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Organization of evacuation from passenger ships – a concept of safety enhancement

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Abstract
This article deals with issues relating to the evacuation of people from large passenger ships. Factors affecting the safety of passenger ships at both design and operational stage are described. The vital regulatory documents concerned with evacuation from ships are indicated. A concept of seeking an optimized evacuation plan at the design stage is presented. It aims at shortening the time of possible evacuation and at current on board planning of evacuation, taking into account inaccessibility of some escape routes.

Introduction

Dynamic development of ship building industry, especially the sector building large passenger vessels capable of accommodating thousands of passengers, imposes a very high level of safety of such ships and reveals that relevant legal regulations are outdated. The new philosophy behind ship design focuses mainly on increased survivability of ships. Nevertheless, accidents at sea happen, like the relatively recent disaster of the *Costa Concordia.* That is why efforts should be made to develop methods of efficient evacuation, the more so because the scope of actions aimed at improving survivability is wide and challenging for naval architects designing new vessels. Similarly, prevention of marine accidents at the operational stage, i.e. at sea, to a large extent depends on the human factor, a weak point in safety systems.

International standards on the organization of evacuation from passenger ships

From the ship designing viewpoint, regulations on evacuation analyses at the design phase are crucial. According to requirements of the SOLAS Convention (II-2/13.7.4) [1] and High Speed Craft Code (HSC) (Ch. 4.8.2) [2] ro-ro pasenger vessels and HSC have to undergo evacuation-related analysis at the design stage, taking into account counterflows (crew moving in opposite direction) and blockage of some routes. The following documents have been prepared as guidelines for evacuation analysis:

– *Interim Guidelines for a simplified evacuation analysis of ro-ro passenger ships* (Msc/Circ. 909) [3];
– *Interim Guidelines for a simplified evacuation analysis of high-speed passenger craft* (Msc/Circ. 1001) [4];
– *Guidelines for a simplified evacuation analysis of high-speed passenger craft* (Msc/Circ. 1166) [5];
– *Interim Guidelines for evacuation analysis for new and existing passenger ships* (Msc/Circ. 1033) [6];
– *Guidelines for evacuation analysis for new and existing passenger ships* (Msc.1/Circ. 1238) [7].

Other important documents are those related to evacuation plans and organization. These include MSC/Circ. 699 [8], revised guidelines for passenger safety instructions. The primary aim of these guidelines is to draw attention of all interested parties to relevant requirements of the SOLAS Convention and detailed recommendations regarding informing passengers on safety by way of audio presentations, announcements or symbols. Another aim is to remind maritime administrations of the necessity to ensure that appropriate measures are put in place to inform passengers on procedures that may be adopted in emergency situations.

Chapter III/B/II/29 of the SOLAS Convention presents guidelines on decision support system for crisis management. The regulations apply to all passenger ships. As a minimum, the system should consist of printed emergency plans. All predictable emergency situations should be defined in an emergency plan. Emergency procedures specified in emergency plans should facilitate the decision-making process based on model plans or their combinations. Emergency plans should have a uniform structure and be easy to use. Apart from a printed version, acceptable are emergency plans using the computer-based decision support system on the bridge. Such system contains all information included in emergency plans. The relevant program has to be able to present a list of recommended actions that should be taken in predictable emergency situations.

Identification of factors contributing to the improvement of passenger safety

Factors affecting safety improvement of a passenger ship may generally be related to two stages: design and operation (Fig. 1).

