APPLICATION OF MODEL "WAYOUT" OF "FIREWIND" SOFTWARE PACKAGE

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ABSTRACT

Application of the evacuation model "WayOut" to practical engineering and forensic problems is demonstrated. The model allows to obtain final results (time of vacating compartments along the route of egress, time of completion of evacuation, etc.) and intermediate distribution of occupants along the route of egress.

This paper is dedicated to applications of the evacuation model "WayOut" which is a part of the fire engineering software package "FireWind" to practical fire engineering problems. This model is based on the unique Russian research by Predtechenskii and Milinskii [1]. Its internal structure and results of validation have been published in Ref. [2] and [3].

Since the time of our previous publications, WAYOUT has been upgraded. Research by Predtechenskii and Milinskii was published more than 40 years ago, but was used for practical purposes mostly in Russia. Since that time, there was a series of Russian research validated this model, and the results have been summarised in Russian Standard (GOST) [4]. In Ref. [1] and [4], the assumptions regarding the dependence of the pedestrian flow on flow density are considerably different, as shown in Fig. 1. Here the flow density is defined as the ratio of the area occupied by people (i.e. number of people in a room times the average cross-sectional area of a person) to the floor area of that room.

The main differences are:

- GOST allows for larger maximum flows than Ref. [1];
- According to GOST, the maximum speed of unconstrained traffic down the stairs is equal to that along the level route. In Ref. [1], the maximum speed down the stairs is assumed to be lower.
- The critical traffic density above which the dense crowd is formed is lower in Ref. [1], which is especially important for downward stair flows.

The inference is that calculations based on the model by Predtechenskii and Milinskii are in most cases more conservative. However, GOST cannot be ignored, being based on the latest Russian research. It has been included in the updated WAYOUT, but is not recommended to use.

Another significant upgrade of WAYOUT is the extension of the model to take into account the difference in the dress. Both sources, Ref. [1] and [4], contain data that can be used for three dress options:

- summer clothes: average cross-sectional area of a person 0.10 m^2;
- mid-season clothes: average cross-sectional area of a person 0.113 m^2;
- winter clothes: average cross-sectional area of a person 0.125 m^2.

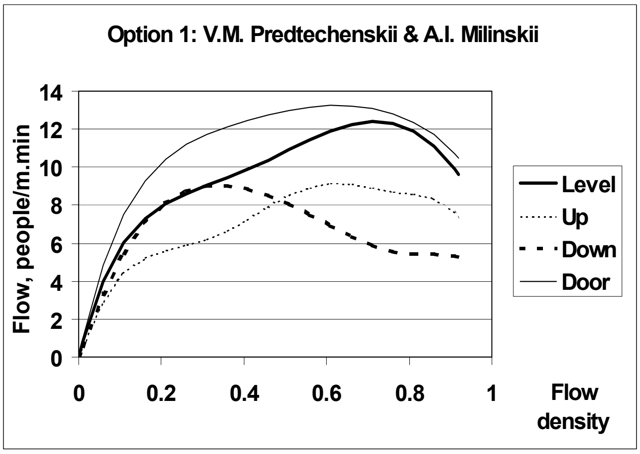
These options are now available in WAYOUT.

WAYOUT differs in the treatment of the pedestrian traffic from other programs, being not a discrete model like Building Exodus [5] and not an optimisation model like EVACNET4 [6]. It treats pedestrian traffic as a non-linear continuous flow. The domain of the traffic, a building or its part, is divided into "twigs". Each twig is characterised by width, length, width of the exit door and initial population. Twigs form an "evacuation tree" as shown in Fig. 2.

Numbers in this figure symbolise populations of twigs. Twigs are not nodes, as it is in Evacnet, but should be understood as pipes. The lines between twigs symbolise connections between twigs. They are not arcs and have no dimensions. Only merging flows are allowed in the model. Branching is not available. Such a limitation allows for a convenient computer logic, where the main procedure describing the flow in a twig calls itself as many times as there are merging twigs. It also allows for a friendly user interface to enter the data into the program for a large variety of complex configurations.

The restriction of the model by merging streams does not prevent application of the model to the situations with multiple exits. To apply to such situation, the area from which the evacuation occurs is divided into “catchments” by “watersheds”, as shown in Fig. 3.

The division into catchments should be made on psychologically plausible assumptions. For instance, if there is a room where occupants can see each other, it can be assumed that they leave this room at approximately the same time through each door, because nobody will wait in a queue at one door, if another door is available. This approach differs in principle from optimisation approach of EVACNET4, where simultaneous time of final exit is achieved. In our view, optimisation does not reflect correctly the reality of human behavior. An example of such a difference is one of our recent studies where there were two egress routes from a restaurant – see Fig. 4.



