HUMAN BEHAVIOUR IN SHIP EVACUATION: CONTRIBUTIONS OF MEPDESIGN

Louis C. Boer
TNO Human Factors
Box 23, NL 3769 ZG, S'berg
Boer@tm.tno.nl

Rolf Skjong
Det Norske Veritas,
NO-1322 Høvik
Rolf.Skjong@dnv.com

Keywords: Crowd evacuation, lifeboats, software simulation

Abstract
The paper presents conclusions from the EU basic research project "MEPdesign" aimed at evacuation of passenger ships. The findings are discussed with regard to passenger flow as a function of design parameters. MEPdesign showed that application of human factors to evacuation is very useful, and that evacuation analyses are bound to be too optimistic if these factors are ignored. The conclusion summarises practical guidelines for improved passenger flow in emergencies.

Introduction

In emergencies, passengers should assemble at their muster stations. From these stations, they can reach the embarkation stations, and leave the ship in lifeboats or other means of escape such as slides and rafts. Mustering, embarkation, abandon ship, and survival at sea are critical for successful evacuation. These processes were the subject of a EU basic research project called "Mustering and evacuation of passengers: Scientific basis for design", or MEPdesign for short. The project started in 1997 and finished May 2001.

Leaving the ship at sea is extremely dangerous. This has been demonstrated for MEPdesign by the Royal Technical University, Stockholm. Slamming of lifeboats against the mothership is likely as soon as there is any significant wave motion (Rutgerson & Tsychkova, 1999). Evacuation by slides is also dangerous as the slide may push the landing platform under water or the slide may buckle, thereby launching passengers in the air while others fall in an angle far to steep towards the platform (Rutgerson & Tsychkova, 2000). Rutgerson and Tsychkova (2000) consequently proposed and tested a free-fall/fast-launch lifeboat (horizontally launched/increased deadrise angle) that avoided most of these dangers (see Tsychkova's contributions to this conference).

Assembling the passengers can be done as a preventive measure, prior to any decision to actually abandon the ship. If abandoning is unavoidable, all is prepared for embarkation. Assembly clarifies the situation to the passengers. The crew have their hands free to assist in the emergency, and fighting a fire is easier without passengers. And if it is possible to save the ship, the passengers can return to the public spaces or the cabins.

Assembling the passengers should be fast and orderly. Fast, because wasting time in an emergency could also waste human lives. Orderly, because chaos reduces the flow of passengers, Helbing et al. (2000), and because many passengers will hold the ordeal they went through against the shipowner.

The flow of passengers is a function of their aims and goals, of their walking abilities, and of the guidance provided. These factors will be dealt with in succession, based on the findings in the MEPdesign project and on general knowledge of human behaviour in critical situations.

Raising the Alarm

The first challenge for orderly and effective emergency evacuation is to make passengers aware of the emergency. People dislike interruptions and interference with their lives. They will protect their plans and routines. Even in the face of disaster, they may ignore the signs or discard them as e.g. "another exercise" and continue their normal behaviour. One reason is that emergencies are, fortunately, rare events. People have difficulty imagining themselves as victims of a disaster; "this cannot be real".

Authoritative guidance is imperative in this phase. In order to affect the passengers, guidance should come from two independent sources, one confirming the other; for example, the massage of the public address (PA) system confirmed by uniformed crewmembers taking control. Note that passengers are wholly unprepared for emergencies and that they are likely to miss significant parts of the announcements. In an evacuation exercise of a high-rise office building, 72% of the occupants failed to recall the contents of the announcements (Proulx et al.;1999). Crewmembers need to repeat the gist of the message. Repetition of a (pre-recorded) message is another possibility.

The message of the PA system should be authoritative, simple, and straightforward. For example "Ladies and gentleman, this is your captain speaking; there is an emergency aboard; all passengers are requested to go to their assembly stations right now; this is an emergency." Repetition of the announcement is recommended, also in other languages for passengers of other nations.