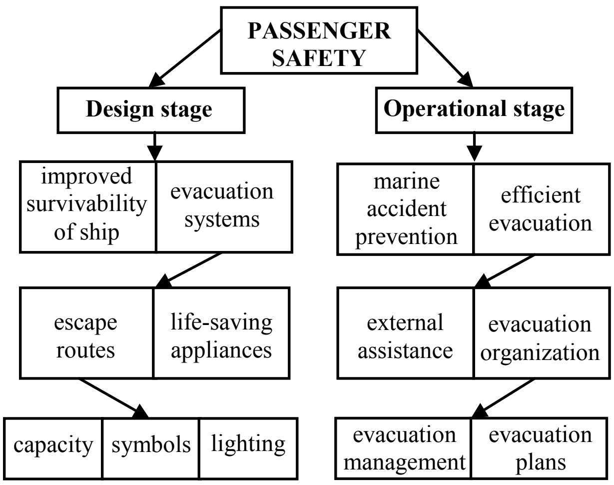

Fig. 1. Factors affecting the safety of passengers

At the design stage efforts should be made to improve the survivability of ships (passenger vessels have to be so designed as to be able to return to port safely after a fire or flooding of a watertight compartment). Work on developing evacuation systems should focus on both life-saving appliances and the design of escape routes. The latter should satisfy a number of requirements, but first and foremost, to effectively perform their function, escape routes should have the proper capacity, symbols and lighting.

Actions that should continually be taken during ship's operation aim at preventing accidents at sea, but these cannot be avoided. Therefore, escape routes have to be correctly designed. If passengers are not evenly distributed (evacuation mismanagement) jams may arise, increasing the risk of panic among evacuees.

A concept of seeking optimized evacuation arrangements at the ship design stage

An evacuation plan can be based on ship's general layout. The plan should include a diagram showing the distribution of passengers from spaces where they may stay the moment evacuation to assembly stations starts. The preparation of evacuation plan requires its optimization as a function of real evacuation time. Calculations of real evacuation time may be based on the simplified method recommended by the IMO or one of the available computer-based methods. The optimization method should be adjusted to the problem being solved and account for the accepted method of coding input parameters. Evacuation time is adopted as the objective function, so available evacuation time is a natural constraint. If evacuation time exceeds available time, the adopted plan of evacuation organization should be revised. If a solution satisfying imposed constraints cannot be found, the existing layout of escape routes should be modified.

When both, escape route layout and evacuation plan are positively verified, obtained information can be further utilized. Based on calculations, the proposed escape route layout can be checked for sufficient capacity, minimizing a risk of jams. Also, guidelines will be obtained for the most effective directing of passenger groups by crew members, so that time to reach assembly stations will be shortened. Such information should also be included in the evacuation plan and used during crew

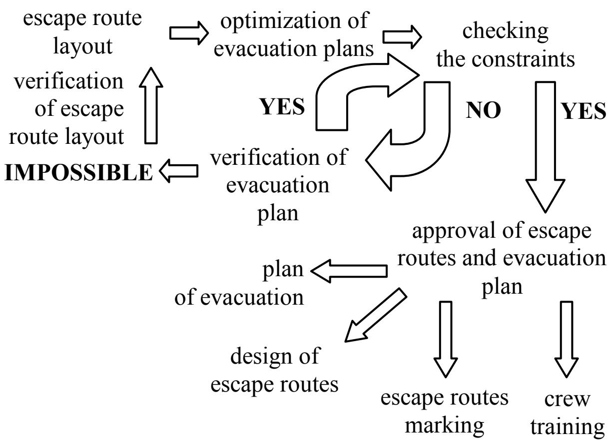

Fig. 2. Concept of the optimization of evacuation plans

evacuation drills. Obtained information on the direction of evacuation from specific starting points should be reflected in the shipboard system of escape route marking and in "Safety instructions for passengers". The proposed concept of optimizing evacuation plans is schematically presented in figure 2.

Concept of current planning of evacuation

Current planning of evacuation takes into account inaccessibility of some routes and offers possibilities of establishing alternative routes so as to avoid jams. It is possible that a longer route will prove better for reaching a destination promptly because a shorter route may have a reduced capacity for a variety of reasons. Figure 3 schematically presents current planning of evacuation.

