Mustering Simulation of Passenger Vessels

Helge Soma

Safetec Nordic AS, Claude Monets Allé 5, N-1338 Sandvika, Norway
E-mail: hs@safetec.no

KEYWORDS:

Mustering, Egress, Evacuation, Simulation, Probabilistic Analysis, Risk Assessment.

ABSTRACT

Several disasters with passenger vessels in the last years have demonstrated a need for safety improvement. Risk assessment, including evacuation analyses, are promising tools in this respect. In the EU project MEP Design, measures for improving evacuation of passenger vessels have been analysed. The computer program Evac was implemented to synthesise the results MEP Design studies in relation to the mustering process. Evac has the potential for significant safety enhancement of passenger ship mustering.

BACKGROUND

In the last years there have been some severe accidents with passenger vessels, as referred in table 1.

Table 1. Accidents with passenger vessels

Ship	Date of Accident	Accident	Fatalities
Herald of Free Enterprise	March 1987	Rapid capsize, high list	193
Scandinavian Star	April 1990	Fire, toxic smoke	158
Moby Prince	April 1991	Fire	140
Estonia	Sept 1994	Rapid capsize, high list	852

The accidents have demonstrated a clear need for improvements, and highlighted deficiencies inherent with the safety regime in force.

LEGISLATION REGIME

The basis for this regime is international co-operation through the International Maritime Organisation (IMO) with specific safety requirements on a detailed level, in combination with approvals from national authorities. The regime suffers from similar deficiencies as those strongly criticised in the UK investigation following the severe accident with the oil platform Piper Alpha. The response was the Safety Case Regime and Goal Setting Requirements.

Work is ongoing in IMO, which may imply a step in the above direction. It seems as if IMO may base their regulations upon Formal Safety Assessment (FSA). This implies that rules will be based upon a risk assessment of a generic ship in representative environment. The design of ships will be based upon the rules.
In the Offshore Industry a detailed Quantitative Risk Assessment (QRA) is performed for a specific installation. Based on the QRA, risks are reduced *As Low As Reasonably Practicable* in the design.
A slogan often heard in offshore projects is: *The Devil Lays in the details.* This slogan originates from a long experience. By performing QRA on a specific ship, possibly built for a particular route, with all technical details defined, there is a fair chance of bringing the devil to light. However, by performing the Risk Assessment on a generic ship, all details are lost and the Risk Analysis methodology looses its power. Hence, a FSA is a poor substitute for a QRA.
Another weakness with a FSA is that the operator of the ship may not be sufficiently involved. The key to improved safety lies in involvement of responsible operator personnel. They need to think in terms of accidents, prevention and mitigation and not in terms of specific regulation requirements. When responsible ship personnel are asked about safety equipment, they tend to say: *Approved by NMD or DNV.* When responsible personnel on offshore installations are asked the same question, they explain the advantages and problems involved. The FSA may not change this situation

If passenger vessels had been treated in a similar way as offshore installations, the ship owner would be responsible for identifying and evaluating all potential accidents, and demonstrate the efficiency of the safety measures implemented to prevent and mitigate the accidents.

What seems likely with respect to passenger ship regulations in the near future, is that it may be required to demonstrate that evacuation can be performed within a certain time limit (1 hour). However, this limit will be a specific requirement, and not be based upon an analysis of accidents that may occur. Anyhow, the process goes in the right direction, and IMO has recognised that mustering computer simulations may improve safety, and work is ongoing with specification of the requirements for such computer tools.

EXPERIENCE WITH COMPUTER SIMULATION

The Norwegian Consulting Company Quasar has through a 15 years period developed computer programs for evacuation simulations, and performed evacuation studies of about 30 installations and buildings. The ownership of the programs has now been transferred to the Norwegian consultant company Safetec, while Quasar and Safetec co-operates in program development and projects.

In order to highlight the development trend in the offshore industry and to compare it with the ship industry, the main development projects and studies of installations and ships are referred in the below table.

Safetec/Quasar Evacuation Reference List

The accumulated experience is shown in the following two tables.

Table 2. Main Simulation program development projects.

Time Period	Description of Project	Clients
1997-2001	Development of the mustering simulation program Evac, as part of the EU project MEP Design. Evac includes several functionalities particular to passenger vessels, but it may also be used for other installations.	EU Commission
1994-1995	Validation of EVACSIM against Benchmark Cases, a Monitored full scale Evacuation of Plaza Hotel and the Scandinavian Star Accident. (Sintef project)	Norwegian Research Foundation.
1991-1993	Development of EVACSIM, a sophisticated tool for egress (Mustering) simulations. Exposure of evacuees to accidental fire loads was included.	Franch-Norwegian Foundation, SIMULOG (France) and Quasar.
1985	Development of the evacuation simulation program EVADE. Evade was based upon a flow model.	Norwegian Carribean Lines