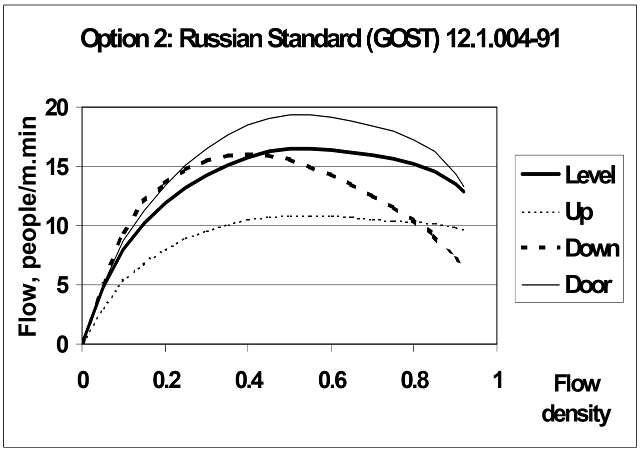


Fig. 1: Dependence of the pedestrian flow on flow density

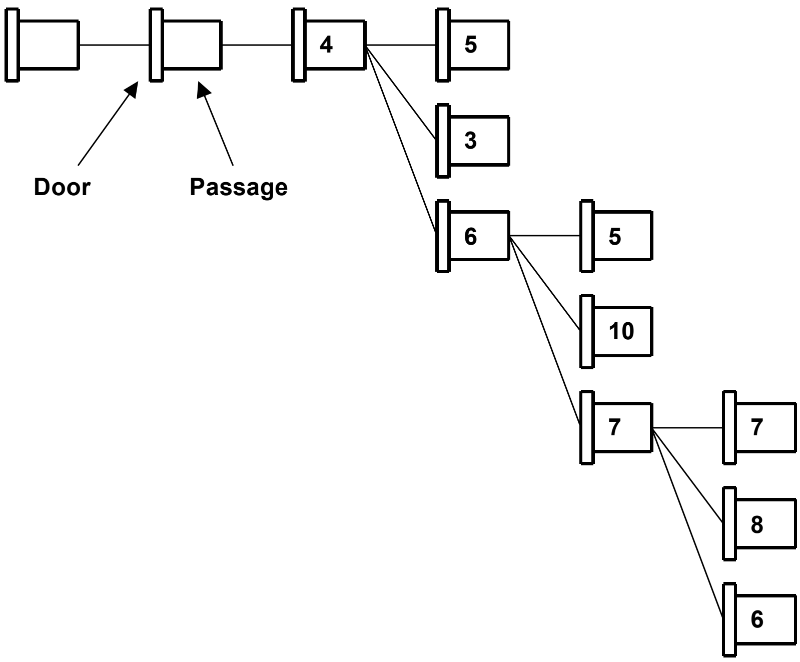


Fig. 2: Example of an evacuation tree

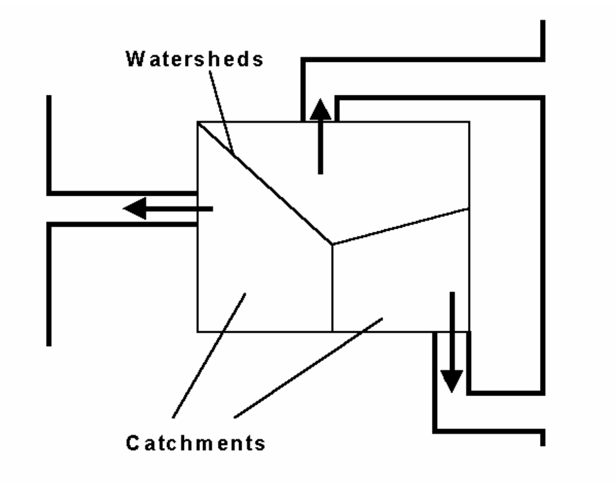


Fig. 3: Application of WAYOUT to areas with multiple exits

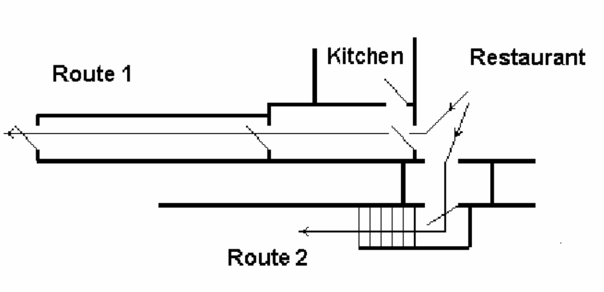


Fig. 4: Example of a practical study: egress from a restaurant

One route is past the kitchen through a long corridor, another down the stair outside of the building. The route down the stair is much shorter, but if a fire occurs in the restaurant, the occupants are assumed to leave the hall of the restaurant at about the same time, because they would not wait in a queue at one door when another exit is available. This results in different times of evacuation for these two routes. The times computed by WAYOUT are:

