Governing Passenger Ship Evacuation

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Within the expansive domain of maritime safety, optimizing evacuation procedures stands as a critical endeavour. After all, evacuation is literally the last and fundamental safety level afforded to mariners and passengers.

Keywords: evacuation ; severe weather conditions ; passenger vessels ; smart devices ; impact assessment ; alternative approaches

1. Introduction

In an era marked by remarkable advancements in maritime technology and a notable surge in global travel, the average size of cruise ships has seen a substantial increase of 30% [1]. This trend, driven by shipping companies seeking economies of scale for profit maximization, has heightened the importance of ensuring passenger safety aboard ships. The evacuation procedures for passenger ships, particularly in the context of the notable increase in vessel size, emerge as a critical aspect of emergency preparedness and response in maritime safety. The safety of large passenger vessels demands immediate and focused attention [2]. In **Figure 1** the accident list, provided by EMSA, records the total number of accidents according to their severity levels between 2014 and 2021. The statistics suggest that despite the slight decrease over the last two reported years in marine casualties, very serious accidents may still occur [3]. Ratzan et.al. underline that between 2005 and 2023, 15 cruise vessels have sunk with 16 persons lost while 448 major cruise ship accidents have taken place [4].

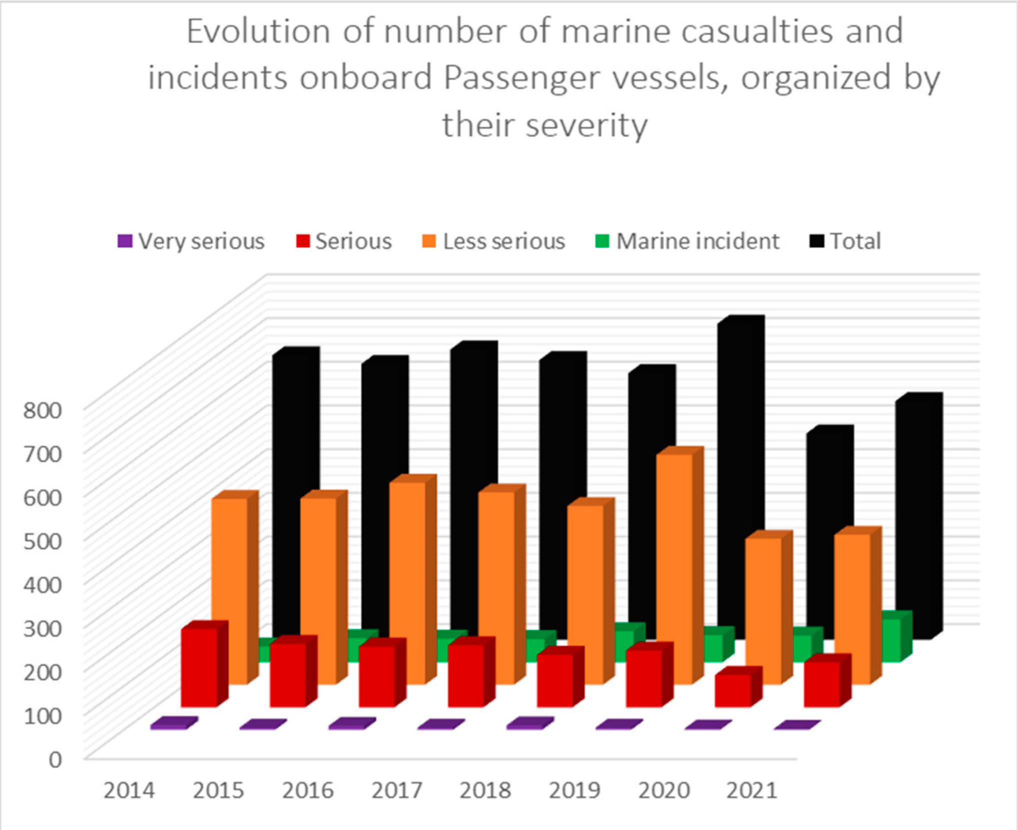

Figure 1. Marine casualties between 2014 and 2021 as per their severity level according to EMSA [3].

