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The Possibility of Application of Algorithms Indicating Maximum Paths in Directed Graphs for Modeling of the Evacuation Process

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ABSTRACT: In the introduction, ways of accounting geometrical, population, environment and procedure parameters in the computer evacuation simulating programs have been shown. In the part to follow the method for graph theory based representation of the geometry of escape routes has been described. Besides, means of indicating the longest time of emergency evacuation is proposed using a modified Warshall's algorithm to find the maximum weights in the directed graph. The use of the algorithm to indicate maximum escape routes makes it possible to verify the arrangement of escape routes in newly designed or existing ships.

1 INTRODUCTION

The trend in building very large passenger ships imposes a necessity for the safety systems of those vessels to be constantly improved. Sea voyages offer an attractive way of spending free time, therefore ensuring safety of people on board should constitute an ultimate goal to be pursued, also in case of emergency evacuation from a vessel. An analysis of factors affecting the evacuation process should precede the actual stage of designing a vessel so that the risks can be, at least partially, eliminated during ship operation. For buildings ashore the actual time of evacuating counts till the moment the building is left. For ships, this process should be divided into the following stages: proceeding to muster stations, abandoning vessel (embarkation on life–saving appliances and their launching or the same combined with evacuation slide system). The time in case of possible emergency evacuation of people should not exceed the time available to carry out the evacuation.

The analysis of evacuating people from a ship is very complex because it involves a large number of factors influencing the evacuation process and specific conditions related with the marine environment. Models accounting for potentially greatest number of factors affecting the evacuation process make it possible to obtain results close to reality. However, they are extremely difficult to verify. While conducting full scale evacuation trials we cannot hurt the volunteers, let them be affected by smoke, etc. which makes the results of those trials different from what can happen during the actual evacuation.

Theoretical analysis and actual trials of passenger ship evacuation (in order to verify the models) are carried out by research centres in collaboration with maritime administration, industry and transport. The development of evacuation analysis is coordinated by the International Maritime Organization (IMO).

From the point of view of population of people taking part in the evacuation, two approaches can be distinguished. In the first one, referred to as the global approach, people in motion are treated as a liquid (hydraulic) medium. The process of movement is described by a simple equation of flow kinematics (e.g. models: EVACNET4 (Kisco & Francis & Nobel, 1998), WAYOUT (Shestopal & Grubits, 1994)). In the individual approach the movement is analysed, often in association with a defined pattern of behaviour, separately for each participant of the evacuation (e.g. models: Simulex (Thompson & Marchant, 1995), PedGo (Meyer- König & Klupfel & Schreckenberg, 2001)).

The decision making process of people who take part in the evacuation is presented in the model on the basis of a relevant method for the simulation of human behaviour. The classification of models according to behavioural systems is as follows (Erica & Kuligowski & Peacock, 2005):

– without behavioural principles (only the aspect of movement is taken into consideration) e.g. models: EVACNET4, PathFinder (Cappuccio, 2000),
– alleged behaviour (models do not declare principles of behaviour, instead they assume them on the basis of alleged behaviour), e. g. models: PedGo, Simulex,

- behavioural system based on principles (system “if, then”), e.g. models: EXITT (Levin, 1998), E-SCAPE (Reisser-Weston, 1996),
- probabilistic behavioural system (principles included in the model are stochastic), e. g. CRISP (Fraser-Mitchell, 2001), ASERI models (Schneider & Konnecke, 2001),
- behavioural system based on artificial intelligence, e.g. models: Legion (Williams, 2005) Vegas (Still, 1994).

Evacuation models differ according to the way the movement of people is presented. In most types of models people have their specific travel speed (actual data). However, in the instances of a greater density leading to queuing there are various methods of describing the movements of people. In the situation of a restricted flow, the following approaches to modeling can be distinguished:

- determining the speed and flow of people (individuals or populations) on the basis of the geometry of the analyzed space (density), e.g. WAY-OUT, STEPS (Hoffman & Henson, 1998) models,
- establishing individual distances between evacuating people and possible obstacles, e.g. SIMULEX, VEGAS models,
- calculating the undisturbed flow, then accounting for disturbances using various coefficients, e. g. ALLSAFE model (Heskestad & Meland, 1998).

In all models the surroundings of evacuation must be presented, i.e. the geometry of the interior (corridors, spaces layout). The space is divided into subspaces and each subspace is attached to the neighbouring ones. Usually two methods are employed:

- space is substituted for a network of polarized spaces of different shapes and sizes, depending on the model (e. g. PedGo, EGRESS models (Ketchell & Cole & Webber, 1994)), making it possible to locate an individual evacuated as well as possible obstacles by the determination of the exact position in the space (room),
- space is shown by means of fields which stand for spaces (rooms) or corridors and are not consistent with actual dimensions, giving the exact position of an evacuated person in a given space (room) is not possible; there is only a possibility to move between the components of the analyzed structure (e. g. EXODUS model (Gwynne & Galea & Lawrence & Filippidis, 1998)).

