Evacuation Notation – a New Concept to Boost Passenger Evacuation Performance in the Cruise Industry

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Abstract

Breaking away from the traditional approach of the marine industry, that of passive (in-built) ship safety, RINA with assistance from the SSRC has recently developed and launched the first ever notation focused on operational issues (active ship safety); it has been tested on a ship of Carnival Cruise Lines (CCL). This Class Notation aims at assessing the effectiveness of crew functionality by comparing the evacuation performance of a ship in several specific scenarios (IMO scenarios, scenarios pertaining to social events, ship at berth and owner specific scenarios to reflect real emergencies) with and without crew assistance. This new concept makes evacuation analysis much more relevant, offering real “means” for enhancing passenger evacuation performance as well as incentivizing passenger ship owners to improve emergency procedures. This paper describes the concept and development of this groundbreaking approach, pertaining to the integration of all major crew functionalities within evacuation analysis (such as controlling spaces, searching cabins, and re-routing) and presents and discusses its implementation on a modern cruise ship, leading to conclusions and recommendations on the way forward.

1. Introduction

In the wake of the Estonia (Ro-Ro/passenger ship) disaster, trends of largely increased capacity of passenger ships, with people onboard now ranging up to 6,000, have brought the issue of effective passenger evacuation, it being the last line of defence in an emergency, to the centre of attention of the maritime industry worldwide. However, the process of evacuating a large passenger ship is a very complex one, not least because it involves the management of a large number of people on a complex moving platform, of which they normally have very little knowledge. These characteristics make ship evacuation quite different to evacuation from airplanes and buildings.

To address the risk associated with passenger evacuation at sea, the term Evacuability (passenger evacuation performance capability) has been devised entailing a wide range of capabilities that encompass evacuation time, identification of potential bottlenecks, assessment of layout, life saving appliances, passenger familiarisation with a ship’s environment, crew training, effective evacuation procedures/strategies, intelligent decision support systems for crisis management and design/modification for ease of evacuation. From a technical point of view, the mass evacuation of thousands of people from an extremely complex environment with unknown inaccessibility problems exacerbated by (potentially co-existing) incidents such as progressive flooding, fire/smoke and the inherent uncertainty deriving from unpredictability of human behaviour, is a problem with severe modelling difficulties at system, procedural and behavioural levels.

Evacuation has been a high priority on the International Maritime Organisation’s (IMO) agenda since 1999 when SOLAS imposed evacuation analysis to be carried out early in the design stage of new Ro-Ro passenger ships. Following this, the Fire Protection Sub-Committee, after three years of work, issued in February 2002 a set of revised Interim Guidelines for new Ro-Ro passenger ships – new cruise ships and existing ships on a voluntary basis – to be carried out either by simplified analysis or computer-based advanced analysis. Such analysis would allow for assessment at the design stage of passive safety (in-built) of the ship evacuation system only, while operational safety (active),
pertaining to any measures to enhance emergency preparedness and to better manage crisis in case of an emergency is only dealt with by means of a safety factor. In this respect, the IMO evacuation scenarios address issues relating to layout and availability of primary and secondary evacuation routes as well as passenger distribution and response times but does not address any real emergencies. Hence the need to prepare for these through better planning, training and decision support, all related to the functionality of the crew onboard, which is as crucial to passenger mustering as a good layout of the escape routes. Breaking away from the traditional approach of the marine industry to design aspects, RINA has recently developed and launched the first ever notation dedicated to operational aspects with help from SSRC and tested it on a CCL ship. This notation aims at assessing the effectiveness of evacuation procedures by comparing the evacuation performance of a ship in several specific scenarios (IMO - and ship-specific scenarios) with and without crew assistance. The final goal of this new concept is to complement the IMO evacuation analysis (which addresses mainly the design portion of ship evacuation) by specifically focusing on the efficiency of on-board procedures; used jointly with the IMO analysis, evacuation analysis would become much more relevant as well as incentivizing passenger ship owners to improve emergency procedures.

