Ship Evacuation – Guidelines, Simulation, Validation, and Acceptance Criteria

Hubert Klüpfel[1]

TraffGo HT GmbH
Bismarckstraße 142 – 47057 Duisburg – Germany
e-mail: kluepfel@traffgo-ht.com

Summary. This paper deals with various aspects of ship evacuation: Guidelines, Simulation, Validation, and Acceptance Criteria. The paper is structured along those aspects. The first chapter deals with general aspects of ship evacuation, like environmental influences, ship motion, the special procedures on board ships, etc. The second chapter covers the guidelines applicable to evacuation analyses for passenger ships developed by the International Maritime Organization (IMO). Chapter 3 is dedicated to the simulation of evacuation processes on passenger ships. The last two chapters deal with the calibration of evacuation models for ships and the validation of simulation results.

1 Ship Evacuation: General

Developments in the evacuation of passenger ships have often been triggered by accidents: most prominently the sinking of the Titanic and the Estonia. In the aftermath of the Titanic tragedy, the International Convention for Safety of Life at Sea was developed and was the initial trigger of further regulatory developments which also led to the foundation of the International Maritime Organization (IMO). Further information on the subject and the IMO itself can be found at the IMO's website www.imo.org.

Concerning the topic of this paper – evacuation analysis for passenger ships – the decisive steps were taken in the aftermath of the sinking of the Ro-Ro-ferry Estonia in the Baltic Sea in 1994, which cost the lives of nearly 900 people. Prior to the development of "performance based evacuation analyses", the layout of a ship's escape routes, evacuation systems, and procedures was evaluated based on the lengths of escape paths, the width of corridors and stairways. [1] Starting with MSC/Circ.909 [13] the IMO issued a number of regulations dealing with the performance based analysis of a ship's evacuation procedures, layout of escape routes, and evacuation systems. This approach is based on a comparison of the available safe egress time (ASET) based on a calculation or simulation and the required safe egress time (RSET), based on fire safety standards applicable to the vessel.

$$RSET \leq ASET \tag{1}$$

[1] This is actually the fact for most building codes up to now.

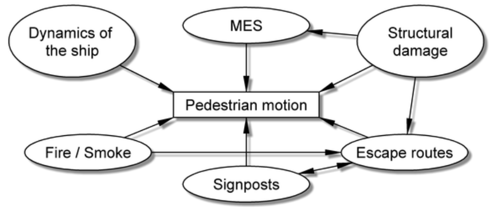

Fig. 1. The different influences on ship evacuation. MES is short for Marine Evacuation System.

The ASET was set to 60 minutes in the first version of the guidelines [13] for Ro-Ro passenger ships.

2 Guidelines for Ship Evacuation

The International Maritime Organization is the sub-organization of the United Nations specifically concerned with (among other areas) safety of ships (not only passenger vessels). In 2002, an extended version of the guidelines [11] was adopted, which contained two methods for performing an evacuation analysis: the simplified method based on a hydraulic or flow model (already present in MSC/Circ.909 [13]) and a so called advanced method based on computer simulations. Both methods are used to determine the RSET.

3 Simulation of Evacuation Processes on Passenger Ships

3.1 The Procedure: Assembly and Embarkation Phase

$$T = a + t + 2/3(E + L) \tag{2}$$

Where a stands for the awareness time, t for the walking time, E for the embarkation time, and L for the launching time. Lower case letters denote individual (person specific), uper case letters global times. The notation used here differs slightly from the notations of the MSC circulars 909, 1033, and 1238. This is due to the fact that the notation has slightly changed between those circulars and the notation used here is intented to make easy reference to the differences.

3.2 Special Influences like Ship Motion

MSC.1/Circ.1238 [14] lists the following categories of parameters:

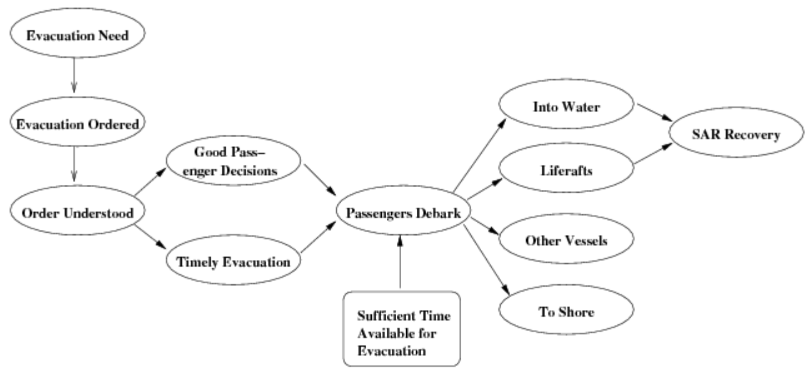

Fig. 2. Sequence of events in an evacuation (adapted from the US Coast Guard Evacuation Analysis Plan, see `www.uscg.mil/hq/g-m/nmc/evacuation/nfpapers.htm`).