	Time to pass the door of the restaurant hall	Time to complete evacuation
Route 1	1 min 8 s	1 min 56 s
Route 2	1 min 4 s	1 min 7 s

The difference in the complete evacuation times is due to congestion in the corridor in Route 1, but people in the restaurant have no means to know about this congestion.

Another important feature of the model is prediction of formation of dense crowd when the population density reaches a critical point, i.e. the maximum of the diagrams shown in Fig. 1. This can be demonstrated using an example of an office building shown in Fig. 5.

This is a 5-storey building with a ground floor foyer and four office floors. The population of each floor is assumed to be 20 persons. When people proceed down the stair, more evacuees are added to the stream, and the flow reaches the maximum. After that, an increase in traffic density causes the decrease in the flow. But the upper evacuees push ahead, and the more they push the more the density increases. Hence, after the flow reaches the maximum, the model assumes that the density jumps from the critical value to the maximum density, which, according to Ref. [1], is 0.92. After that, the wave of maximum density spreads upwards, when more people who walk fast at the upper floors join the slow movement at the lower level. Such an upstream wave of high-density crowd moving slowly can be observed in our everyday experience in public transport during rush hours.

In the model by Predtechenskii and Milinskii, the critical densities are as shown in Fig. 6.

For the level and upstairs movement, critical densities are 0.76 and 0.62, i.e. relatively high. However, for the downstairs movement, the critical density is only 0.34, which is very low. In the modern Russian GOST model, this effect is slightly mitigated: the critical density in a downstairs flow is 0.40.

The singularity of pedestrian flow due to the density jump is reflected in the results of practical evacuation studies. For instance, in one of our studies for a 3-storey residential building, a discontinuity of the results looked as it is shown in Fig. 7.

The validity of model “WayOut” can be demonstrated on the example of a forensic fire safety analysis of a fire in Gothenburg Disco published in Ref. [7] where comprehensive data allows for a comparison with the real happenings and with the analysis made using Building Exodus evacuation model. This fire occurred in a disco licensed for the occupancy of 150, but the number of people in the disco was 400. The premises had two fire stairs, but one stair was blocked and used to store chairs. The fire originated in this storage. 63 people died, and many more were injured.

In accordance with Ref. [7], the upper floor of the disco and the stair are modeled for the purposes of the analysis as a sequence of virtual rooms, as shown in Fig. 8. The available exit is marked as twig “1”.