Furthermore, accidents similar to Costa Concordia's that required around 6 h to be evacuated, Norman Atlantic with a total evacuation time of around one day, and Viking Sky with an evacuation time of approximately 5 h, depart greatly from the SOLAS prescribed maximum 60/80 min (depending on the total number of main fire vertical zones (MFVZs)).

2. Regulatory Framework

The regulatory landscape governing passenger ship evacuation is shaped by international standards, with organizations such as the International Maritime Organization (IMO) taking a leading role.

In the realm of maritime safety regulations, the IMO has undergone a series of updates to enhance evacuation analyses for passenger vessels. In recent years, several key regulations have been superseded and summarised by [5][6]. In a landmark development for maritime safety, MSC.1/Circ.1533, issued on 6 June 2016, marked a significant evolution in the guidelines concerning evacuation analyses for both new and existing passenger ships [7]. This circular superseded all prior regulations on the matter, consolidating and advancing the framework for assessing evacuation procedures. The directive underscores the importance of optimizing evacuation procedures for passenger ships. Furthermore, insights and recommendations stemming from the 4th session of the IMO Sub-Committee on Ship System and Equipment (SSE 4) have contributed significantly to the ongoing evolution of safety measures within the maritime sector [2].

The recent circular introduces several key features in the realm of evacuation analysis regulations. Firstly, it extends the mandate beyond ro-ro passenger ships to encompass all passenger vessels constructed on or after 1 January 2020, marking a significant expansion in its applicability. A critical aspect of this regulation is the mandatory determination of evacuation time, underscoring a proactive approach to enhancing passenger safety. While obligatory for newer vessels, the regulation encourages the voluntary performance of evacuation analyses for existing passenger ships. This proactive stance assists in identifying congestion points and critical areas, facilitating the adoption of operational measures to ensure evacuation times remain within permissible limits. In terms of methodology, MSC.1/Circ.1533 ensures flexibility for operators by allowing the evaluation of evacuation time using either the simplified or advanced method, consistent with earlier regulations. The simplified method adopts a “fluid-dynamic similarity” approach, conceptualizing corridors and stairs as tubes through which passengers flow. The circular provides specific procedural guidelines for the application of this method. On the other hand, the advanced method involves representing passengers individually with distinct characteristics. Evacuation time calculation is facilitated by virtual reality-based software, offering a more nuanced understanding of evacuation dynamics. However, it’s important to note that this analysis is conducted under simplified day and night scenarios, without explicitly considering the influence of flooding (and fire) hazards [7][8]. For thorough evacuation analysis, it’s advised to compute the complete evacuation time of each passenger using the method outlined in **Figure 2**. It’s recommended to repeat this process at least 50 times to accommodate the random factors inherent in the analysis.

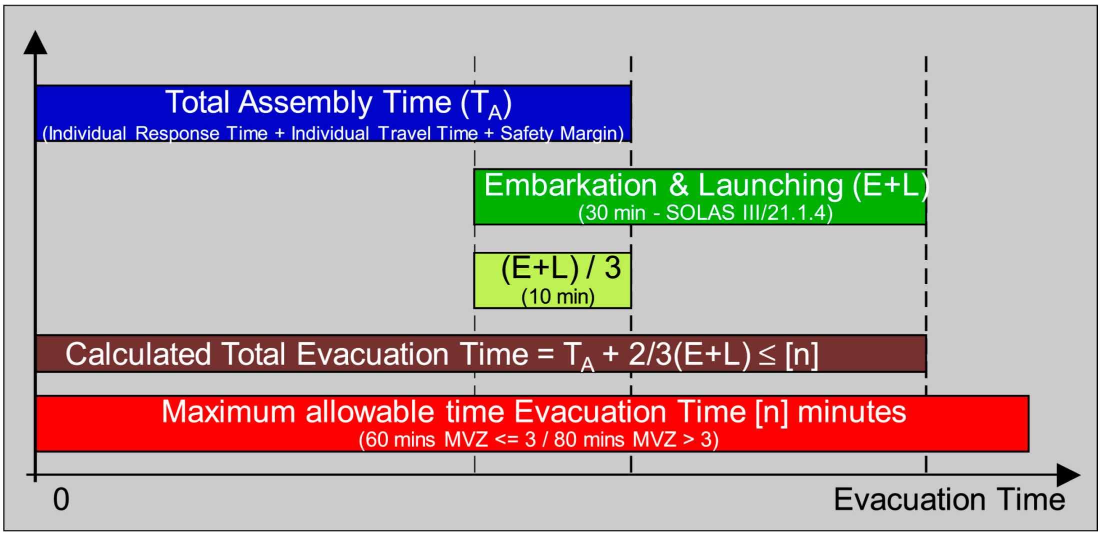

Figure 2. “Advanced” evacuation time [7][9].

