main objective was to disclose State-of-the-Art (SoA) within navigation and manoeuvring technologies, but also with respect to passenger safety in general. Expectations within future technology development needs were also discussed in a three-to-five-years perspective (i.e., towards 2026-2027). Based on an inductive approach, the findings were generalized to provide the necessary background knowledge allowing for completion of the second stage.

Based on existing crew safety instructions from the project's two use-cases, the second stage was devoted to analysing the different crew roles onboard, and to what extent the allocated tasks could be automated or not. Also considering the allocation of tasks between the safety crew onboard and the supporting operator at the remote control centre (RCC). The results was then generalised to derive some concluding remarks on future possibilities for reducing safety crew onboard passenger ships. This includes a proposed definition for a safety responsible officer onboard, but also future needs within technology development. The leading criteria for the analysis was the preservation of passenger safety, but also safety of the surrounding environment.

Moreover, the following limitations and presumptions applies for the analysis and results presented herein:

- In a three-to-five-years perspective, technological advances are expected to facilitate the completion of voyages with unattended bridge and machine room, including docking and mooring operations. Safety crew remain onboard to handle passenger logistics and comfort in general, but also in case an abnormal situation should occur. An RCC is established as a support function, with the ability to take control over ship navigation and manoeuvring in case the on-board automation system shortfalls.
- Human-automation interaction is limited to notifying when the ship is ready to disembark from quay, when passengers are cleared to embark or disembark the ship, or in case of an abnormal situation – setting the ship in the preferred fallback state.
- Finally, the operational environment for the two use cases is classified as sheltered waters.

3. State of the art – ship autonomy

SoA within autonomous maritime passenger transport can be divided into three main categories, namely the required technology and technological solutions safeguarding navigation and manoeuvring of the ship from quay to quay; technology and processes ensuring passenger safety given the occurrence of an abnormal situation (e.g., fire, loss of ship stability, man overboard, and evacuation); and relevant rules and regulations having an impact on both aforementioned categories.

3.1. *Navigation and manoeuvring*

Technology and technological solutions allowing autonomous navigation and manoeuvring of ships is today at autonomy level 2. Originally defined by Rødseth and Nordahl (Rødseth and Nordahl, 2017), and adapted by the Norwegian Maritime Authority (NMA) in their Circular RSV 12-2020 for national approval of alternative solutions (NMA, 2020), autonomy level 2 is applied when a ship can perform automated operation under continuous surveillance from the bridge (e.g. advanced form for auto-pilot). Meaning that significant parts – or the entire – voyage is completed automatically with the master being ready to take possession of the ship controls at any point in time.

Supported by large research initiatives, such as AUTOSHIP (Bolbot, et al., 2020), AEGIS

(Krause, et al., 2022) and SFI AutoShip (2020), the maritime industry has taken significant steps in the development of technological solutions towards realising autonomous navigation and manoeuvring of ships. As such, the passenger ferry operating between Moss and Horten, being one of Norway's busiest fjord crossings measured in traffic volumes per annum (Stensvold, 2020), exemplifies the operational equivalent to the SoA. Over a period of two years, the service has been operated by two ferries equipped with systems allowing for auto-docking and crossing, but with continuous surveillance from a master on the bridge. The service therefore represents an important testbed for further technological development for level 2 and above (e.g., autonomy level 3 and 4). Level 3 being defined as operating periodically unmanned, which in practical terms means that it is allowed to sail with reduced crew and with periodically un-attended bridge. A RCC monitor the ship operation and has the possibility to take control of the ship operation if required by the situation (NMA, 2020).

However, to reach higher levels of autonomy (i.e., above level 2), further development within the area of situational awareness is still needed. More specifically within the establishment of robust and verified solutions catering for object detection and collision avoidance. In addition, few conclusions are made regarding how an autonomous ship should interact with conventional ships at sea (Rødseth, et al. 2020).

3.2. *Passenger safety*

Advances within new solutions realizing a reduction in safety crew for small- to medium sized passenger ships has so far been close to non-existent. Although new navigational technologies in theory can open for a realistic discussion on crew reductions under normal operations, total crew size still rests upon the required safety crew.

Today, passenger safety on ships is mainly regulated through technical and operational standards that are prescriptive, e.g., for damage stability, fire zones, extinguishing systems, and evacuation equipment. Operational standards are mainly regulated through the STCW code (IMO, 2018) and the ISM code (IMO, 2013a), and national equivalents, where the latter also is used to create the ship's safety management system (SMS). All these requirements and documents are assessed by the flag state and used to approve technical installations, and to issue the "Minimum safe manning document". In addition, the EU has published a guideline on safety goals for small passenger vessels (EU, 2019).