This paper describes the concept and development of this groundbreaking concept, pertaining to the integration of all major crew functionalities within evacuation analysis (such as controlling spaces, searching cabins, and re-routing) and presents and discusses its implementation on a modern cruise ship, leading to conclusions and recommendations on the way forward.

2. Evacuability

Before proceeding with the intricacies of evacuation, it is important to define the problem we try to solve and the degree to which this problem is formulated adequately for any evacuation analysis, conducted through numerical simulations, to be meaningful. In general, the ability to evacuate a ship environment within a given time and for given initial conditions (Evacuability) may be defined as follows (see Fig. 1):

\[ E = f\{ env, d, r(t), s(n_i); t \} \]

Thus, Evacuability is a function of a set of initial conditions, \( env, d \), and \( r(t) \), and evacuation dynamics, \( s(n_i) \), as explained next.

Initial Conditions: the following initial conditions (\( env, d, r(t) \)) should be defined and remain fixed during the execution of the simulation:

- **\( env \):** ship environment model, pertaining to geometry, topology and domain semantics. For any comparisons to be meaningful we need to assume a time invariant environment for evacuation simulations. An environment changing with time (e.g., blocking doors and exits online) could not easily allow for quantifiable assessment of these effects, as it would be very difficult to repeat any such action in precisely the same state of the simulated system. However, the ability to change the environment online could offer a strong basis for crew training and for decision support in crisis management. Moreover, fire/smoke spreading and progressive flooding, the principal hazards giving rise to the need to evacuate, result in a time varying environment. Hence for any comparisons concerning global and local effects to be meaningful, any environment changes ought to be affected in a deterministic way.

- **\( d \):** initial conditions of the evacuation problem, pertaining to spatial and temporal demographics of the people onboard. People in the environment will actually be randomly distributed with the possibility of fixing some initial values, e.g., placing physically disabled people on the embarkation decks and/or near an exit. As such, the initial distribution of people’s demographics ought to be sampled to identify its effect on evacuability. The latter could be avoided if the distribution is known with sufficient accuracy (confidence) that a specific spatial distribution in a given time is taken to define a specific scenario for any operational or design purposes.

2
• \( r(t) \): response time, which according to the IMO definition, is intended to reflect the total time spent in pre-evacuation movement activities beginning with the sound of the alarm. This includes issues such as cue perception provision and interpretation of instructions, individual reaction times, and performance of all other miscellaneous pre-evacuation activities. In addition, in-situ response time or any change in the state of a moving agent through intervention of e.g., crew ought to be considered. Response (awareness) time is certainly a random variable hence it has to be sampled for various distributions in order to evaluate its effect on evacuability.

![Evacuability (E) Diagram](image)

Evacuation Dynamics: relates specifically to walking speed, which constitutes the main motion variable of evacuation dynamics as explained next:

• \( s(n_i) \): walking speed of individual flow units (agents/persons). The fact that each person onboard is dealt with as an individual flow unit and that every procedural (evacuation plan) / functional (crew assistance) / behavioural (microscopic behaviour) parameter could be accounted for as a multiplicative factor ascertaining walking speed, provides for a unique and relatively easy way for simulating evacuation, essentially being able to deal with the effect of all of these parameters by simply following a given evacuation plan, accounting for crew assistance in some agreed quantifiable way and then sample walking speed for each individual flow unit from a corresponding distribution dependent on the environment and demographics. Using the relevant mobility impairment index (MII) the walking speed in each case can straightforwardly be calculated. From a development of realistic simulation of evacuation point of view, a great deal of effort may have to be expended to accurately quantify MII for all the pertinent microscopic behaviour as well as for specific crew assistance.

On the basis of the above thinking, it may be stated that evacuability is a well-defined problem that can be formulated and solved (simulated) for given initial conditions and passenger flow parameters.