The second source of guidance may be crewmembers appearing on the scene. With no crewmembers forthcoming, the second source be a fellow passenger leaving his place and evacuate. Usually, this implies a delay of several minutes because without crewmembers, passengers will not act immediately to the PA announcement. After the first passengers leave, the rest will suddenly follow; a snowball effect ascribed to the "herd instinct" (Helbing et al., 2000). Imitating others behaviour is a sensible thing in itself; you see the outcome of the behaviour of the others, and judge whether or not it is safe. Seeing others open a door and leaving safely shows that this door is safe.

After passengers are alert and fully aware of the emergency, they may pursue private aims before they go assembling. Relevant factors are "group binding" and "property binding". Group binding, or the care for family or friends, means that passengers search for others before evacuating. Property binding means that passengers get back to their cabins or other places to retrieve or secure property. These bindings create a counterflow of passengers, and slow down the assembling process. Within the MEPdesign project, the Danish Maritime Institute (DMI) collected data on the expected incidence of group and property binding (May, 1998). Retrieving property can mean passengers carrying belongings such as bulky luggage, which claims extra space and reduces propagation speed.

Assembly – Walking Speed

When passengers are moving smoothly to their assembly stations, the time required can be estimated on the basis of normal walking, that is, human walking speed in buildings (e.g., see IMO, 2001). In other words, the effects of ship motion on walking speed are not considered. One of the aims of the MEPdesign project was to see what happens when walking on a moving platform or one that leans to one side in imitation of list/heel and roll/pitch. TNO did studies in the ship motion simulator shown in Figure 1. Data included:

- Walking on listed, rolling and pitching floors (climbing and descending)
- Walking in listed, rolling and pitching stairs (climbing and descending)

All data were presented as a function of age group.

The data are described in detail in Bles et al.(2001). In general, ship motion reduced walking speed. Evacuating a 15-20 degree listed platform would require 33% extra time. The same increase holds for vehement ship motion. This clearly shows that the estimates of the simplified analysis of the IMO guidelines are too optimistic because they ignore ship motion.

Another finding was that ship list reduces the effective width of escapeways because (a) the wall leans towards the passengers, reducing the effective floor space and (b) they need to hold the handrail. The capacity reduction due to the last factor is dramatic in large open spaces; with handrails on both sides, the effective escape capacity is reduced to maximum two persons abreast. The required two handrails only when longitudinal corridors are wider than 1800 mm and transverse corridors only when wider than 1000 mm, may seem rational but should be applicable to all passenger ships (SOLAS II-2, Regulation 28-1, Paragraph 1.2 & IMO (1995) only applies to ro-ro passenger ships).

Climbing and descending stairs pose problems in an emergency situation, as stairs may be tilted in a pitching or rolling environment. In the MEPdesign experiment, Bles et al.(2000), found that climbing stairs was much more difficult than expected, especially ascending stairs tilted upward and descending stairs tilted downward. In the latter condition tall subjects had to be careful not to hit the ceiling overhead. Subjects often missed the first step or put only the toe of the shoe on the first step, leading to unstable behaviour when ascending an upward tilted stair. The handrail was an absolute necessity in these conditions. With angles of more than +10 ° the majority of the subjects pulled themselves up with two hands on the handrail. Most subjects were surprised by the difficulty of the task, and it was agreed that an important factor provoking these problems was that the whole surround was listed together with the stairs. Because of those problems senior subjects were not examined in the MEPdesign experiment.

In Bles et al.(2001) a second handrail was added, allowing for manual support on both sides. Although the same problems remained as mentioned for the MEPdesign experiment, the subjects were much more stable on the stair. SOLAS Chapter II-2, 28, paragraph 1.5.1 requires handrails on both sides of stairs. The experiments confirm that this is a rational requirement.

The data of MEPdesign can be used in software simulations of evacuation, for example, for evacuation analyses at the early design stages. Such analyses are mandatory for ro-ro passenger ships constructed after July 1999 (as described in SOLAS regulation II-2/28-1.3) and are expected to be mandatory for more classes of passenger ships.