There is some published research focused on manned passenger ships, but this is mainly targeting large passenger ships and mostly limited to damage stability (Vassalos, 2014), fire (Spyrou and Koromila, 2020), and evacuation (Bucci, et al., 2016). Most of these results stems from research projects particularly funded by the European Commission, e.g., DSS_DC (2007), FLAGSHIP (2011), and HULLMON+ (2003). However, small ships have very different characteristics, so except for some statistics (Carter, et al., 2019), little or no relevant results are available. Still, there is some published work on integrated emergency management (Pennanen, et al., 2015), providing input in the context of remote support for small passenger ships. In addition, the work of Thieme, et al. (2019), provides relevant background information by presenting a pre-hazard analysis for a small passenger ship, hereunder covering input for risk reducing measures. IMO has introduced the "safe return to port" principle for large passenger ships (IMO, 2006), but although the principle is applicable in this context, the specific requirements and solutions are not directly suitable for small ships.

The number of safety crew required onboard a passenger ship is strictly regulated, and ultimately based on an evacuation analysis that is highly influenced by verified solutions within lifesaving appliances and the uniformity of the ship design itself. This in turn, is then an important basis for developing the crew safety instructions. Any such analysis must comply with IMO Circular 1533 – Revised guidelines for evacuation analysis for new and existing passenger ships (IMO, 2016), meaning that an autonomous passenger ship with reduced safety crew must be able to present a safety level equivalent to conventional ships.

In total, this leaves a significant gap for technology and technological solutions that are required for achieving the necessary reduction in safety crew.

3.3. *Rules and regulations*

As of today, there are no rules and regulations specifically developed for the certification and approval of autonomous ships. This means that IMO Circular 1455 - Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments (IMO, 2013), is the guiding document for flag states in their efforts to support the maritime industry towards realising approval of alternative solutions.

As an effort to support the Norwegian maritime industry, the Norwegian Maritime Administration (NMA) has produced a more specified version of the IMO Circ. 1455 (2013b). Limited to Norwegian waters, the NMA Circular RSV 12-2020 main objective is to provide guiding principles and requirements regarding mandatory documentation needs necessary for the approval of autonomous ships or alternative onboard systems (NMA, 2020). As such, and due to the absence of an adapted set of regulations, the NMA circular assures compliance with existing rules and regulations. Moreover, according to the NMA, there are two main principles that must be adhered to in order to obtain an approval.

The first principle is that the safety level shall be treated equally and be equivalent to – or higher – when compared to conventional solutions. The second principle is that s ship that is built and planned to operate at a certain autonomy level must comply with the existing rules and regulations for the type of ship in question.

4. Use-case descriptions

This paper have based the analysis on two use cases: The first use-case is a new slow-moving harbour ferry planned to operation in a sheltered water harbour basin, and the second is modernisation of a fjord-crossing service currently operated by a high-speed passenger craft Although both use-cases are located in sheltered waters, they differ significantly in complexity, both in terms of sailing- distance and speed, but also in passenger capacity and distance to land (Holte and Wennersberg, 2021). Both ships are envisaged to be operated as constrained autonomous with a common remote control centre.

4.1. *Use case 1 – Harbour ferry*

The harbour ferry concept is projected to operate at an average speed of five knots with a capacity of up to 99 passengers. The total sailing distance is approximately 550 meters as illustrated in red in Fig. 1. An existing service is also illustrated with black dotted line in the same figure. The crewing requirements for the existing route is one person (i.e., master), if the number of passengers does not exceed twenty-five. In all other cases, the minimum onboard safety crew is set to two persons (i.e., master and ordinary seaman). Since the proposed harbour ferry currently does not exist, it is assumed that the crew safety instructions is applicable for both services.

Fig. 1. Intended route (red line) for use case 1.

4.2. *Use case 2 – High-speed craft*

The high-speed craft is shown in Fig. 2 capable of transporting 147 passengers at an average speed of approximately 22 knots, covering a distance of 3.8 kilometers in approximately 10 minutes (see red line). Hence, due to the high speed, the total number of passengers, and the weather conditions, the minimum safety crew required to operate the service is three persons, consisting of a master, a chief engineer, and an ordinary seaman.

Fig. 2. Intended route (red line) for use case 2.

5. Results and discussions

Leading to the proposed description of the future onboard safety responsible, presented herein are the generalized results from analyzing the crew safety instructions of the two use-cases. Important development needs for novel safety solutions are also derived, regarded as fundamental if autonomous passenger ships with reduced onboard safety crew is to be realized (Holte and Wennersberg, 2021).

5.1. *Analysis of safety tasks for onboard crew*

In the occurrence of an abnormal situation, the different crew roles on conventional ships have a defined set of tasks to be completed. Depending on the scenario in question (i.e., fire, loss of stability, man overboard and evacuation), this may vary between ship type and area of operation. Nevertheless, if autonomous passenger ship transport is to be realized, automation of tasks that today require human intervention is required.