3. Evacuation Procedure

The evacuation procedure on passenger ships involves a muster list that outlines various protocols for coordination. In an actual onboard emergency, the ship’s master has the authority to decide whether to follow the evacuation plan specified in the muster list or make modifications based on specific emergency circumstances. Factors influencing this decision may include the presence of smoke, the ship’s listing, the need to disembark if the ship is berthed, and other pertinent considerations. Specifically, during the evacuation process on large cruise vessels, passengers are instructed to go to their cabins to retrieve and don their life jackets before proceeding to designated confined areas known as muster stations. Similarly, for large ferries, the procedure is akin, with the distinction that those without reserved cabins are directed to seat lounges to collect their life jackets before moving to the muster station (see **Figure 3**).

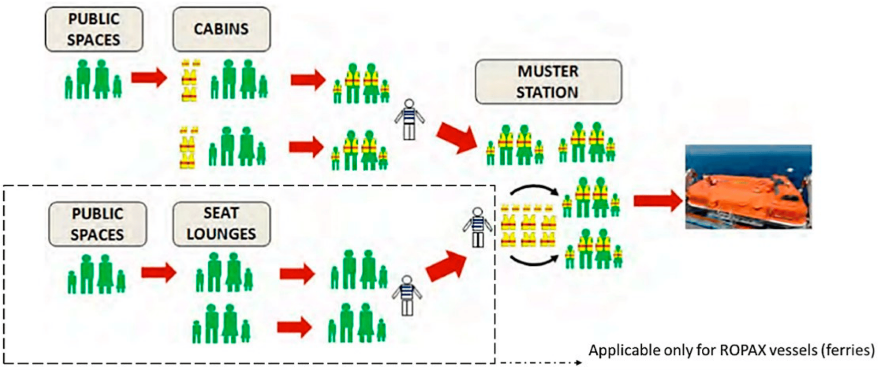

Figure 3. Procedure followed on board large passenger vessels during evacuation [10].

4. Evacuability

The ship–sea evacuation problem is a multifaceted challenge. Distinct from evacuations in airplanes and buildings, ship evacuations face complexities due to the ship's unique geometries, the need for preparation for survival in harsh maritime environments, and the uncertainties arising from the unpredictability of human behaviour. The RoPax Norman Atlantic evacuation serves as a tangible example of the difficulties encountered. More precisely, evacuation process was one the most challenging ones that had to be dealt with over the last years due to the stormy weather. As a result, it was not clear whether abandoning the flame engulfed vessel was supposed to be a safer choice rather than embarking on the lifeboats of the vessel during such dangerous conditions. The procedure for all passengers and crew members to follow either on board or at sea during an evacuation is summarised in **Figure 4**.