2 THE REPRESENTATION OF THE GEOMETRY OF SHIP’S ESCAPE ROUTES BASED ON THE GRAPH THEORY

On the basis of ship evacuation plan it is possible to present the layout of evacuation routes on the ship (corridors, stairways and spaces) in the form of a hydraulic network. In the next stage, utilizing the graph theory and accounting for the movement of passengers along escape routes, the layout of the escape routes is brought down to the format allowing for further use in the designed model of evacuation.

Particular stages of encoding the escape routes layout in the form of the directed graph is shown in Figure1.

When using this kind of record, it is suggested that one of the ways of looking for the maximum evacuation path be employed to form the most disadvantageous scenario of evacuation, that is, to calculate the maximum weights of the graph. To this end the modified Warshall’s algorithm was used (Ross, 2005).

The devised method will be presented using a chosen vessel as an example.

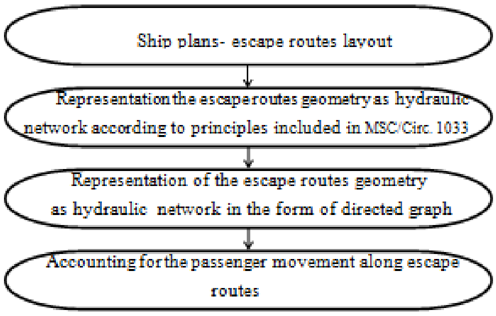

Figure 1. Algorithm of encoding the emergency escape routes arrangement into the form of the directed graph.

In room PP there are 180 people, who split up the moment the evacuation commences and proceed through three exits: towards the staircase *b* and the doors *a* and *c*. Figure 2 shows the escape routes arrangement together with the direction of the evacuation.

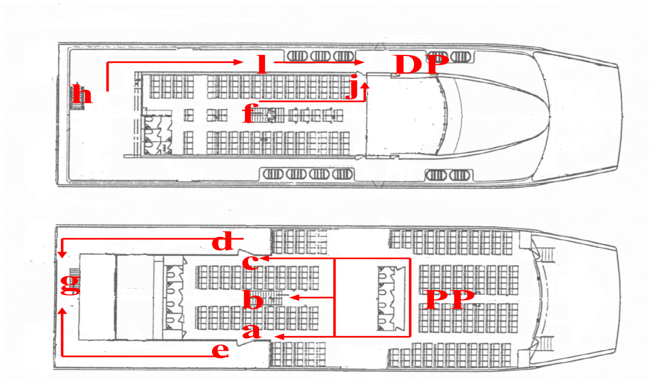

Figure 2. Escape routes arrangement together with the direction of the evacuation

The escape routes arrangement is represented as a digraph in which a set of vertices represents the particular sections of escape routes, while the edges represent the connections among them (Fig 3). In the digraph which represents escape routes, the weight of the edge can be interpreted as the walking time of a given evacuation group along this kind of path.

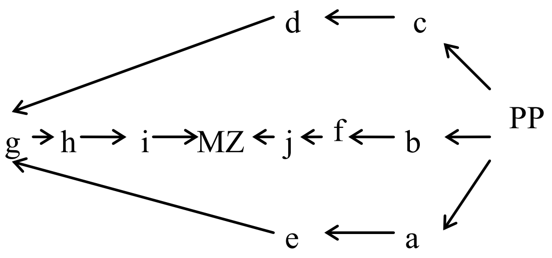

Figure 3 The escape routes arrangement is represented as a digraph.

To calculate the time of evacuation T_c , the method of calculating the flow of people through respective nodes of the arrangement was used.

The time of the transit of x passengers along a given arc (passageway, space) is:

$$T_c = \frac{L}{S_{śr}} + \frac{x}{\left(F_s \cdot W_c\right)} \tag{1}$$

where:

$S_{śr}$ - mean speed of people along the escape routes can be assumed as ca. 0.5 m/s when the ship is listing (Yoshida& Murayama & Itakaki, 2001), (Ando& Ota & Oki, 1988),

L- the length of passageways

W_c – the breadth, measured betwen the handrails, for the passageways and stairways, and the door breadth when fully open,

F_s – specific flow is assumed to be 0.43 (person/ms) (acc. SFPE Fire Protection Engineering Handbook, 2nd edition, NFPA 1995),

The time obtained should be increased by coefficients accounting for: passenger age, passageways inaccessibility, restricted visibility, flow of people in the opposite direction and other factors which may hinder the evacuation.