Based on the presumptions as noted in section 2, SoA and expectations regarding future technology development in a three-to-five years perspective, Table 1 summaries the findings from analyzing the existing safety instructions for both use-cases. This by identifying which tasks can be automated, and those who appear much more difficult to automate, in which the latter thereby requiring the attendance of safety crew onboard and RCC intervention. As such, the analysis not only presents which tasks that need further attention in terms of automation, but also possible allocation of task between safety crew onboard and the RCC. Moreover, it should be noted that to what extent tasks identified as "difficult to automate" actually can be automated or not, is highly dependent on future developments within safety solutions – stretching beyond the defined presumptions for this study. Also note that the analysis does not attempt to derive any concluding remarks or quantify the potential for actual reductions in safety manning. Rather, it concertizes the challenges related to realizing low-crew or unmanned passenger ships in general.

5.2. *Resulting distribution of tasks*

As noted in the SoA, despite technological advances and expectations within future technology development, the analysis clearly shows that several fundamental challenges remain to be solved if low-crew or crewless passenger ship transport is to be realized. In which some appear more difficult to automate than others.

One of the most challenging aspects of low- or unmanned passenger ships appears to be related to crowd control and the attendance of anxious passengers. The magnitude of this challenge further grows when considering differences and variations in demographics that naturally occur within a population, and thus also within the public transport domain (e.g., differences in age, physical abilities, language, mental health).

This means that given the occurrence of an abnormal situation, the safety crew must be ready to assist passengers, and to such an extent that the general safety level is not corrupted compared to conventional standards.

For evacuation, a particularly challenging aspect on top of the aforementioned is related to the release of MES station and life raft.

Table 1: Automation of crew tasks in an abnormal situation (Holte and Wennersberg, 2021)

Fire (machine room, energy storage room, passenger area)		
Possible (Automated tasks)	Difficult (Safety crew onboard)	Difficult (RCC required)
Automatic detection and release of fire- alarm.	Visual inspection of the scene of the fire.	Keep passengers correctly informed over PA system.
Automatic activation of fire-extinguishing system.	Local firefighting in e.g., limited parts of passenger area.	Identification of "false positive" situations.
Automatic notification to RCC and emergency units.	Attend anxious passengers and/or those in shock, while also assuring crowd control.	Secure safe navigation of the ship while catering for passenger safety.
Automatic notification to passengers over PA system.	Coordinate the onboard operation.	Assures activation of automatic fire-extinguishing system.
	Together with RCC, evaluate the need to initiate evacuation.	Assure situational awareness to all relevant stakeholders.
Loss of ship stability (collision, grounding, water ingress)		
Possible (Automated tasks)	Difficult (Safety crew onboard)	Difficult (RCC required)
Automatic detection of water ingress and loss of stability.	If required, bring portable bilge pump and initiate necessary action.	Keep passengers correctly informed over PA system.
Automatic notification to RCC and emergency units.	If possible, take the necessary actions to stop water ingress.	Secure safe navigation while catering for passenger safety.
Automatic notification to passengers over PA system.	Attend anxious passengers and/or those in shock, while also assuring crowd control. Coordinate onboard operation.	Assure situational awareness to all relevant stakeholders

	Together with RCC, evaluate the need to initiate evacuation.	
	Man overboard	
Possible (Automated tasks)	Difficult (Safety crew onboard)	Difficult (RCC required)
Automatic detection and notification to RCC (incl. transmission of exact position).	Responsible for local rescue and assistance of casualty (e.g., lifebuoy).	Secure navigation of ship to safe position enabling rescue of casualty.
Automatic issue of mayday-message to nearby ships.	If necessary, call assistance from passenger(s).	Assure situational awareness to all relevant stakeholders.
Automatic notification to passengers over PA system.	Maintain casualty after he/she is saved (i.e., lifesaving assistance).	Coordinates support from local rescue services.
	Coordinate onboard operation.	Maintains coordination of operation in collaboration with safety crew.
	Evacuation	
Possible (Automated tasks)	Difficult (Safety crew onboard)	Difficult (RCC required)
Automatic transmission of ship position and technical status to RCC.	Meets at mustering station and coordinates the operation on board.	Assure situational awareness to all relevant stakeholders. Notifies on ship technical status, position, number of passengers, weather, etc.
Automatic notification to passengers over PA system.	Decide on timing and perform release of automatic life raft and MES (Marine Evacuation System).	Ensure safe navigation of the ship while catering for passenger safety.
	Attend anxious passengers and/or those in shock, while also assuring crowd control.	Keep passengers correctly informed over the PA system.
	Assures that passengers wears life jackets correctly before entering MES system.	Supported by cameras and sensors, assist safety responsible in searching the ship for passengers, assuring complete evacuation.
	Enters the MES system as last person on the ship, after a physical search of ship for possible remaining passengers.	