3. Crew functionality

The decision to evacuate passengers from a ship in distress is taken only as a last resort, and it is usually part of detailed contingency plans developed for modern cruise vessels as regards specific emergency situations on board including fire & explosion events, collisions, man overboard, unlawful acts, etc, Vlaun et al. (2001). In cases where mustering is necessary, whilst all passengers and most of crewmembers are directed to their respective muster stations to await for further instructions, the remaining crewmembers are assigned specific emergency duties to ensure that the situation is kept under control and that passengers and crew reach assembly stations in a rapid and orderly manner; these duties include inspection of public/accommodation spaces, preparation of lifeboats/liferafts,
technical response (fire-fighting, flooding control, etc) and evacuation assistance (along the escape routes), among others. In terms of evacuation assistance (referred to also as crew functionality), the following factors are taken into account for assigning different tasks to the crew:

- the age profile of the passengers
- the degree of mobility impairment
- the varied degree of familiarity of passengers with the layout (less familiarity with secondary escape routes)
- group/friends/family behaviour
- uncertainties in human behaviour
- specific emergency procedures onboard

The last issue is of particular importance as some of the procedures may add a significant overhead to the travel time (time for reaching the assembly stations) and raise the potential for congestion. An example of this is the fact that in large cruise vessels, passengers usually must pick up their lifejackets from their cabins before proceeding to muster stations; this leads to increased counter flow and likelihood of bottlenecks on stairs. The potential negative impact associated with all other factors, are addressed through crew assistance.

It is obvious then that actual mustering on board large passenger ships may significantly deviate from the standard IMO scenarios, *IMO (2002)*, which were developed for design purposes (thus simplifying the crew role); indeed, due to differences in vessel type and operational profile, each operator has its own evacuation strategy and procedure, reflecting individual experience and operational feedback. When it comes to passenger safety, the most pro-active ship operators are now keener in having their safety policies and procedures properly quantified, recognised and acknowledged; in this respect, RINA’s Class Notation is a step in this direction. In line with these developments, SSRC’s evacuation simulation model *Evi* has been enhanced to explicitly accommodate all relevant crew emergency tasks (see Fig. 1) and allow quantifying their effect on the mustering process. This is done through increased interaction between the user and all the elements of the evacuation model platform, namely the passengers, crewmembers and the environment.

The new capabilities allow the assumption that a proportion of the passengers will have difficulties in finding their way to their (known) destination and are then assumed to be “lost” (it is noted that this is a conservative assumption since it is very unlikely that 30% of the passengers will be lost). Moreover, crewmembers can be assigned specific tasks, according to the procedure under analysis, like: searching passenger areas (SEARCH), directing/guiding passengers along escape routes and assisting lost passengers in finding their way to final destination, be it cabins, the closest muster station, etc. (GUIDE and CONTROL). Modelled agents (passengers or crew) can be programmed to give and receive real-time messages and to perform other specific and more complex tasks. As evacuation procedures may differ between different ship types and operators, the new capabilities are extremely useful for accurately modelling, quantifying and evaluating specific responses to any emergency scenario.

### 4. Measures of effectiveness of crew functionality

The evacuation performance of a ship with and without crew can be assessed on the basis of the time history of passenger Objective Completion (illustrated in Fig. 2), showing the arrival times (to their respective assembly stations) of all evacuees taking part in the simulation. In the vertical axis, the cumulative number of evacuees is shown while the time line is shown in the horizontal axis. This graph (Fig. 2) can be “normalised” with respect to the total number of evacuees, so that the cumulative percentage of evacuees that have, at a given time, reached safely at the muster station is shown in the vertical axis (Fig. 3). The *normalised* graph is referred to as the Passenger Objective Completion (POC) curve for which a number of parameters can be quantified to characterise the outcome of an evacuation simulation. Among others the following are noteworthy (see Fig. 3) as investigated by the SSRC whilst implementing crew functionality:
• The time $t_k$: the time corresponding to the moment when a $k\%$ ($k$ percentile) of the total number of evacuees has reached safety (the assembly station). Representative percentile values of 5, 50 and 95 can be used for comparison;
• The area below the POC curve, which although it has time units (average time), may be interpreted in terms of risk as the 1’s complement of the normalised POC curve expresses the risk of loss of life (equivalent to the probability of an evacuee not having completed his/her objective at a given time);
• The time $t_{\text{max}}$: the assembly time of the last evacuee to reach safety – this time should obviously be shorter than the minimum time available before reaching untenable conditions (associated with capsizing, sinking, fire and/or smoke contamination, etc.);
• Time interval $t_{95}-t_{5}$: statistic of the duration of the significant assembly process (reflecting the process duration for 90% of the evacuees) – the assembly time of the quickest and slowest 5% of the evacuees are not accounted for.