Assembly–Wayfinding

Software simulations of evacuations and guidelines for the estimation of evacuation time assume that passengers follow the intended route without hesitation or error. This is not quite realistic. In reality, passengers need guidance. Crewmembers are valuable assets in this respect. They can direct people with voice commands, correct those getting lost, and address the ones in need of a personal reminder. Crewmembers should be clearly identifiable by uniforms, caps, or lifevests. Confusion may arise because some passengers may wear uniforms too—for example, coach drivers. Identification with caps is better because the crew is still identifiable when lifevests obscure uniforms. Alternatively, the crew could don lifevests different from those of the passengers. The requirement of two different types of lifevests, however, adds to the costs.

A reasonable expectation is that the procedure of posting crewmembers at strategic locations before raising the alarm is safe. The procedure is expected to more than compensate the time lost delaying the general alarm. But the procedure may not be possible in real evacuations, as opposed to "staged" evacuations, or exercises.

The real incident or disaster includes chaos—a stage that no-one knows what the problem is. Moreover, the amount of time left for evacuation may be unclear because the speed of further escalation is unclear. The extra time to cope with chaos is reflected in a recent IMO paper of the International Council of Cruise Lines (ICCL, 2000). The ICCL report reviewed the time to get the passengers at the assembly stations for (a) exercises and (b) real incidents. The average time required was 11.5 minutes for the exercises (36 evacuations on 14 different ships) but 20 minutes for the real incidents (7 evacuations on 6 different ships). Fortunately, all assembly times—even the slowest time, 28 minutes—were within the prescribed 30-minute limit. But the report indicates that the outcomes of exercises are 200% optimistic.

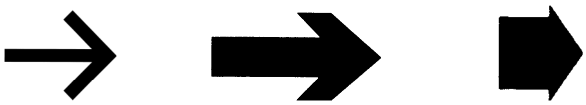
Wayfinding problems are one of the reasons for slow evacuation. When there is no crew around for assistance, the passengers should find their assembly stations on the basis of signs alone. Despite care of the IMO, not all signs have been standardised, and these signs can be improved for human visual perception. Figure 2 presents an example for arrows. The arrow in the middle of the figure is the IMO standard. It is a rather "fat" symbol. Arrows less fat (left side of the figure) will retain their visibility longer during conditions such as smoke and are, hence, better. The figure also illustrates lack of standardisation.

In 1993, TNO let lone individuals find the way to their assembly station using these signs (Boer et al., 1993). On average, the time needed was 200% of the normal walking time. That is, the individuals went astray. The conclusion was that existing signs provide an inadequate level of guidance. There is ample room for improvement in interior design of ships and signposting.

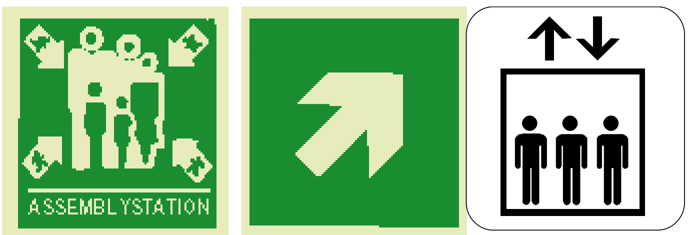
Within the MEPdesign project, wayfinding behaviour was studied in experiments with people in imitated ship interiors. Both a level and a listed environment were used for these tests. A large number of volunteers participated group-wise and as single individuals. Video cameras recorded their wayfinding behaviour. To approximate the stress of the real disaster, the volunteers were made uncertain. Blindfolded, they were escorted to their cabin. After the blindfold was removed, they became aware the list, and the concomitant conflict between the visual upright ("the bulkhead is horizontal") and the true vertical. After a PA announcement of the "captain", they started evacuating. At the most difficult choice point, 22% of the lone individuals went astray. Considering that the evacuation route may have a large number of choice points, the probability of error-free wayfinding becomes quite low. In a design situation the number of such choice points could be reduced, thereby lowering the probability of wayfinding errors.

