Dorota ŁOZOWICKA
Maritime University of Szczecin
Stefan CZYŻ
Maritime University of Gdynia

AN ANALYSIS OF MARITIME EVACUATION MODELS

Key words

Evacuation, computer simulation, passengers ship, modelling, human behaviour.

Summary

Evacuation performance is dependent on many parameters including the following: the physical nature of the enclosure, the function of the enclosure, the nature of the population and the nature of the environment. For the purpose of calculating the evacuation time, two approaches can be used for evacuation analysis: macroscopic (simplified) models and microscopic (advanced) models. In a simplified model, the flow of persons is described like a fluid and the escape routes are schematised as a hydraulic network. The essential aspect of a microscopic model is a detailed description, the flow consist of many individual entities that interact with each other. The microscopic model may provide greater accuracy in the prediction of the evacuation time.

Quantitative validation of advanced models poses a number of challenges, the most significant being a shortage of suitable experimental data.

Introduction

Analysing the evacuation of persons from spaces with restricted output traffic capacity is a very complicated and difficult task. Due to the very large

number of factors affecting evacuation, a full analysis of the process requires the working out of a computer model, which in turn needs to be verified by very expensive and labour-consuming research on human behaviour in real conditions, as well as gathering suitable statistical data over a span of many years.

For the purposes of vessel evacuation analysis, parallel theoretic, experimental and statistical research has been conducted for over fifteen years, making use of the state of knowledge in this scope in other fields [2, 11, 12]. The research shows that various objects of various types like buildings, planes, seagoing vessels or rail vehicles, differing in construction and operational conditions, have a lot of common features and features characteristic of only one particular type of construction. The basic characteristic feature different for various structure types is the permissible evacuation type. According to requirements in various economy sectors, the maximum evacuation time equals [2, 6]:
– 25 minutes – for buildings
– 90 seconds – for planes
– 60-80 minutes – for sea-going vessels

It is a well-known fact, however, that the mentioned boundary values are arbitrary and sometimes are not confirmed with reference to real situations in the scope of a particular branch, which is why the currently introduced or modified requirements for the analysis of passenger vessels are directed towards the determination of general evacuation time and identifying congestion in order to optimise the route systems or evacuation procedures. For analysing (simulating) the evacuation process macroscopic (simplified) and microscopic (advanced) models are applied.

Theoretical analyses of real trials of evacuating passenger vessels (aimed at model verification) are conducted by research institutions in cooperation with marine administration, industry and transport. Countries most involved in the research include Germany (TraffGo program), Japan (institutes NM RI, SRA), Great Britain (universities at Greenwich and Strathclyde), the USA (Coast Guard), Canada (Transport Canada), Australia, France, Norway and Sweden. The development of evacuation analyses is co-ordinated by IMO.

On the basis of research results, the adequacy of models in relation to reality is assessed and parameter values are worked out for analysing, e.g. walking speed, initial distribution, awareness and reaction time, human behaviour simulation functions, external conditions, procedures and standard scenario conditions.

1. Calculation models of evacuation analysis

One of the two calculation models may be used for analysis – the simplified, or the advanced model. In the simplified model, persons in motion are treated as a fluid (hydraulic) medium, and living spaces, corridors, stairs, decks

and doors are respectively made up of tanks, pipelines and valves. The movement process is described by simple flow kinematics equations.

The assumptions inherent to the simplified method are, by their nature, limiting. As the complexity if the vessel increases (through the mix of passenger types, accommodation types, number of the decks, and number of stairways) these assumption become less representative of reality. In such cases, the simplified method is more time-consuming than computer analysis, and it gives different results of transition times and congestion for the same vessel in comparison to advanced analysis (among other things due to non-consideration of space geometry depictions, the course of movement parameters and its disturbances by the counterflow). However, in early design iterations of the vessel, the simplified method has merit, due to its relative ease of use and its ability to provide an approximation to expected evacuation performance. For more complicated processes, the advanced model would be preferred.