Considering that the arrival time of the evacuees is a random variable, the POC graph is different every time a new simulation run is conducted. Thus, in order to have a statistically significant result, an average (from $n$ runs) POC curve (referred as to an APOC curve) can be obtained by calculating the average time from every percentile level of the $n$ POC curves.

![Fig. 2: Time history of passenger Objective Completion from evacuation simulation](image)

Given that crew functionality (as implemented) relates mainly to SEARCH, GUIDE and CONTROL, and that these functions may significantly affect the shape of the POC curve – and consequently the characterising parameters, the following reasoning can be made for developing a performance criterion for evaluating the effectiveness of crew functionality:

• The POC graph and the above parameters can be calculated and compared for any evacuation scenario and for the following cases:
  \[ \Rightarrow \text{Active crew:} \text{ crew tasks, according to the evacuation procedure, are modelled} \]
  \[ \Rightarrow \text{Passive crew:} \text{ crew are treated as normal evacuees, no interaction with passengers.} \]

• Functions (in Evi) like SEARCH, GUIDE and CONTROL will certainly affect the risk of evacuees not reaching their destination on time (before a threshold time). The joint effect can be quantified by area and a measure of the effectiveness of crew functionality in terms of that risk can be expressed as follows:

$$\frac{t_{\text{max}} - \text{area}_{\text{active}}}{t_{\text{max}} - \text{area}_{\text{passive}}}$$
The SEARCH function determines how quickly the evacuees are alerted (minimum response time). If the minimum response time was reduced, then the assembly process would end sooner. A measure of the effectiveness of these functions at different phases of the assembly process, beginning (k=5%), middle (k=50%) and end (k=95%) of the process can be expressed as follows:

$$\frac{t_k^{\text{active}}}{t_k^{\text{passive}}}$$

The CONTROL and GUIDE functions determine how fast the evacuees reach their destination (by affecting travel speed and choice of escape route) and the duration of the assembly procedure. A measure of the effectiveness of these functions can be calculated as follows:

$$\frac{t_{95}^{\text{active}} - t_5^{\text{active}}}{t_{95}^{\text{active}} - t_5^{\text{active}}}$$

Fig. 3: Passenger Objective Completion (POC) curve – Characteristic parameters for the calculation of the crew functionality index (CFI).

In synthesis, the POC curve can be characterised by a number of parameters that expressed individually or jointly can be used to quantify – in terms of computer evacuation simulation, the assembly process in a given scenario for given initial and evolving conditions. These concepts are implicitly reflected in the performance criteria specified in the EEMS notation developed by RINA, as described next.

5. Enhanced Evacuation Management System (EEMS) – RINA notation

The basic goal of developing a class notation for evacuation was to complement the current IMO evacuation analysis requirements (MSC/Circ. 1033) and provide, once used in conjunction with IMO’s analysis, a complete assessment of the evacuation safety strategy onboard consisting of a comprehensive quantitative (yet theoretical) and qualitative evaluation of the operational procedures onboard. Accordingly, the acceptance criteria (which require as a pre-requisite that the vessel fulfil IMO’s analysis requirements) address the evacuation performance of the first 95% of the evacuees in a quantitative manner, and the remaining 5% of evacuees qualitatively.
5.1. Quantitative assessment

Quantitative assessment is carried out with advanced evacuation analysis (as described in MSC/Circ.1033, but enhanced to include modelling of crew functionality). The performance criteria are as follows:

- **Time Criterion (P1):** (applied to Standard Day and Night scenarios only) requires that, taking into account the active interaction between passengers and crew members, after 45 minutes (2700s) at least 95% of the passengers have reached their respective muster station\(^1\). Thus it covers the initial and central part of the evacuation process, where most (95% of total number) of passengers (evacuees) are mustered. It can be expressed as follows (see Fig. 4):

\[
P_{\text{active}}(45') \geq 0.95 \quad \text{or} \quad t_{95} \leq 45'
\]