The message from the experiments was again that existing signs provide inadequate guidance (Boer, 1998). Causes of wayfinding error are both visual and psychological. Some of the factors related to human visual perception are:

- Signs can be placed poorly, thus confusing the passengers. An example is a horizontal arrow near a stairwell. It is unclear whether to go up or down. Improved guidelines are required for the placement of the assembly signs.

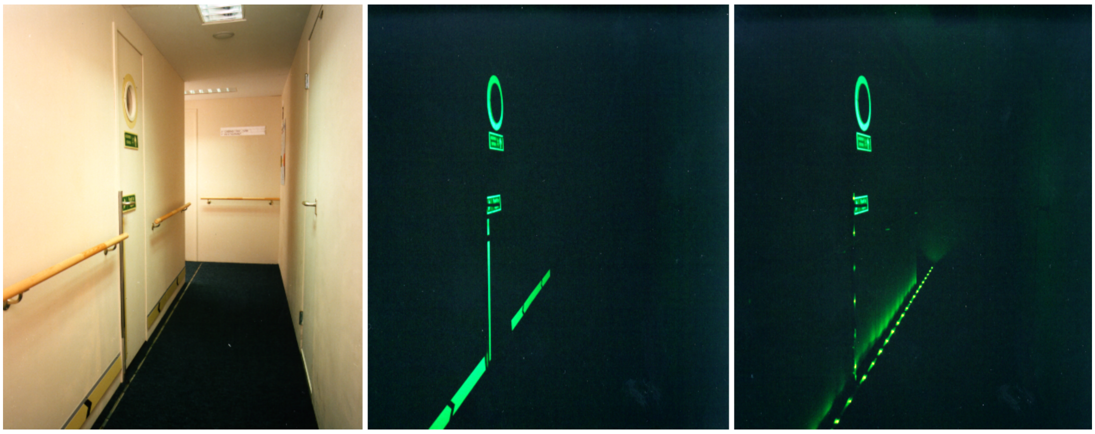


- Some symbols can be improved for better human visual perception. Figure 2 presents an example for arrows. The arrow in the middle is a rather "fat" symbol. "Lean" arrows (left side of the figure) will retain their visibility longer during conditions such as smoke and are, hence, better. The reason is that poor visual conditions reduce symbols to meaningless "blobs"; symbols that are already blobs to begin with (right arrow in Figure 2 will be affected first). Figure 3 also illustrates poor standardisation.
- Signs may visually drown in the "noise" of advertisements and other information. The signs themselves are not very conspicuous in the first place. If competing against advertisements, they will loose the battle for the attention of passengers. Illustrative is the finding of MEPdesign of faster evacuation during imitated power failure. The reason was removal of attention competition; the (luminescent) assembly signs remained visible whereas advertisements and pointers to other locations (restaurant, bar) became invisible. (This suggests how perfect visual guidance can be reached. Design and test of such a system could easily be carried out.)
- Signs can be in conflict with other signs. Assembly signs can be placed next to other pointers (to the restaurant, bar). Assembly signs can be placed next to an indication of the elevator (Figure 3).



Within the scope of MEPdesign experimental systems were considered. The Danish Maritime Institute reviewed guidance systems; TNO implemented and tested two new guidance systems. The first system was based on moving lights (by turning on/off arrays of LEDs; in Figure 4c, all LEDs are lighted). The promise of such systems is the possibility to program the direction of evacuation, for example, if an escapeway is blocked by fire. The guiding effectiveness of the system was tested in day and night ("power failure") situation. The results were disappointing. Under normal lighting conditions, the system was invisible; in the dark, the system was a nuisance. It failed to improve wayfinding behaviour, and during post-test interviews very few volunteers mentioned assistance by the system.

The second guidance system was based on photoluminescent low-location-lighting strips with arrowheads added for direction (Figure 4a, b). The system proved better than both moving LEDs and the traditional system both with regard to time required and wayfinding errors. Experiments were also carried out with marking on the floor and elsewhere that may be critical in an emergency. Using all possibilities of the system will prevent 90% of the wayfinding errors



a) b) c)

Figure 4. Photoluminescent (b) and electrical marking (c).