– geometrical,
– population,
– environmental, and
– procedural.

3.3 ASET in the Case of a Ship

The determination of the available safe egress time in the case of a ship has already been briefly addressed in the previous sections. One approach is to determine the ASET based on fire resistance, i.e. if a fire resistance of 60 minutes is assumed and required by the regulations, then this time is taken. A more elaborate approach is to determine the ASET based on a hazard identification (HAZID) and risk analysis. The simulation of fire and smoke is part of such an analysis and can be used to determine the ASET.

4 Calibration of Evacuation Models for Ships

Calibration in statistics is a reverse process to regression. The calibration problem is the use of known data on the observed relationship between a dependent variable and an independent variable to make estimates of other values of the independent variable from new observations of the dependent variable.

In software project management, software testing, and software engineering, **Verification and Validation** (V&V) is the process of checking that a software system meets specifications and that it fulfills its intented purpose. **Verification** ensures that the final product satisfies or matches the original

design (low-level checking) i.e., you built the product right. This is done through static testing.
Validation checks that the product design satisfies or fits the intented usage (high-level checking) i.e., you built the right product. This is done through dynamic testing and other forms of review.
(all quoted from www.wikipedia.org)

It is important to keep in mind that verification is a matter of checking the correct implementation of a specified design. It does not check whether the design is fit for the intented purpose. This is mainly a matter of software engineering and does not say anything about the model. Validation is the second step. In order to be able to validate the product design (i.e. the model and its implementation) it has to be verified first. The results of a verified implementation of a model can be used to validate the model itself. MSC.1/Circ.1238 [14] lists the following categories of validation/verfication:

1. component testing
2. functional verification
3. qualitative verification, and
4. quantitative verification.

The first two items in the list would be called *verification* according to the definitions in the previous section. The other items belong to *validation*.

5 Validation of Simulation Results

Validation will be used here in the same way as in the previous section. Therefore, verification refers to the implementation and validation refers to the results obtained from the simulation. Simulation is used in two different ways (which is not unambiguous but reflects the generally accepted use): (1) as the implementation of the model, i.e. *simulation program* or computer program and (2) the activity of performing a simulation, i.e. applying the computer program. This loose terminology has the disadvantage of meaning different things (software / activity), but has the advantage of being intuitively understood by the majority of people in the field and being generally accepted.

When speaking of validation of simulation results, this comprises dynamic testing and other forms of review. Test cases are in that sense not part of the validation process but rather a means of verification. If the results are judged by an expert in the field, though, validation is the appropriate term. Just comparing a specified input and output in forms of numbers is not.

There are therefore at least three forms of validation:

1. Simulation of test cases like those provided in the Guidelines [14],
2. Comparison of evacuation exercises with simulation results, and
3. Comparison of simulation results with incident investigation reports.

6 Acceptance Criteria

As mentioned earlier, one acceptance criterion is the overall evacuation time. This criterion has been formulated in eq.1 as comparison of the required safe egress time as determined by the calculation or simulation and the available safe egress time specified in the guidelines (60 minutes for Ro-Ro passenger ships and other passenger ships having less or equal than three main vertical zones and 80 minutes for passenger ships other than Ro-Ro passenger ships having more than three main vertical zones).

7 Information Resources

For the sake of easy reference, here is a list of information resources (as a starting point, not an exclusive reference):

- `www.imo.org` — The International Maritime Organizations website
- `www.traffgo-ht.com/en/pedestrians/downloads/index.html` — contains a list of publications (including the author's) and a free demo-version of the software AENEAS for simulating ship evacuation
- `www.ped-net.org` — The pedestrian and evacuation dynamics network
- `www.evacmod.net` — The evacuation modeling network

8 Conclusions and Outlook (Safe Return to Port)

In this paper recent developments in the area of ship evacuation and its simulation were presented. Additionally, the regulatory regime was addressed. Concerning the expected future developments, the safe return to port (*The ship is its own best lifeboat* is expected to have a considerable impact on the evacuation procedures of (especially large) passenger ships. The most recent ships under construction are certified to carry up to 6,000 persons. Ships with up to 10,000 persons on board might be built within the next decade. One aspect that has not yet been addressed in this paper is Search and Rescue (SaR), which is one major reason why the safe return to port approach has been adopted by the IMO. Search and Rescue for that many people is a very difficult task. Bringing several thousand persons from lifeboats and life rafts back to other ships and finally back to shore might exceed the SaR capacities currently available.

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