- **Efficiency Criterion (P2):** (applied to all evaluated scenarios) requires that after 45 minutes, the area of the normalised POC curve (% of evacuated passengers vs. time) calculated for the active case is greater than the area calculated in the passive case. This implies that implemented crew procedures must have a positive effect after 45 minutes and can be expressed as follows (see Fig. 4):

\[
E_{45} = \frac{\text{area}_{45-\text{active}}}{\text{area}_{45-\text{passive}}} = \frac{\int_0^{t_{\text{max}=45'}} P_{\text{active}} dt}{\int_0^{t_{\text{max}=45'}} P_{\text{passive}} dt} > 1.0
\]

![Fig. 4: Performance criterion for EEMS RINA notation](image)

5.2. Qualitative assessment

Qualitative assessment covers the final part of the evacuation process, where it is assumed that (on the basis of operational experience) the remaining 5% of the evacuees are delayed due to unforeseen and rather specific problems (e.g. mobility impairment, panicking, etc.), which cannot be formally modelled and included in the advanced simulation analysis. Therefore the analysis is to be carried out in qualitative terms by using a checklist.

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\(^1\) Embarkation and abandonment phases are not dealt with at this stage
6.  Case study

In calibrating the EEMS notation, SSRC (with the assistance of RINA and CCS) carried out more than 100 different simulations covering a wide range of situations. In the following some results are provided for the sake of illustration. These results are relevant to a large and modern cruise ship from the CCL fleet, accommodating more than 2,500 passengers and close to 1,000 crewmembers. It is noted that the aim of the analysis was to calibrate RINA’s notation and was not meant to check CCL’s procedures; on the contrary past experience show that CCL procedures are very effective and have therefore been used as a best practice on which to tune the EEMS notation.

Four scenarios were addressed, namely: Night standard (IMO), Day standard (IMO), Recreational Day, and Recreational Night (see Table 1). The performance criteria of the EEMS notation were evaluated by comparing two cases:

- **Passive**: the crew does not influence the passengers’ movement, reaction time or way finding abilities, and
- **Active**: the crew influences the passengers’ movement, reaction time and/or way finding abilities.

In both cases, 30% of the evacuees are assumed not to be familiar with the route to their destination (as mentioned earlier, this is a very conservative assumption), thus the effectiveness of crew assistance can be assessed.

| Table 1: Scenarios and parameter for quantitative analysis (EEMS RINA notation) |
|---|---|---|---|---|
| Index | Scenario | Demographics | Awareness time | Initial distribution |
| 1 | Night – standard (IMO) | MSC/Circ 1033 | MSC/Circ 1033 Uniform (600, 180) | MSC/Circ 1033 (> 2,500 pax) |
| 2 | Day – standard (IMO) | MSC/Circ 1033 | MSC/Circ 1033 Uniform (300, 90) | MSC/Circ 1033 (> 2,500 pax) |
| 3 | Night – Recreational | MSC/Circ 1033 | Uniform (300,90) | see description below |
| 4 | Day - Recreational | MSC/Circ 1033 | Uniform (600,180) | see description below |

6.1.  General assumptions

The “Recreation Day” scenario was designed to simulate an at sea condition where passengers are mainly located on open decks. In this case passengers are distributed in recreational areas of open decks and in fitness areas (e.g. spa, gymnasium, beauty centre), filled to their maximum capacity as defined according to the FSS Code, and in shopping spaces and in all other areas, which are likely to be occupied during the day, e.g. libraries, children play room, etc. Crewmembers are distributed as in “Day standard” scenario.

In the “Recreation Night” scenario passengers are distributed in all recreational spaces which are likely to be occupied by night (e.g. theatre, disco, night-club, piano bar), filled to the maximum capacity determined according to the FSS Code, and among other internal and external recreational areas. Crewmembers are distributed as in Day standard scenario. This scenario was designed to assess the evacuation performance of means of escape from large internal public spaces.