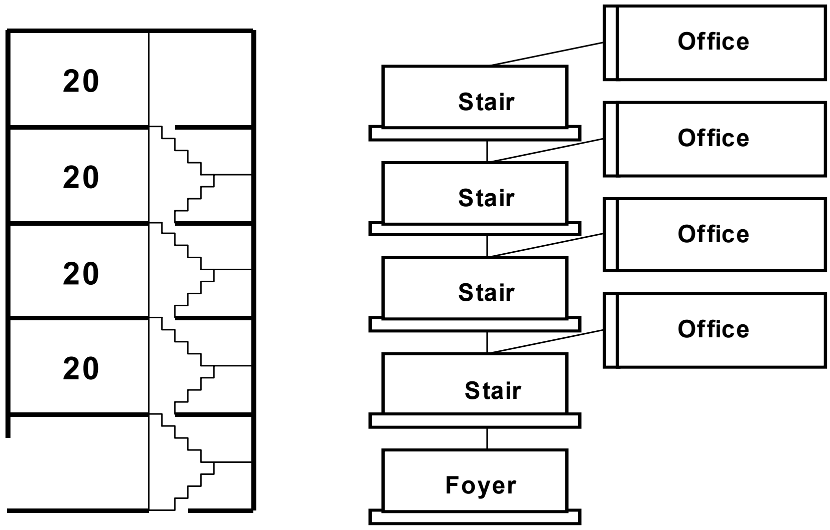


Fig. 5: Example of a situation where a dense crowd is formed: office building

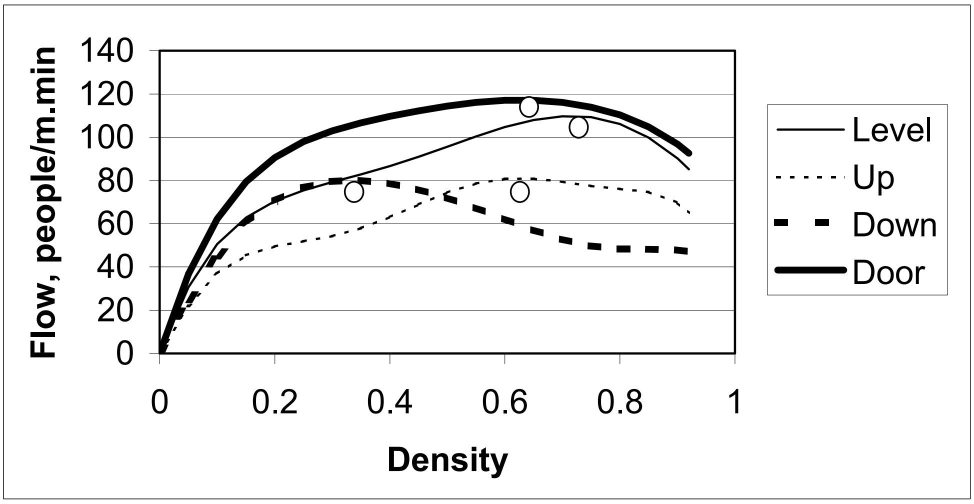


Fig. 6: Critical flow densities in the model by Predtechenskii and Milinskii

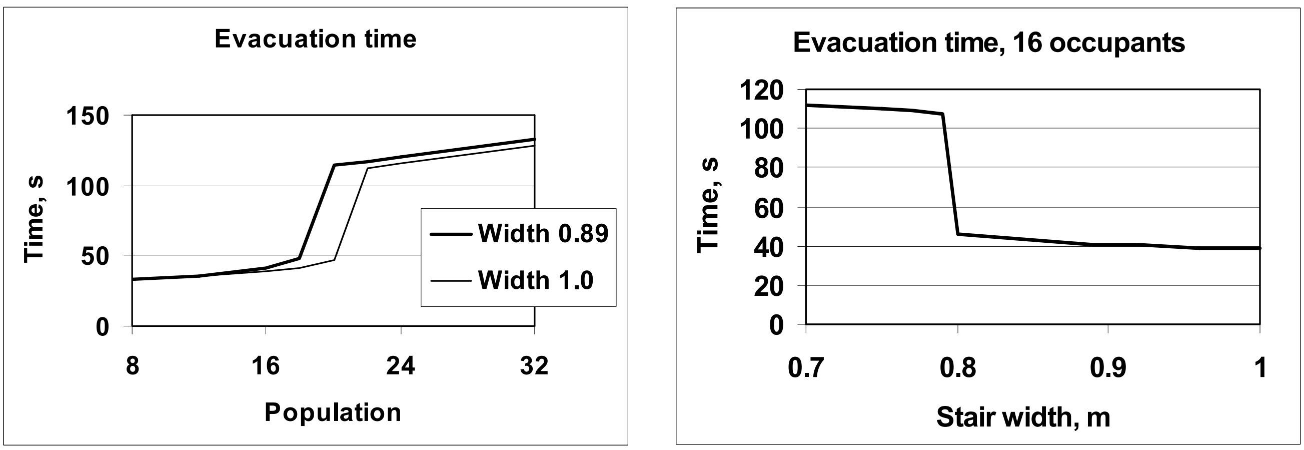


Fig. 7: Effect of the formation of a dense crowd on the results of modelling

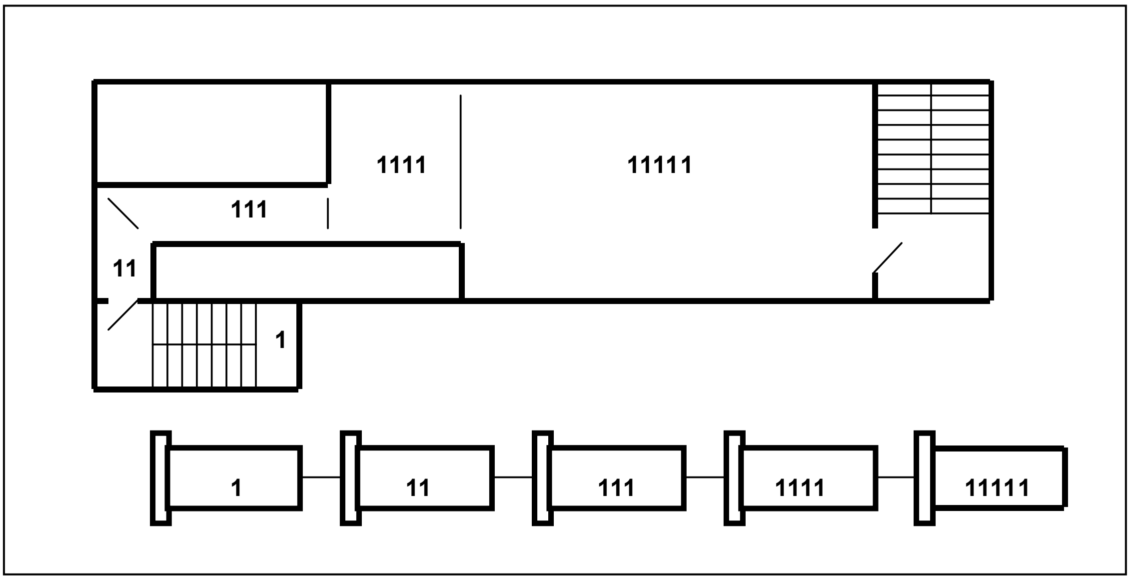


Fig. 8: Modelling of the Disco first floor by a sequence of virtual rooms

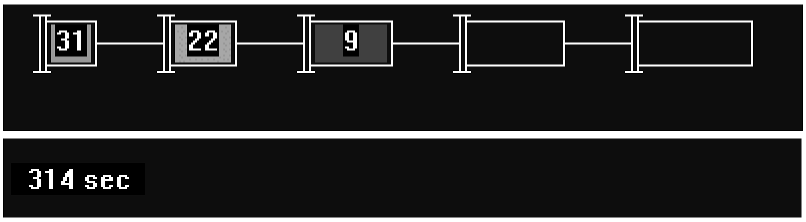


Fig. 9: Parts of the screen of "Animation" feature of WAYOUT
(Numbers in the twigs show populations at the time 314 s)

The following scenarios have been modeled:

(1) Number of occupants 400 persons, and only one exit available;
(2) Number of occupants 150 persons, and only one exit available;
(3) Number of occupants 400 persons, and two exits are available.

The fire occurred at the end of October, so that the mid-season dress has been assumed. Modelling of Scenario 1 should take into account all occupants, but needs to be finished when 63 occupants remain in the building. This has been done using facility "animation" of WAYOUT. Animation allows to be terminated at a desired stage in the evacuation process. Images of the animation screen of WAYOUT are shown in Fig. 9. The computed time when the evacuation has been terminated and everybody who managed to get out the building is 5 min 14 s. It is in correspondence with the calculations by Building Exodus where the total evacuation time (the time for the last person to evacuate, as defined in Ref. [7]) was 5 min 17 s. In the option of GOST, the total evacuation time is 4 min 32 s, which is considered to be overly optimistic.