The advanced evacuation method consists of computer simulation of each person's movement, taking into consideration the vessel's construction system, mutual interaction of persons and the effect of the surroundings on their behaviour.

A computer program of the evacuation process takes into account 4 categories of parameters [6]:
a) geometrical (layout of escape routes, their obstruction and partial unavailability, initial passenger and crew distribution conditions);
b) demographic (sex and age distribution, range of changes in reaction time and differences in marching time);
c) environmental (static and dynamic vessel conditions);
d) procedural (e.g. number of crew members involved in passenger assistance).

For advanced evacuation analysis, computer simulation programs are used in accordance with projects: EXODUS (University of Greenwich), BY-PASS, PED GO, PESOS (TraffGo Institute – Germany), CROWD MOVEMENT MODEL (NMRI-Japan). General characteristics of all the models include the following:
1) Each person is represented in the model individually.
2) The abilities of each person are determined by a set of parameters, some of which are probabilistic.
3) The movement of each person is recorded.
4) The parameters vary among the individual of the population.
5) The basic rules for personal decisions and movements are the same for everyone described by a universal algorithm.
6) The time difference between the actions of any two persons in the simulation is not more then one second of simulated time, e.g. all persons proceed with their action in one second (a parallel update is necessary).

2. BY-PASS program

In BY-PASS computer evacuation model, the longest individual evacuation time among all persons is assumed as the total evacuation time:

$$t_0 = t_{0imax} \qquad\qquad (1)$$

where: $t_{0i} = t_a + t_{ri} + t_{wi} + t_p + t_e + t_l$

time t_p being concurrent with time t_{ri}.

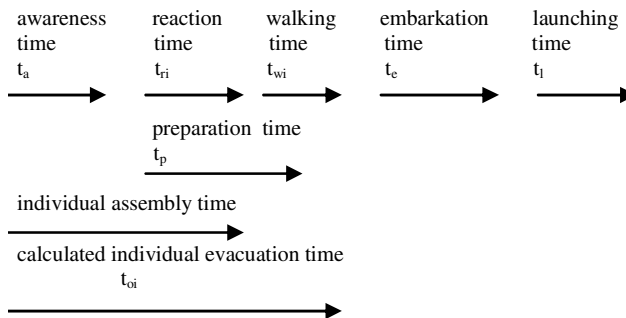Fig. 1 presents a graphic interpretation of evacuation time according to the BY-PASS model.

Fig. 1. Graphic interpretation of individual evacuation time

Values t_{wi} are calculated by means of a simulation program, which determines iteratively (in intervals of 1s) the positions of particular persons in their movement on the evacuation route from the starting point (e.g. in the cabin) to the final point (at the embarkation station).

For this purpose, the geometry of evacuation routes is mapped in the form of a grid of orientated elementary fields (cells) with coordinates x, y and z determining the deck with information about possible movement direction. A cell area of 0.4x0.4 m^2 corresponds to the position of 1 person.

In analysing particular individuals, consideration is taken of the effect of geometric, procedural, demographic and environmental factors, in particular the following parameters:
1)   initial position (x, y, z),
2)   coefficient of reduced walking speed in doors and stairs (0.5),
3)   maximum walking speed $V_{max} = 2–5$ cells/s,
4)   coefficient of movement pauses (orientation frequency) $O_i = 0–3$,
5)   probability of walking direction changes (swaying probability) due to vessel's rolling and pitching $S_i = 0–0.01$,

6)   boundary waiting time (patience) for movement performance (due to route blockade) $p_i = 10–40$ s,
7)   range of sight $d_i = 10–100$ cells.

Parameter values of probabilistic character (pos. 3–7) are assumed in accordance with normal distribution.