The increasing coefficients are assumed to be 2.3 (IMO, Circular MSC/Circ.1033).

The table of the weights of the analyzed example has the following form:

$$\begin{bmatrix}
-\infty & 363 & 343 & 363 & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & 357 & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 312 & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & 357 & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 147 & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 147 & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 361 & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 556 & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 204 & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 428 \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 357 \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty
\end{bmatrix}$$

The symbol ∞ indicates that in the graph there is no path between given vertices.

3 WARSHALL ALGORITHM FOR FINDING THE MAXIMUM PATHS

In connection with the intended adaptation of the Warshall algorithm for finding the maximum paths all cases of ∞ were replaced by values $-\infty$, whilst $-\infty + x = -\infty = x + (-\infty)$ for a given x and $-\infty < a$ for all real numbers a.

The maximum weight is called the largest weight of path leading from one vertix to the other and is denoted as M.

The general formula of the Warshall algorithm to form the table of the maximum weights of the graph is as follows (Ross, 2005):

{Data: matrix W_0 of non-negative edge weights of the directed graph without loops and multiple edges}

{Results: matrix M the weight of maximums of this graph}

{ Auxiliary variables: matrix W}

W:=W_0

for k =1 n perform

  for i =1 up to n perform

    for j =1 up to n perform

      if W[i,j]<W[i,k]+W[k,j], then

        replace W[i,j] with the sum W[i,k]+W[k,j]

M:=W

The calculations of the maximum weights functions table of the analysed example are as follows:

$W=W_0=$

$$
\begin{bmatrix}
-\infty & 363 & 343 & 363 & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & 357 & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 312 & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & 357 & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 147 & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 147 & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 361 & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 556 & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 204 & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 428 \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 357 \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty
\end{bmatrix}
$$

Due to the fact that we deal with a sequence of events, the algorithm is to be simplified because we focus only on the maximum paths coming out of the vertix PP, that is, we assume that $i=1$.

$W_1=$

$$[-\infty \quad 363 \quad 343 \quad 363 \quad -\infty \quad -\infty \quad -\infty \quad -\infty \quad -\infty \quad -\infty \quad -\infty \quad -\infty]$$

$W_2=$

$$[-\infty \quad 363 \quad 343 \quad 363 \quad 363 \quad 720 \quad 363 \quad 363 \quad 363 \quad 363 \quad 363 \quad 363]$$

$W_3=$

$$[-\infty \quad 363 \quad 343 \quad 363 \quad 363 \quad 720 \quad 675 \quad 363 \quad 363 \quad 363 \quad 363 \quad 363]$$

etc.

As a result, the following maximum weights from the vertix PP are obtained.

M=

$$[-\infty \quad 363 \quad 343 \quad 363 \quad 363 \quad 720 \quad 675 \quad 867 \quad 1423 \quad 1627 \quad 1373 \quad 2055]$$

In the analyzed example of escape routes arrangement the longest time of evacuation amounts to 2055 s (ca. 34 minutes). The longest evacuation time there is for the following paths:

PP-a-e-g-h-i-MZ

PP-c-d-g-h-i-MZ

We assume that each of those paths is passed by 60 persons. Those groups of people achieve following time of moving by analyzed edges of graph:

PP-a (PP-c) -343 seconds

c-d (a-e) – 357 seconds

d-g (e-g) – 147 seconds

g-h – 556 seconds

h-i – 204 seconds

i -MZ – 428 seconds

Alternative paths (PP-b-f-j-MZ) is definitely shorter than above mentioned.

4 CONCLUSION

The purpose of the paper was to present an application of the Warshall algorithm to calculate the longest time of evacuation on the ship.

The ship evacuation plan can be presented in the form of a digraph with assigned weighted edges of the graph. Then, by applying one of the algorithms determining maximum paths, the longest evacuation time can be set for assumed evacuation scenarios.

The analysed example was simplified by an assumption that the evacuees would split up proportionally to head for the available exits. However, it is not seldom that everyone chooses one particular egress (so called "herd instinct"), leaving the remaining ones unused. This can ultimately lead to congestions or decelerating the evacuation. Therefore this phenomenon is to be taken into account in further studies.

The method of representing the evacuation routes arrangement as a digraph and the application of the algorithm to determine the maximum paths enables the design solutions of escape routes to be verified both for newbuildings and ships in operation.

At present it is mandatory to carry out an evacuation analysis for passenger vessels of the ro-ro and high speed craft type. However, in the future it is intended to include all passenger vessels carrying more than 1000 people. It shows that further studies on modeling the evacuation process are needed, which is justified by the fact that evacuation scenarios recommended by the IMO are inaccurate and have proved inadequate to real-life situations.

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