Table 3. Main Experience with Mustering Analyses

Time Period	Description of Analyses	Clients
1982-2001	Egress and Evacuation Analyses of several of the North Sea platforms as part of the QRA. Main focus is given on exposure of evacuees to fire loads (radiation, heat and toxic smoke). Escapeway vulnerability is particularly evaluated. The fatality rate is assessed. Sophisticated CFD smoke spread calculations form the input to the Egress analysis. (Safetec analyses-mainly manual)	All main Oil Companies in the Norwegian Continental Shelf
1990-2001	Detailed Emergency Preparedness Analyses of several North Sea Installations, addressing all technical and operational aspects of evacuation. (Safetec analyses-mainly manual)	All main Oil Companies in the Norwegian Continental Shelf
1995	Escape and Evacuation analysis of Statfjord A. (Evacsim)	Statoil
1993	Evacuation Analyses of the Pipelying Barge Concept, SOLITAIRE, according to NMD Requirements (Evacsim)	Allseas Engineering bv. Netherlands
1992	Evacuation and Escape Analysis of the ALBA FSU (Evacsim)	Chevron UK
1990-1995	Evacuation Studies of the Heidrun TLP. Egress simulations with Evacsim. (Evacsim)	Conoco Norway Inc.
1990	Investigation and Analyses of the Evacuation Operation of the Passenger Vessel Scandinavian Star, after the Fire Accident Resulting in 158 Fatalities.	Nordic Investigation Committee for Scandinavian Star.
1987	Evacuation Analyses of the Sleipner A Platform, by use of Evade	Statoil
1985	Evacuation simulations of the cruise ship concept Phoenix (7000 POB) and the Cruise Ship Norway, with Evade.	Norwegian Carribean Lines A/S

Mustering in ships involves particular problems, relating to passenger performance in case of ship list and on their moving capability in a ship exposed to waves. Lack of relevant empirical data has represented a severe limitation with respect to computer simulation of passenger ship mustering, but this situation is now improved, as explained in this paper.

EVACUATION OF PASSENGER VESSELS

The evacuation process of a passenger vessel may be divided into the following phases: Mustering, Embarkation and Evacuation.

When the captain has decided to muster the passengers, the alarm will be activated and PA announcements will inform passengers and crew about the situation. The passengers are assumed to leave their cabins and walk along the marked escapeways to their muster areas, where the crew will support them in donning their life wests. If the situation deteriorates, embarkation of the lifeboats, which in the meantime have been swung out, will be started. The lifeboats will normally be sequentially launched.

Some of the crew will systematically search the cabins and others will be posted at strategical positions to guide passengers to their muster stations. The crew members shall be dressed in their uniforms to be perceived as authority persons by the passengers. This contribute in preventing inappropriate or dysfunctional behaviour among passengers. Otherwise, they may adopt the behaviour of other persons appearing to behave with authority, who in the worst case this may be panicking people.

PROBLEM AREAS

Decision Taking

In case of a severe accident on a passenger vessel, the captain is responsible for deciding whether the ship has to be evacuated. The history shows several examples that delay to take a decision or incorrect decisions have contributed in creating disasters. On the other hand, premature evacuations may also cause loss of lives.

Behaviour of passengers

Passengers may show a range of behaviour patterns when the alarm sounds. Hearing disabilities or extremely deep sleep caused by sleeping medicine or drugs may prevent some passengers from hearing the alarm. Some passengers may wait for the crew to rescue them in their cabins, while others immediately may start to evacuate. Different types of disabilities may prevent some passengers from mustering. Several passenger may try to find some authority person to follow. In situations with flooding or list of the ship, passengers will try to get up in the ship and out as fast as possible, for fear of being trapped. In severe accidents, dysfunctional behaviour like panic and apatia may dictate the behaviour of some passengers.

Guidance

Guidance to passengers during mustering are given in terms of signposting along the evacuation route and by crew members who are posted along the escape route.

The traditional way of signposting is to attach luminescent signs with arrows and symbols at eye height at decision points along the escape route. There are two main deficiencies involved, as highlighted by the Scandinavian Star disaster: In the exposed areas where passengers perished, escapeway marking lead towards the scene of the fire. However, due to short visibility in the dense smoke, signposting played a minor role and did neither guide evacuees to a certain death nor to safety.
The Scandinavian Star disaster shows that it might have been very desirable to provide a dynamic signposting system carrying directional information, by which the captain could direct passengers through the safest routes in a fire event. This is possible to achieve with the present technology, i.e by moving lights (Light Emitting Diodes -LED technology). To utilise the potential of this system, it has to be supported by an efficient decision support system, which gives the emergency management correct information about the accident. Otherwise accidents could occur, similar to the fire at the King Cross station in London, where evacuees were directed in the wrong direction with several fatalities as the consequence.