Among the total crewmembers, less than 300 were explicitly modelled since they are those who, according to the procedure, carry out tasks (“Active”) significantly affecting passenger movement, reaction time and wayfinding abilities, as indicated in Table 2. The remaining crew (although contributing in real life to the safe execution of the evacuation process) are assumed not to have a direct effect on the passengers’ movement towards muster stations and are simply modelled as defined in MSC/Circ 1033 (worth noticing, this is another conservatism in the EEMS notation).
Table 2: Summary of total and modelled Active crew (according to ship’s Muster List)

<table>
<thead>
<tr>
<th>Team</th>
<th>Crew No.</th>
<th>Tasks description</th>
<th>Crew No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspect &amp; clear</td>
<td>117</td>
<td>Assigned to clear specific accommodation areas or spaces</td>
<td>83</td>
</tr>
<tr>
<td>Evacuation</td>
<td>215</td>
<td>Crew assisting passengers at muster stations (103 crew)</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crew assisting passengers along escape routes at a fixed position (79 crew)</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crew with special duties for evacuating critical areas or passengers, without a known position (stretcher team, youth staff) (33 crew)</td>
<td>-</td>
</tr>
<tr>
<td>Embarkation</td>
<td>176</td>
<td>Crew assigned to lifeboat/raft stations for preparation of the LSA</td>
<td>-</td>
</tr>
<tr>
<td>Technical</td>
<td>95</td>
<td>Crew in charge of dealing with the emergency (e.g. fire patrol)</td>
<td>-</td>
</tr>
<tr>
<td>Other</td>
<td>21</td>
<td>Crew available for performing special activities</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>624</td>
<td>No. of crewmembers explicitly modelled</td>
<td>248</td>
</tr>
</tbody>
</table>

6.2 Discussion of results

The analysis demonstrates (even though this was not the aim of the analysis) that the evaluated procedures, applied to the vessel under analysis demonstrate a very good evacuation capability: as mentioned earlier, this was expected from past operational experience; therefore it demonstrates that the EEMS performance criteria are able to capture the essence of a good evacuation procedure.

6.2.1. Compliance with Time Criterion (P1)

The time criterion applies to the two Standard scenarios (“Night standard” and “Day standard”). It requires that, taking into account the active interaction between passengers and crewmembers, at least 95% of passengers be evacuated after 45’ (2700s). The results obtained for the CCL ship are presented in Table 3 and Fig. 5 to Fig. 8.

Table 3: Time Criterion (P1)

<table>
<thead>
<tr>
<th>Case</th>
<th>% of pax evacuated after 45’</th>
<th>CCL ship status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Night Standard</td>
<td>100</td>
<td>FULFILLED</td>
</tr>
<tr>
<td>Day Standard</td>
<td>96</td>
<td>FULFILLED</td>
</tr>
</tbody>
</table>

6.2.2. Compliance with Efficiency criterion (P2)

The efficiency criterion is to be met for all the four scenarios. It requires that after 45’ the area of the normalized curve (% of evacuated passengers vs. time) calculated for the active case is greater than the one calculated in the passive case. The results obtained for the CLL ship are presented in Table 4 and Fig. 5 to Fig. 8.

Table 4: Efficiency Criterion (P2)