Although the procedure and technicalities of doing this are relatively uncomplicated with new and automated solutions, operational experience and training is required to decide the on the optimal timing for performing the actual release of the raft. But also deciding which side of the ship to evacuate from by carefully considering a number of factors, such as the given weather conditions (i.e., wind and waves), possible heel of the ship, exposure to fire, smoke, etc.

Moreover, given that both fire and loss of ship stability are triggering events of an evacuation, the number of tasks that the safety crew must be able to handle in a short period of time are potentially significant. In addition to handling the onboard situation, coordinating the situation with external actors is also required. This further complicates the matter of reducing the number of safety crew onboard passenger ships, and to a large extent calls for totally re-thinking the safety solutions of passenger ships. Both in terms of technological solutions, but also allocation of tasks between the involved actors, e.g., RCC, safety crew and emergency response units.

For the RCC, the most important task appears to be assuring situational awareness to all relevant stakeholders, ensure safe navigation of the ship, and to coordinate the operation in question in collaboration with the safety crew onboard. This requires efficient and robust communication solutions with the ship, but also towards relevant external emergency response units.

Hence, in case of an abnormal situation onboard, human presence and intervention still appear to be highly needed, and to such an extent that overloading the different remaining roles is avoided. Meaning that any reduction in number of safety crew onboard compared to conventional standards must be carefully considered, thereby requiring further developments within new safety solutions. Possibly also regulatory amendments. This applies for all the pre-defined abnormal situations.

5.2.1 *Definition of safety responsible officer*

Referring to the above, also considering that the navigation and maneuvering of the ship is handled by the onboard ship autonomy system, it is possible to derive a generic description of a new onboard role. Namely a safety responsible officer handling both normal and abnormal situations.

Safety responsible – normal situations: Before passengers are allowed to embark or disembark the ship, the safety responsible assures that the ship is safely docked and that the automatic gangway is fixed in position. Assists passengers with special needs and assures the general safety of the passengers by being available and overlooking the passenger area. This also includes the ability to reject boarding of persons that may represent a safety threat to other passengers, such as intoxicated and mentally unstable persons. Before activating the procedure for the ship to sail to the next quay, the safety responsible assures that all passengers are safely onboard.

Safety responsible – abnormal situations: Always carrying a VHF radio, the safety responsible responds to the alarm in question and meets at the ship mustering station. The person is responsible for leading the onboard situation, performing risk reducing measures, and keeping passengers informed over the ship PA-system. Coordinates the operation with support from the RCC and jointly decides on the need to call for external assistance from local search and rescue services. Assures passenger safety onboard for all pre-defined abnormal situations, including crowd control, attending anxious passengers (and those in shock). Also ensures correct use of personal life saving appliances.

5.2.2. Development needs for safety equipment

As the analysis of the safety instructions show, if reductions in safety crew onboard passenger ships is to be achieved by increased autonomation of tasks, the need for technological advances within safety solutions is quite evident.

Particularly related to evacuation and the use of life rafts, two main strategies for future development are relevant: One being to further develop today's solutions as an integrated part of the ship, but even more automated. The ability to perform remote operation, meaning that the RCC could release the life raft if necessary, should also be pursued. An alternative strategy could be to develop a set of fallback states which do not include passengers leaving the ship, as this presumably will make significant contributions to reducing the of tasks in which the safety responsible officer needs to handle in an abnormal situation. This has clear parallels to the IMO principle "safe return to port", but a more suitable version for small ships is required.

Moreover, further advances are also necessary within the areas of how to mitigate the risk for fire outbreak, but also on how to secure a minimum level of ship stability.

6. Conclusions

This paper has analyzed existing safety instructions for two different passenger ships to investigate whether safety crew on autonomous ships can be reduced towards zero.

Specific tasks allocated to the different onboard roles were analyzed with regards to the possibility of becoming automated or not. Based on this, input for further development of new safety solutions was derived, but also a generic description of an onboard safety responsible officer. The latter represents a possible definition of a role as a safety crew officer onboard autonomous passenger ships.

The results clearly show that if passenger ships are to reach a point where safety crew can be reduced compared to conventional solutions, new lifesaving appliances and related technological breakthroughs are necessary. This incorporates advances in ship design, life-saving appliances, and to a large extent a total re-design of the entire passenger ship safety system. In which closer cooperation and knowledge sharing across actors in the supply chain appears to be a critical premise for success.

Moreover, as bringing new safety solutions to the market can be a time-consuming process, covering necessary steps such as technology development, testing and verification, the need for having safety responsible officer's onboard passenger ships appears highly relevant for years to come.

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