The other problem relates to how efficient information is communicated to the evacuees. There are several reasons that evacuees may overlook the information, as follows:

- Competing information and announcements, which confuse evacuation signposting.
- The signposting may not be sufficient striking to catch the attention of the evacuees
- Darkness or bad illumination
- Reduced visibility due to smoke

Effect of ship motion or list

Ship motion and list may make walking difficult and even impossible. Such events may further create dysfunctional reactions. The experience from accidents shows that passengers in a listing ship have a strong desire for walking up in the ship and out, for fear of being trapped in a capsizing or sinking vessel. Until recently there did not exist much empirical data on the effect of list and motion of a ship on the motion capabilities and behaviour of evacuees.

Effects of mustering Groupwise

The experience with accidents shows that people who are related to each other are likely to muster as a group. If they are separated when the mustering starts, they may try to find each other rather than to muster individually. During the mustering, they will move as a group and take decisions together. The effects of such behaviour have not been studied until recently.

THE MEP DESIGN PROJECT

Seven European companies with different expertise decided to co-operate in improving the evacuation safety by resolving the above problems. They agreed on a project plan in 1997, and applied from support from the EU commission. The support was granted from the *Industrial and Materials Technological Research and Technological Development program.* Hence, in 1997 the EU project *Mustering and Evacuation of Passengers: Scientific Basis for Design (MEPdesign)* was launched.

The project will be finished in 2001. The main objectives of the project are to improve the evacuation process of passenger vessels and to provide computer models with adequate data bases. The most relevant studies with respect to computer program development, are shortly described in the following. Note that the views expressed in this paper, represents the view of the author and not of the MEP Design consortium.

TNO (Netherlands) is the project leader of MEP Design. Their main professional contribution relates to empirical studies on behavioural aspects of evacuating passengers. TNO used mock-ups of passenger cabins and a motion simulator to study passenger motion in corridors and stairs, which were listed to represent a damaged ship or moving to represent ship motions in defined sea states. The volunteers, who participated in the empirical study, constituted a representative sample of the population. In the presentation of the results, they were divided into four age categories. TNO also performed an empirical study on *Improved Signposting for the Evacuation of Passenger Ships.* In this study the following variables were addressed:

- Traditional route signs, Low Location Lighting (LLL) as required by IMO, photo-luminescent stripes with directional arrows and moving lights (LED).
- Mustering in light or dark
- Mustering as group or individually
- Ship list or level

The performance of the evacuees with respect to way finding errors and mustering time, were recorded and analysed with respect to statistical significance. The main result was insufficient potential of existing wayfinding systems, despite they were compliant with existing regulations. Measures for improvement were implemented and tested.

DMI and Scandlines (Denmark) were responsible for the practical studies. They collected population and behavioural data for passengers with particular focus on group binding and with respect to their tendency to collect their luggage before mustering.
A full scale mustering exercise was performed with the passenger vessel Kronprins Fredrik. About 600 passengers participated in the exercise. They were informed they were going to participate in some sort of tests, and they were offered free meals and "tax-free". When the alarm sounded, the passengers were dining in restaurants. The mustering was performed in an orderly manner according to the procedures and it was monitored and recorded for later references.

KTH (Sweden) performed comprehensive model tests with launching of lifeboats and with a slide evacuation system.

DNV is responsible for evaluating the pragmatic value of the project. IFN (Institut Francais de Navigation) performs QA. Quasar/Safetec develop computer programs.

THE MUSTERING SIMULATION PROGRAM EVAC

The mustering simulation program EVAC is developed as part of the MEP Design Project. It utilises data and knowledge created in the MEP Design project, but the program is also based on experience from earlier programs.

The objective of EVAC is to simulate the mustering operation on passenger vessels. The mustering time is the main result from the simulations. Bottlenecks in the escapeway system are also identified.

Individuals, each with his distinct property, constitute the basic entity for the simulations. The motion of each passenger, including his interactions with other evacuees, is simulated. The Evac model is therefore microscopic, as it is very detailed. (The opposite would be a typical flow model, which is macroscopic).

Evac performs Monte Carlo simulations as several of the variables in the program are assigned values based on weighted drawings from probability distributions. Hence, if the same simulation case is repeated several times, the results will differ depending on the results of the weighted drawings. Therefore, a large number of replications is calculated in a particular case. The number of replications should at least exceed 15-20. The results from the replications are used for predicting evacuation times in statistical terms.

An evacuation scenario with specified environmental conditions, ship heading relative to oncoming waves, potential initial heel, etc., forms the basis for the analysis.

The user may chose to use representative default distributions with respect to age and social relation among passengers, or he may define his own data.
Each individual has his own properties with respect to walking speed in different situations, reaction time, group relation and binding to his luggage. He will be assigned his individual properties based on weighted drawings from statistical data. First, his age category is assessed, based on statistical data on age of passengers. Then his behavioural data, like walking speed, are assessed based on statistical data for the age category in question.