<table>
<thead>
<tr>
<th>Case</th>
<th>Efficiency $E_{45}$</th>
<th>CCL ship status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Night Standard</td>
<td>1.182</td>
<td>FULFILLED</td>
</tr>
<tr>
<td>Day standard</td>
<td>1.027</td>
<td>FULFILLED</td>
</tr>
<tr>
<td>Recreation day</td>
<td>1.027</td>
<td>FULFILLED</td>
</tr>
<tr>
<td>Recreation night</td>
<td>1.029</td>
<td>FULFILLED</td>
</tr>
</tbody>
</table>
The value of efficiency obtained in the “Night standard” scenario is significantly higher than that obtained in all other cases. This is mainly due to the fact that, according to the procedure considered, the “Active” crew are alerted before the general alarm is given (5 minutes in the simulations). Note that this is a realistic, though conservative assumption; generally, when the safety officer on duty detects a potential emergency, the crisis management team, i.e. the “Active” crew is alerted and only when the potential crisis is confirmed, the general alarm is given; in other words, the “Active” crew is activated well before the remaining crew and passengers are alerted. Needless to mention, the 5 minutes value is a lower bound, hence the conservatism. This means that the “Active” crew is already proceeding towards (but has not necessarily reached) their assigned position on the ship before passengers and the remaining crew start moving (10’ after the general alarm is activated, according to IMO criteria). However, the main reason for such a significant improvement is that, in a night case, few persons need to go back to their cabins to collect their life jackets. In all other cases the value of the efficiency is close to unity after 45’. This does not mean a limited efficiency: in several cases the parameter is well above 1.0 for long periods of time (meaning a very high efficiency of the procedure e.g. during the first half of the evacuation process) while evacuees move to the stairways and muster stations. Eventually when a large number of evacuees are closer to the muster stations the efficiency reduces due to the increased density of people entering the muster stations. This high density is however limited to the stairway enclosures in the vicinity of the muster stations, hence easily manageable by the personnel assigned in these locations (whose duty is to calm down the evacuees and, if necessary, direct them in the final few meters of the evacuation path).

In the “Recreational Night” scenario the lower value of the efficiency during the first half of the process is due, in the specific case shown in this paper, to some congestion in the proximity of the aft stairway. In real life, this congestion would be easily dealt with by re-routing some of the passengers, thus further increasing the efficiency. Nevertheless this type of action is to be decided only on a case-by-case basis by the crewmembers having the authority to decide, depending on the type of emergency. Noticeably, this is an example of the usefulness of the analyses required by the EEMS.
notation: besides an objective assessment of the procedure, it leads to a useful feedback on potential critical locations onboard, thus providing a useful input for possible training of the crewmembers having the authority to decide evacuees re-routing.

Significant congestion (signified by local passenger densities being beyond 4 persons / m$^2$ for more than 10% of the assembly time, in accordance with IMO criteria) was never observed across the cases prior to the application of the full evacuation procedures.

Notwithstanding the above, when the actual procedures on board were modelled (full evacuation procedure in which passengers are prompted to return to their cabins with crew influencing the evacuation process) the main observation is the increased level of congestion due to counter flow. Indeed, in all day cases local density in many of the stairways around deck 3 were above 4 persons / m$^2$ for about 15% of the assembly time duration.

Accepting that the need for passengers to return to cabins to collect life jackets is a part of large passenger ship evacuation procedures, it is interesting to note that appropriate timing of procedures can significantly reduce levels of congestion. For the night case with crew procedures in place (Fig. 5), it is noteworthy that crew searching passenger cabins were able to clear most of the accommodation decks before “non Active” crew in cabins on lower decks started to fill the upper stairs. Consequently, passengers were able to travel down the stairs before being restricted by crew travelling up to their assembly station.

The size of staircases may be a contributing factor in the formation of congestion during counter flow situations. Smaller crew staircases used in evacuation may congest much more easily than larger main staircases (Fig. 9). Certainly, for very large passenger vessels, if the “return to cabins” is used, it is something that should be investigated in more detail, e.g. considering staggering the crew evacuation (i.e. pre-determined groups of “non Active” crew moving at slightly different times, a procedure which proved successful in High Speed Craft).

![Fig. 9: Counter flow on a smaller crew staircase while the larger staircase in the adjoining fire zone remains clear.](image)

### 7. Concluding remarks

Five years since the introduction of the first Interim Guidelines for a Simplified Evacuation Analysis, developments around the world concerning evacuation in the maritime context have increased in a staggering pace and research activities through multi-million projects are paving the way towards holistic approaches that address this problem as part of design/operation/training, systematically and scientifically.
When it comes to passenger safety, the most pro-active ship operators are now keener in having their safety policies and procedures properly quantified, recognised and acknowledged; in this respect, RINA’s EEMS Notation is a step in this direction. In line with these developments, SSRC’s evacuation simulation model Evi has been enhanced to explicitly accommodate all relevant crew emergency tasks and allow for quantification of their effect on the mustering process. This is done through increased interaction between the user and all the elements of the evacuation model platform, namely the passengers, crewmembers and the environment.

8. References


9. Acknowledgment

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