The validity of these test results is limited as they pertain to these particular systems only, and this particular layout of corridors. The systems can be improved, for example, by packing the LEDs more densely. The cost of the system plays a role as well; more densely packed LEDs will increase cost. Lifetime and maintenance are also relevant. Photoluminescent materials are subject to ageing. Sulphur-zinc compounds may need replacement within 3-5 years. Strontium-aluminium compounds may last up to 20 years.

Psychological causes of wayfinding error include reluctance to go through (unknown) doors, or a preference for open areas; and a preference for the familiar. Doors may be psychologically perceived to lead to all kind of trouble like danger, confinement, or being scolded by the crew (Edelman et al., 1980). Passage doors should be designed in such a way that passengers can see that there is no danger behind the door, e.g. by using portholes.

Firedoors are a special case. They shut close in case of a fire. Prior to the fire the doors seem to be part of the bulkhead and are, therefore, as good as invisible. In a fire the passengers may perceive them as part of another wall. A corridor that used to be is suddenly gone, and corridors leading to open spaces are suddenly dead-ended. This disorients passengers. And even after the passengers conclude that it must be a firedoor, they may not know that manual opening is possible. In the disaster of the Achille Lauro, several passengers panicked as they considered themselves trapped between two firedoors. One died of heart attack. Similar panic at closed firedoors is reported during the accident of the Universe Explorer (NTSB, 1998). The message is clear: design the firedoors in such a way that passengers perceive the door, and immediately see that manual opening is possible.

A cause of wayfinding error is the psychological conflict between normal use and emergency use. In the Boer et al. (1993) investigation some assembly routes crossed "crew-only" areas, the no-entry sign hanging on an elegant chain across the corridor. The passengers avoided these areas, supposing that they misread the assembly signs, or that there was a way around. In another example (a high-rise office building), the emergency route went right through the lavatories (the common wash area, not the stalls) to the stairwells. In ordinary life, lavatories do not afford thoroughfare. Designers should avoid creating conflict between normal and emergency use.

Conclusions

Measures that promote fast and orderly assembly of passengers are

- Authoritative and clear messages on the PA system
- Authoritative and clear guidance of the crew to the passengers
- Crew clearly recognisable by uniform or cap (caps will remain recognisable also after crewmembers have donned lifevests)
- Assembly symbols improved for human visual perception
- Improved placement of assembly signs (guidelines)
- Conspicuity of assembly symbols enhanced by reducing "attention competition" of advertisements.
- Assembly route should have as little choice points as possible; especially, passage doors in the assembly route are to be avoided
- If the assembly route *has* to include a door, take measures to abate or remove "fear of doors"
- Make firedoors clearly recognisable for the (lay) public. Indicate the possibility of manual opening.
- Assembly routes should not lead through areas that are normally inaccessible (in the eyes of the passengers)

In short, systematic removal of bottlenecks enables improvement of passenger flow. At the same moment, there is no general solution to guarantee perfect guidance and smooth and orderly passenger flow in all evacuations (collision, grounding, fire, arson, etc.). There is also a lack of systematic assessment of the effect of various potential improvements considering the likelihood of the scenarios, the improvement in evacuation and the costs, similar to studies carried out for other ship types (Skjong & Wentworth, 2000).

Exercise and software simulation are optimistic predictions of passenger flow in emergencies. Exercises miss the chaos of the real incident. Software is good to predict the time required *for a smooth and orderly flow of people*, but excludes chaos, panic, and way-finding problems. Software can now include the reduced walking speed due to ship motion; MEPdesign collected the data (Bles et al., 2000), and developed a prototype of such a model (Orset & Drager, 2001). Addition of human factors such as awareness time, group binding, way-finding error is a legitimate ambition that requires more data than currently available. Carefully designed human factor research could provide the required data.