The escapeway system is modelled by marking escapeways and stairs on raster copies of arrangement drawings, which are shown on the computer screen. The program automatically links together stairs on different levels. This way of collecting data for describing the escapeway system is rather fast as tedious measurements and input of numbers is avoided.

The initial personnel distribution must be defined by the user. He must specify how many persons are present in different areas and rooms.

The expected initial delay of passengers may be based on a default distribution, or be specified by the user. The delay should depend upon the accident scenario. In some scenarios the evacuees are not likely to know whether the evacuation is initiated by a false alarm or by a real accident. In other scenarios, the initiation may be violent, causing either an immediate evacuation or severe delay due to apatia.

Evacuees are in general assumed to follow the defined and marked escape route. However, they may chose an incorrect route at some instances. In particular, this may happen when they leave their cabins. If they have chosen a bad route, they are assumed to follow this route until they reach the next decision point.

The walking speed of a passenger may vary along his route. He walks with his individual speed when walking in corridors and stairs. If the ship lists, the speed depends on the orientation of the corridor or stair relative to the inclination axis, as they may become more or less steep. Evac calculates inclination data for all escapeways, and interpolates correct factors for walking speed reduction, based on the empirical data from the TNO tests. Further, there may be defined obstructions and corners throughout the escape route which may cause delay.

Evac calculates evacuation times for each replication of a simulated case. Instead of developing a dedicated routine for the statistical analysis, it has been chosen to apply a statistical program package for this purpose. The main results will usually be mustering time for the last evacuee, the time when 95 percent of the evacuees have mustered and average mustering time. These times will be described by result or confidence intervals. It may e.g. be shown that the maximum evacuation time will be 20 minutes, the most likely 15 minutes and the minimum 12 minutes. With respect to average evacuation time, the confidence interval will be calculated. An increased number of replications will reduce the confidence interval, but not the result interval.

In addition to the above results, a lot of intermediate results from individual replications can be presented. The flow of passengers can be calculated at counters, which can be defined at selected positions. The motion of evacuees can be visualised on the PC screen.

Evac is based on empirical data with respect to the motion capabilities of persons. The validity of the program in this respect may therefore not be questioned. What is of much concern, is the validity with respect to human behaviour in severe accidents. The experience from accidents shows that people behave relatively rationally, but this does not imply they can be expected to follow the procedures. They may walk up and out in a listing ship whatever the procedures tell, and they may try to find and support friends and relatives instead of mustering. Some of them may even be so attached to their luggage that they may attempt to pick it up before mustering. Such behaviour is implemented in Evac, based on experience from passenger vessels and also some judgement. Dysfunctional behaviour have been decisive for the outcome of some accidents, but these events should rather be considered exceptions than the rule. Hence, extreme apatia and panic are not implemented in Evac.

Prior to the full scale evacuation test with Kronprins Fredrik, the mustering time was predicted with Evac. The study, which was documented in a report, was based on assumptions with respect to number of passengers and their distribution. These assumptions proved afterwards to be reasonably correct. The predicted mustering time was 20 minutes, while the recorded mustering time at the test was 24 minutes. These figures show an acceptable correspondence, and give an indication that the Evac predictions may be reasonably correct.

CONCLUSION

Based on the work carried out, as well as on earlier experience with mustering analyses of ships and offshore installations, Evac represents a significant potential for safety improvement of the mustering operation on passenger vessels, provided that the movement in IMO away from detailed requirements towards Goal Setting requirements proceeds.

REFERENCES

1. Ship motions, ship motions for the passenger ferry m/f Kronprins Frederik. BriteEuram project 97-4229 “MEPdesign” WP 1c.DMI.
2. Wayfinding Systems, A proposal for new wayfinding systems for passenger ferries. Brite/EuRam project BE97-4229. MEPdesign- Work Package 1a. DMI.
3. Design Features. A proposal for new design features on board passenger ferries. BriteEuram project 97-4229 “MEPdesign”. WP1b. DMI.
4. Groupbinding: Emergency behavior of ferry passengers. BriteEuram project 97-4229 “MEP design” WP2c. DMI.
5. Software Quality Assurance Plan WP3a, Mustering. BriteEuram project 97-4229 “MEPdesign” WP3a. Quasar.
6. Design Features:effects of ship listing and ship motion on mustering speed. BriteEuram projects 97-4229 “MEPdesign” WP2b. TNO (Bles and Boer).
7. Signposting for the Evacuation of Passenger Ships. TNO, Boer.
8. H. Soma. *Validation of Egress Simulation Programs.* OMAE 1996, Florence.
9. H. Soma. *Computer Simulation for Optimisation of Offshore Platform Evacuation. OMAE 1995 København.*