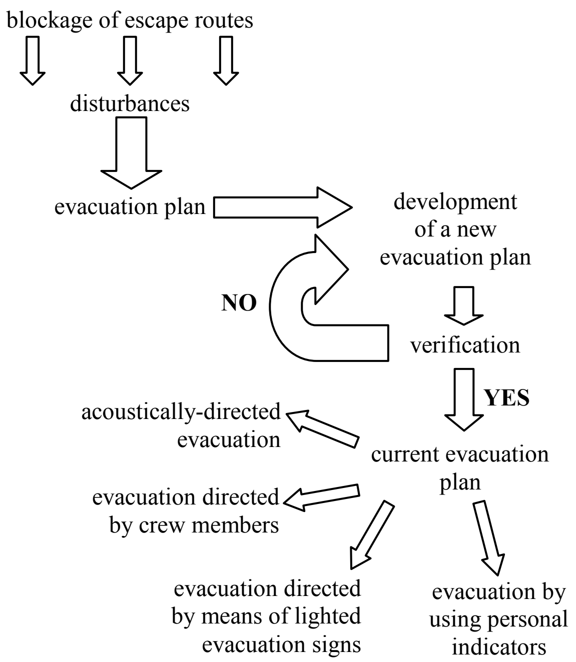

Fig. 3. Diagram of current evacuation planning steps

Information on blocked escape routes obtained from, e.g. a hazard detection system, should be used for determining a new allocation of escape routes to passenger groups. The given escape route or routes that are blocked for any reason should be removed from the encoded network of escape routes. Of several variants of evacuation that satisfy the assessment criteria for proposed solutions obtained through the optimization method used, the selected variant will be the one with the shortest time of reaching assembly stations. This variant becomes a current evacuation plan, superseding the previous one, until new information on route blockages appears (e.g. due to spreading fire). Calculations should be made until all groups of passengers reach allocated assembly stations. There are various ways of using a currently updated evacuation plan. The simplest use of current information would be for optimal allocation of escape routes by crew members in charge of evacuation. The crew members could be informed about the current state of escape routes by any of internal communication systems.

The proposed system can also be coupled with acoustic system of evacuation management. Directional sound is a new technology that is supposed to help passengers find the way out to assembly stations or other safe places for evacuees when a danger exists, especially when smoke or darkness dramatically reduce visibility [9].

Another solution can be two-directional arrows indicating which way to go. Depending on the present direction of evacuation, the proper part of the arrow would be lit. The arrow system may be based on LEDs, activated by the system from the bridge.

In the future, personal portable indicators of escape route direction might be an option, first of all for the crew members directing the evacuation, but also for passengers. A gadget like this would receive information on passability of escape route from the central system which would determine optimal escape routes for groups of passengers. In the light of today's dynamic development of information technologies we may expect that in the future all passengers will be equipped with small devices with an interactive map "You are here" and marked directions of evacuation. The device would allow to identify the best escape route instead of that instinctively followed by the passenger that will not always be the quickest one.

Short example of searching the optimum evacuation planning

The following is a calculation of the evacuation time for the simple escape routes arrangement for testing if the distribution of passengers have an influence for evacuation time.

We assume the initial presence of 900 people at public space (PP) (Fig. 4).

We assume the following dimensions of corridors [m]:

Length = {15; 10; 8; 10; 11; 3; 7; 10; 12; 5; 7};
Width = {2,4; 3; 2; 3; 3; 4; 2; 3; 1; 5; 2,4};
Stream 1 follows by points 1-2-3 to destination point (DP);
Stream 2 follows by points 5-6-7-11 to destination point (DP);
Stream 3 follows by points 4-8-9-10-11 to destination point (DP).

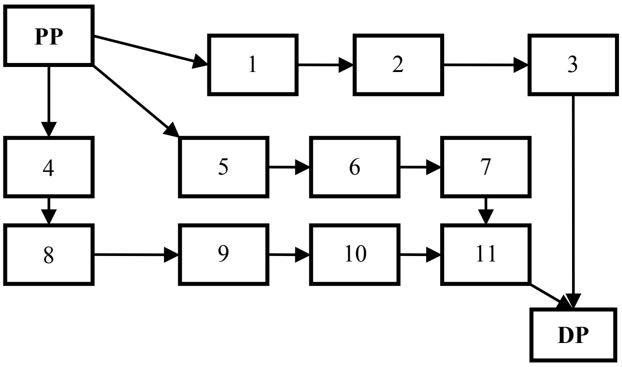

Fig. 4. Schematic distribution of the escape routes

Then the evacuation time calculations were made using a three optimization methods (genetic algorithm, pattern search and minimax optimization).

Obtained the shortest evacuation time about 15 minutes with the following distribution of passengers on each route: stream1 = 265 persons, stream2 = 437, stream3 = 198 people. The calculation results are shown in the graphs (Figs 5, 6 and 7).