The program for simulating movement in interval $t = 1$ s for particular persons covers the following operation sequence:

1)   Selection of person;
2)   Checking the condition for starting movement (realisation of times t_a and t_{ri});
3)   Checking the possibility of continuing movement as regards parameter Q_i;
4)   Identifying destination cell on the basis of parameter d_i;
5)   Determining maximum movement d_{max} (number of cells);
6)   Determining movement direction;
7)   Change of movement direction to opposite or roundabout, respectively with zero patience or with $t > p_i$;
8)   Translocation of a person:
     a)   identification of a free cell closest to the cell of destination,
     b)   completion of movement in the case of free cell,
     c)   change of movement direction by 45°, if parameter S_i surpasses any freely chosen number from interval (0.1),
     d)   movement to the identified free cell,
     e)   repetition of steps (a–d) until realisation of d_{max} (completion of movement);
9)   Identification of cell after movement completion on way d_{max} (translocation of person);
10) Assuming initial value of parameter p_i;
11) Including the person into register of persons who have completed movement;
12) Decreasing the value of parameter p_i by 1 s in the case of no translocation;
13) Marking walking time with $t = t_{wi}$ and exclusion of the person from the iteration process if they have reached the final point.

This procedure is repeated until all persons reach the final point.

3. EXODUS program

The EXODUS program comprises five core interacting subprograms, among which there are as follows:

1) Movement subprogram;
2) Population subprogram, defining the effects of different personal traits (e.g. age, sex, knowledge, physical efficiency, reaction etc.);
3) Human behaviour subprogram, defining the effects of conflicts, patience and escape strategy;

4) Toxicity subprogram, defining the effect of fire hazard;
5) Environmental hazards subprogram, defining *inter alia* the effect of evacuation route geometry and condition.

The results of computer analysis are displayed textually or by means of 2D animated graphics, which permits the observation of the evacuation process in progress and analysis of events and human behaviour. An output data base with tools for interpreting them is also available, as well as an animated 3D presentation of evacuation, permitting a comparison of simulation with the real image registered with a camera.

4. Verification of computer models

The verification of computer models is the basic condition of their development and usefulness in practical application. It includes the following:
- test of components,
- functional verification,
- qualitative verification,
- quantitative verification.

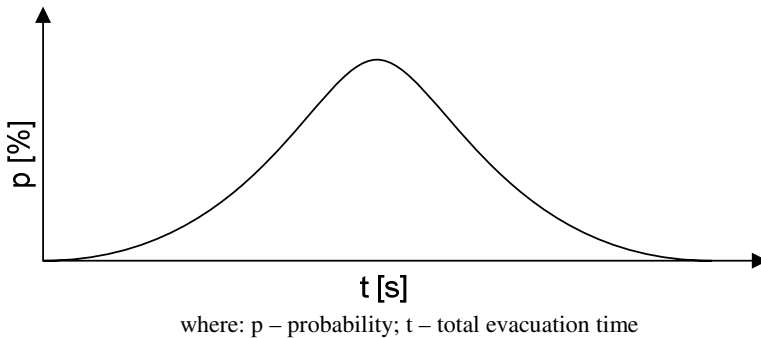where: p – probability; t – total evacuation time

Fig. 2. Hypothetic evacuation time distribution for assumed combination of structure/population/environment

The basic and, so far, the unsolved problem of computer model development is quantitative verification; its essence is comparing model predictions with data from evacuation demonstration and real incidents.

The preparation of a complete database for verification encounters serious difficulties, rooted in the dependence of evacuation on a large number of parameters, the following being among them:
- the object's physical features (shape, dimensions, number of spaces, number of decks, number and dimensions of exits, stairs, obstacles *et alias*);
- the intended use of spaces (office, cabin, hall etc.);

- population features (number of persons, distribution of sex and age, distribution of physical efficiency, mutual relations, knowledge of spaces *et alias*);
- environmental features (day/night, season of the year, marking of route, vessel's rolling and pitching, traffic jams, fire etc.).

The changeability of these parameters, in particular the different behaviour of persons (the crowd), complicates experiments to the degree of their unrepeatability. The process of evacuation can be expected to take the course in accordance with the distribution presented in Fig. 2 for each combination of structure/combination/environment.