References

Bles, W., Groen, E.L. & Boer, L.C. (2000). *Design features: effects of ship listing and ship motion on mustering speed*. Soesterberg (NL): TNO Human Factors.

Bles, W. Nooy, S. & Boer, L.C. (2001). *Influence of ship listing and ship motion on walking speed.* Proceedings of "Pedestrian Evacuation Dynamics" (4-6 April). Duisburg (GE): Duisburg University.

Boer, L.C., A.H. Wertheim, E. Ellens, C.E.S. Brisland and H.A.M. Daanen (1993). *Ship listing: reactions of passengers*, IZF 1993 C-26. Soesterberg (NL): TNO Human Factors.

Boer, L.C. & A. Vredeveldt (1999). *Trouver son chemin: comportement des passagers et systèmes de guidages*. Revue Navigation, 47 (188), 428-439.

Boer, L.C. (1998). *Improved Signposting for the Evacuation of Passenger Ships,* TM-98-C081. Soesterberg (NL): TNO Human Factors.

Edelman, P., Herz, E. & Bickman, L. (1980). A model of behaviour in fires applied to a nursing home fire. In D. Canter (Ed.) *Fires and human behaviour*, pp. 181-203. London: Wiley.

Helbing, D, Farkas, I & Vicsek, T. (2000). *Simulating dynamical features of escape panic*. Nature, 104, 487-500.

ICCL (2000). *Recommendations on evacuation analysis for passenger ships and high-speed passenger craft*, *Passenger vessel evacuation analysis* “IMO document FP 45/3/1.

IMO (1995). MSC Circ.699 (Marine Safety Committee, Circular no. 699) “Revised Guidelines for passenger safety instructions”, 17 July 1995.

IMO (1999). MSC Circ.909 “Interim Guidelines for a simplified evacuation analysis on ro-ro passenger ships”

IMO (2001) *"Recommendations on evacuation analysis for passenger ships and high-speed passenger craft.. Report of the Correspondence Group*. IMO document FP/45/3/3

May, M. (1999). *Group binding: Emergency behaviour of passengers*. Lyngby (DK): Danish Maritime Institute.

National Transportation Safety Board (1998). *Fire on board the Panamanian passenger ship Universe Explorer in the Lynn canal near Juneau, Alaska*, NTSB/MAR-98-02. Washington (DC): National Transportation Safety Board.

Steinar Orset, K. Harald Drager (2001). EVAC Description and User Manual. Oslo: Quasar Consultants.

Proulx, G., D. Tiller, B. Kyle and J. Creak (1999). *Assessment of photoluminescent material during office occupant evacuation*, Internal Report 774. Ottawa (CA): Institute for Research in Construction, National Research Council.

Rutgersson, O. and E.Tsychkova (1999). *Experimental investigation of lifeboat/davit evacuation systems*. Stockholm (SE): Royal Technical University.

Rutgersson, O. and E. Tsychkova (1999*). Experimental investigation of "slide" and "fall" evacuation systems*. Stockholm (SE): Royal Technical University.

Skjong, R. and B.H. Wentworth (2001) Formal Safety Assessment of Life Saving Appliances for Bulk Carriers, DNV Report 200-0539. (Also published as IMO document MSC 74/5/5 and on the web http://research.dnv.com/public/FSA_LSA_BC.pdf)

SOLAS (2001), Safety of Life at Sea, Consolidated edition, IMO 2001.

Author biography

Dr. Louis C. Boer studied human behaviour in emergencies for the last 10 years. He co-ordinated the BriteEuram project "Mustering and Evacuation of Passengers" 1997-2001. He advised on escapeway markings for train and road tunnels. In 2001, the ministry of interior affairs asked him to study a national disaster—the new year's fire in Volendam. Boer appeared on national TV several times.

Dr. Rolf Skjong has 20 years experience in risk and reliability analysis. He is Norwegian adviser in several international bodies. He is project manager and project responsible of a number of international joint industry projects, including QRA and structural reliability projects, for ships, offshore, and the process industry. He published over 50 papers in conferences and technical journals.