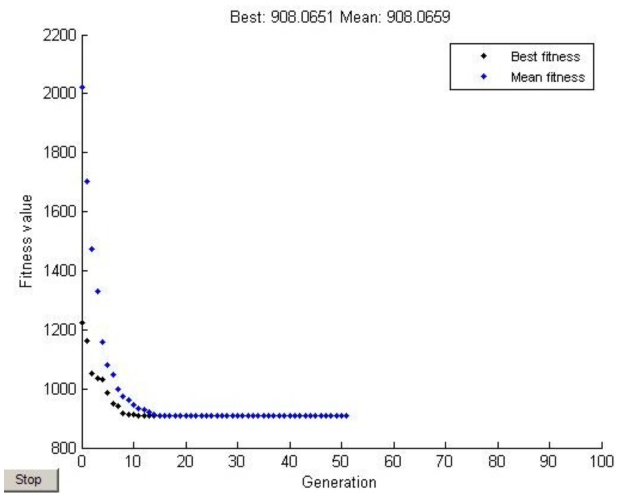

Fig. 5. The calculation results of the genetic algorithm

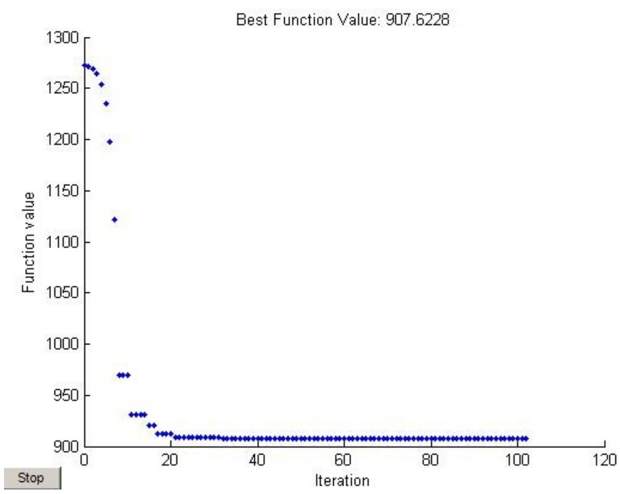

Fig. 6. The calculation results of the pattern search

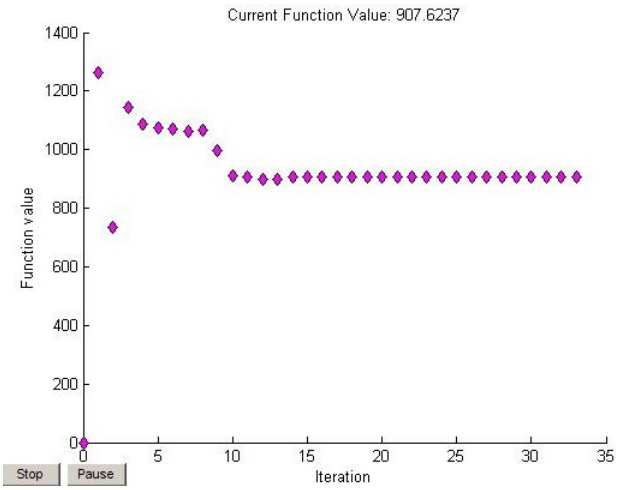

Fig. 7. The calculation results of the minimax optimization

Sample calculations are presented for simple distribution of rooms and a small number of people. The simulation results seem to indicate however that this method is also effective in the search for the optimal evacuation organization in real buildings with complex arrangement.

Conclusions

Unlike the past voyages of passengers travelling to a place of destination, sea cruises are today an attractive way of spending free time. Ship operators should ensure that passengers feel comfortable on board, as well as safe. The safety of people should also be assured in case the vessel has to be abandoned. An analysis of factors affecting the process of evacuation should be done at the stage of vessel design, as then some threats that might occur during vessel operation can be avoided.

Since evacuation from a ship in distress can hardly be avoided, efforts should aim at minimization or elimination of human errors that lead to threats and consequent evacuations. This should be done at various stages: design, construction and operation of the ship. The history of shipping and various disasters that many a time took deadly toll show that safety is a crucial issue. To sum up, it is essential to keep improving evacuation systems, including both life-saving appliances, design of escape routes and enhancement of evacuation procedures.

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