Conclusions

The advanced (computer) methods of analysing evacuation can ensure a higher accuracy of predicting evacuation time than the simplified method; therefore, specialised centres continue simulation analyses and real evacuation trials, in order to solve the problem of quantitative verification of applied computer problems [6, 11, 12]. Taking into account the positive results of this work, in the IMO recommendations on evacuation analysis for new and existing passenger vessels, the application of computer models (developed methods) has been considered with the possibility of their initial verification.

A perfect data set would require the staging of an evacuation trial with a representative population in realistic surroundings, which is practically impossible (e.g. involvement of injured persons in conditions of real fire, smokiness and toxicity). The registration of parameters with reference to individual persons aimed at reproducing the succession of events is a minor problem. The difficulties of the experiment are getting larger and larger along with the increased number of participants and structure dimensions; finally, the costs of many-times repeated full-scale evacuation demonstration are becoming unacceptable, which is why current attempts at working out a set of verification data are directed towards determining one or more standard evacuation scenarios, based on real statistics of events.

Bibliography

1. Czyż S.: Uwagi o metodach analizy ewakuacji statków pasażerskich. 20 Sesja Naukowa Okrętowców, Gdańsk 2002.
2. Galea E.R.: Simulating Evacuation using the EXODUS Software. IMO, FP Sub-Committee, 45-th session 2001.
3. Gwynne S., Filippidis, L., Galea E.R., Cooney, D., Boxtall, P.: Data Collection in Support of the Modelling of Naval Vessels. Proc Pedestrian and Evacuation Dynamics, Springer, Germany, 2007.
4. International Convention on Safety of Life at Sea, Reg II-2/13.7.4, IMO 2000 (SOLAS 2000).

5.   International Maritime Organisation (IMO), Interim Guidelines for evacua-
      tion analysis for new and existing passenger ships, MSC Circular
      n. MSC/Circ.1033, 26-th June 2002.
6.   International Maritime Organisation (IMO), Sub-commiteee on Fire Protec-
      tion, 46-th session 2002: Recommendation on Evacuation Analysis for
      New and Existing Passenger ships, FP 46/WP.10, FP 46/3, FP 46/3/1, FP
      46/3/2, FP 46/INF.3, FP46/UP2.
7.   International Maritime Organisation (IMO), Interim Guidelines for a Sim-
      plified Evacuation Analysis of High Speed Passenger Craft, MSC Circular
      n. MSC/Circ.1001, 26-th June 2001.
8.   International Code of Safety for Hihg – Speed Craft, Section 4.8.2, IMO
      2000.
9.   Klupfel H.: The simulation of crowd dynamics at very large events- Cali-
      bration, empirical data, and validation. Proc Pedestrian and Evacuation
      Dynamics, Springer, Germany, 2007.
10.   Meyer-Konig T., Valanto P., Povel D.: Implementing ship motion in
      ANEAS-Model development and first results. Proc Pedestrian and Evacua-
      tion Dynamics, Springer, Germany, 2007.
11.   University of Strathclyde: Rep[ort on Passenger Evacuation Simulation-
      Evi- IMO Test Model. IMO, FPSub-committee, 46-th session 2002.
12.   Yoshida K.: Study on Evacuation of Escape Route in Passenger Evacuation
      Simulation and Full Scale Trials. IMO FP Subcommittee, 46 session 2002.

Recenzent:
Adam WOLSKI

**Analiza mikroskopowych (rozwiniętych) modeli symulacyjnych procesu
ewakuacji statków**

Słowa kluczowe

Ewakuacja, modelowanie, czynnik ludzki, statek pasażerski.

Streszczenie

Przebieg ewakuacji zależy od wielu parametrów, do których należą: geome-
tria i przeznaczenie pomieszczeń, cechy populacji osób oraz warunki środowi-
skowe. W celu obliczania czasu ewakuacji do analizy tego procesu stosuje się
dwa modele: makroskopowy (uproszczony) i mikroskopowy (rozwinięty).
W modelu uproszczonym osoby traktowane są jako płynne medium, a trasa
ewakuacji jako rurociągi. Model mikroskopowy może zapewnić większą do-
kładność predykcji czasu ewakuacji.