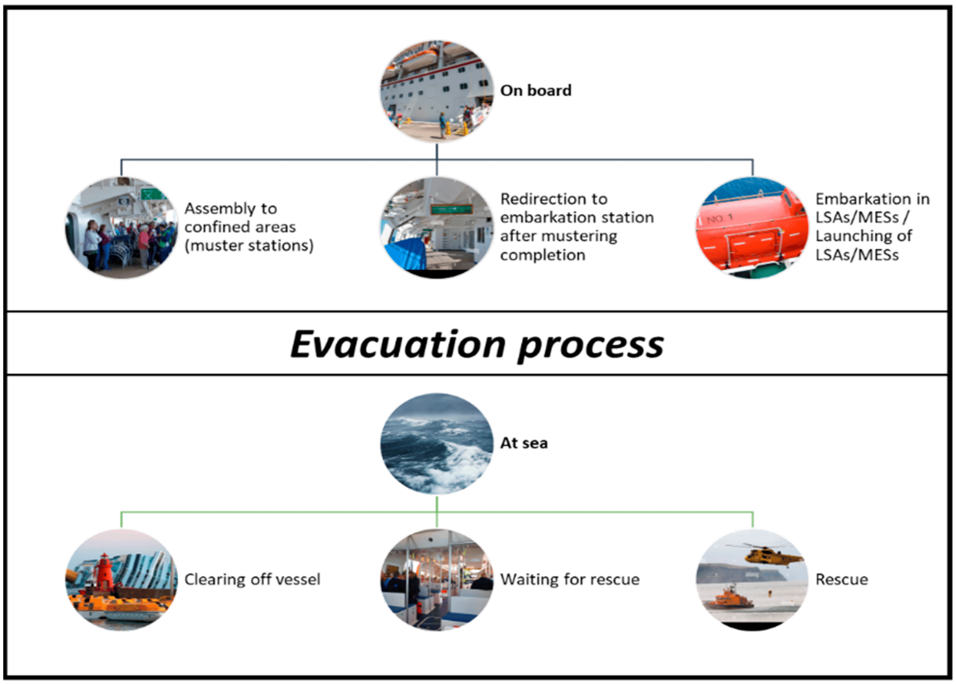

Figure 4. Evacuation process [11].

The concept of "evacuability" encapsulates passenger evacuation performance, considering factors like evacuation time, vessel general arrangements, life-saving appliances, passenger familiarization, crew training, effective procedures, intelligent decision support systems, and design modifications for ease of evacuation. All these aspects are regulated by various rules and regulations.

However, evacuability problems persist, including mass evacuations from complex environments, unknown inaccessibility issues, progressive flooding, fire/smoke, and the inherent uncertainties tied to human behaviour, all constrained by limitations in time. Addressing these challenges requires a comprehensive approach to enhance the effectiveness and safety of ship–sea evacuations [11]. The definition of the time required for a systematic evacuation and abandonment, as approved by the IMO MSC, is clarified as follows: "The duration, starting from the moment the casualty threshold is surpassed until all individuals have successfully abandoned the ship, during which the ship remains viable for this purpose ”[9].

5. Time-Domain Simulation Tools

Following the introduction of the advanced method for evacuation, there have been several projects focusing on developing evacuation models for passenger ships and striving for a full-scale simulation of a damaged ship [12]. For instance, the Maritime-EXODUS project at the University of Greenwich, led by Gwynne in 2003, aimed to create a comprehensive simulation for evacuating a damaged ship under the propagation of fire. The EXODUS platform incorporates five major components, including a velocity-based pedestrian model, population distribution, human behaviour model, fire and smoke spread model, and environmental hazard subprogram [13].

Following the IMEX project, ref. [14] focused on developing a model capable of simulating various evacuation procedures from public transportation systems, including buildings, ships, and aircraft. Utilizing a discrete-cells spatial representation, this model can simulate the movements and behaviour of each individual in a crowd. Another notable solution is the BY-PASS model, introduced by Meyer-König in 2002, which offers an intelligent approach to ship evacuation. This model is characterized by the general features of evacuation models, a dynamic model, and an intelligent human behaviour model [15].

Similar to IMEX, ANEAS was developed by Meyer-König in 2007 to address challenges arising from the inclusion of ship motions in evacuation modelling, implementing velocity reduction coefficients specific to various deck inclinations [16].

VELOS introduced virtual reality to evacuation simulation to establish a platform facilitating design feedback in the initial phases by immersing multiple users in dynamic operational scenarios [17].

Over the past decades, scientists have explored diverse approaches to designing frameworks for human evacuation. The EVAC simulation program, presented by Drager [18], employed a microscopic method to simulate the evacuation process through interactions between passengers with individual characteristics. However, this model did not incorporate dynamic effects and ship motion characteristics.

Concurrently, the passenger evacuation simulation system Evi, as introduced by Jasionowski et al. [19] utilizes a real-time, multi-agent, and mesoscopic approach. A distinctive feature of Evi is the application of a virtual environment to enhance the efficiency of evacuation performance, making it the most appropriate model for passenger evacuation simulation on a multi-level planning structure. A typical representation of the Evi environment is depicted in **Figure 5**.

Another issue is that considering the velocity of a human as the sole determining factor in their movement, is not entirely accurate. Human movements are influenced by both natural (physical) and social forces [12].