As a result, the following times have been computed:

Scenario	Total evacuation time
1	5 min 14 s
2	2 min 38 s
3	3 min 30 s

These results confirm the inference made in Ref. [7]: if the second stair had been available or if the population had been kept at a licensed level of 150, then the tragic consequences of the fire would have been avoided.

CONCLUSION

Program WAYOUT is shown to be a useful tool of fire engineering analysis correctly predicting the major features of pedestrian flow.

REFERENCES

1. V.M. Predtechenskii and A.I. Milinskii, Planning for foot traffic flow in buildings, Amerind Publishing Company, Inc. New Delhi (1978).
2. V.O. Shestopal and S.J. Grubits, "Evacuation model for merging traffic flows in multi-room and multi-storey buildings", Fire Safety Science – Proceedings of the 4th International Symposium, IAFSS, Ottawa, Ontario, 1994, pp. 625-632 (1994).
3. V.O. Shestopal, "Computer modelling of merging pedestrian traffic", In: E.R. Galea (editor), Pedestrian and evacuation dynamics, University of Greenwich, London, pp. 395-403 (2003).
4. GOST 12.1.004-91, Occupational safety standards system. Fire safety. General requirements. (Russian).
5. E. Galea, M. Owen and P. Lawrence, "The EXODUS model", Fire Engineers Journal, July, pp. 26-30 (1996).
6. T.M. Kisko, R.L. Francis and C.R. Noble, EVACNET+ user's guide, Department of Industrial and System Engineering, University of Florida, Gainesville, Florida (1984).
7. H. Jiang, S. Gwynne, E. Galea, P. Lawrence, F. Jia and H. Ingasson, "The use of evacuation simulation and experimental fire data in forensic fire analysis", In: E.R. Galea (editor), Pedestrian and evacuation dynamics, University of Greenwich, London, pp. 341-353 (2003).