Importantly, the influence of flooding and fire-related hazards can be integrated into EVI both temporally and spatially. The software possesses the capability to assimilate time histories of ship motions and flooding in ship compartmentation from time-domain flooding simulation tools like PROTEUS-3.1 [20].

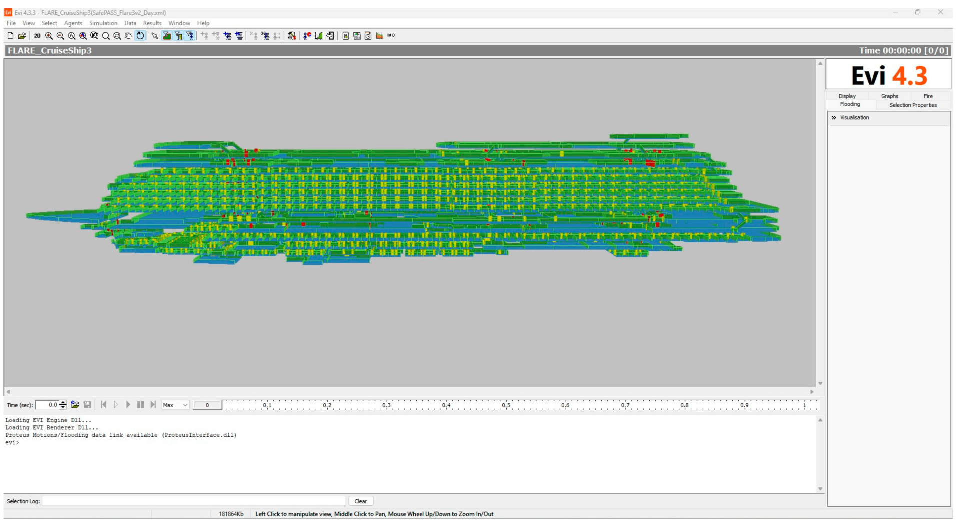

Figure 5. EVI software environment [21].

These approaches solely consider the kinematics of ship movements, introducing reduction coefficients for the velocity of passengers. The velocity values of each person in the crowd are calculated for various static values of angles of roll or pitch. The effects of ship motions and floodwater on individuals are simulated by applying walking speed reduction coefficients as correction factors based on the MEPDesign project results [18]. These coefficients are determined by functions representing the inclination of escape routes due to the ship's heel and/or trim resulting from damage [7][22]. The software also models the impact on the environment by treating regions directly affected by floodwater as inaccessible [23]. As a result, flooding data are used to influence the awareness and walking speed of agents [24].

6. Evacuation improvements

Given the challenges identified in traditional evacuation procedures amid severe weather conditions, it is clear that innovative approaches are indispensable for enhancing the safety and efficiency of evacuations on large passenger vessels.

Leveraging insights from the SafePASS project, innovative solutions have been developed, utilizing smart devices and augmented reality to revolutionize marine emergency response and vessel evacuation. Real-time risk metrics and a common operational picture (COP) provided by these solutions enhance crew training, offer personalized evacuation instructions, and improve decision-makers' situational awareness throughout all evacuation stages.

These solutions cover all evacuation stages, from alarm to rescue, promising tangible improvements in safety and efficiency, irrespective of hazards, weather conditions, or passenger demographics. Most precisely, they encompass various components, including a core engine, common operational picture, next-generation life-saving appliances (LSAs), ship layout alterations, indoor localization sensors, and integration of smart components such as dynamic exit signs, smart wristbands, passenger chatbots, passenger mobile applications, and smart lifejackets. Additionally, crowd dynamic simulators and risk modeling tool have been developed to further enhance evacuation procedures.

Additionally, conventional port evacuation procedures (when the vessel is moored at port) following the International Security Management (ISM) code may not always be suitable, leading to concerns about prolonged evacuation times. Modified procedures onboard passenger vessels aim to streamline evacuation processes and minimize response times, especially in port scenarios.

In conclusion, the integration of cutting-edge technological solutions and the refinements of the evacuation procedures enhance the safety, efficiency, and effectiveness of evacuations on large passenger vessels under various scenarios, ensuring swifter, smarter, and more secure outcomes.

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