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APPLICATION OF MATHEMATICAL METHODS AND INFORMATION TECHNOLOGIES TO CALCULATE THE EVACUATION TIME OF PEOPLE FROM PUBLIC BUILDINGS IN THE EMERGENCY SITUATION

Nechvoloda L. V. *– PhD, Associate Professor at the Department of Intelligent Systems of Decision Making, Donbas State Engineering Academy*
ORCID ID: 0000-0002-7584-6735
Researcher ID: HPB-8625-2023

Krykunenko K. M. *– Assistant Professor at the Department of Intelligent Systems of Decision Making, Donbas State Engineering Academy*
ORCID ID: 0000-0003-1530-216X

In the modern world, with the active development of computer equipment and In the modern world with the active development of computer technology and information technologies, there is a need to improve the calculation methods used to assess the safety of people during an air raid or during shelling or fire. Therefore, this necessitates the development of algorithms for modeling the evacuation process using information systems, which are critically important for effective planning of evacuation measures in emergency situations, as they help collect, analyze and exchange data in real time, which contributes to quick decision-making and coordination of actions. In this case, it is possible to model various scenarios of events, determine optimal evacuation routes, taking into account various factors such as the number of people, the presence of obstacles, etc. In addition, information systems provide timely notification of the population about the threat and coordinate the actions of various services involved in the evacuation, which increases the efficiency and safety of evacuation measures.

The article examines the principles of evacuating people from dangerous areas in the event of an emergency, analyzes the methods of calculating the evacuation time from structures and buildings. The authors found that the most suitable method for automating the subject area under consideration is the use of calculation based on human flows, which is based on calculating the density and intensity of movement of groups of people through areas of various types (horizontal paths, stairs, doorways). The practical value of such a method is to increase the speed of the evacuation process from a public building in the event of an emergency by automating the preliminary calculation of the evacuation time and the ways of carrying out evacuation measures. The use of such an approach will allow developing a clearer strategy for the behavior of rescuers when evacuating people from potentially dangerous areas.

Key words: *evacuation, evacuation methods, evacuation time, emergency, mathematical model.*

Нечволода Л. В., Крикуненко К. М. Застосування математичних методів та інформаційних технологій для розрахунку часу евакуації людей з громадських приміщень в надзвичайних ситуаціях

У сучасному світі з активним розвитком комп’ютерної техніки та інформаційних технологій стає потреба у вдосконаленні розрахункових методів, вкладених в оцінку безпеки людей під час повітряної тривоги або при обстрілі чи пожежі. Тому це зумовлює необхідність розвитку алгоритмів моделювання процесу евакуації за допомогою інформаційних систем, які є критично важливими для ефективного планування евакуаційних заходів у надзвичайних ситуаціях, оскільки вони допомагають збирати, аналізувати та обмінюватися даними в режимі реального часу, що сприяє швидкому прийняттю рішень та координації дій. При цьому можна моделювати різні сценарії розвитку подій, визначати оптимальні маршрути евакуації, враховуючи різні фактори, такі як кількість людей, наявність перешкод тощо. Крім того, інформаційні системи забезпечують своєчасне оповіщення населення про загрозу та координувати дії різних служб, залучених до проведення евакуації, що підвищує ефективність та безпеку евакуаційних заходів.

В статті досліджено принципи проведення евакуації людей з небезпечних ділянок при виникненні надзвичайної ситуації, проаналізовано методики розрахунку часу евакуації зі споруд та будівель. Авторами було з'ясовано, що найбільш підходящим методом для автоматизації розглянутої предметної області є використання розрахунку на підставі людських потоків, що ґрунтується на обчисленні щільності та інтенсивності руху груп людей дільницями різних видів (горизонтальні шляхи, сходи, дверні отвори). Практична цінність такої методики полягає у підвищення швидкості процесу евакуації людей із громадського будинку у разі виникнення надзвичайної ситуації за рахунок автоматизації попереднього розрахунку часу евакуації та шляхів проведення евакуаційних заходів. Застосування такого підходу дозволить розробити більш чітку стратегію поведінки рятувальників при евакуації людей з потенційно небезпечних ділянок.

Ключові слова: *евакуація, методи евакуації, час евакуації, надзвичайний стан, математична модель.*

Introduction. Today, the number of people who die in fires in Ukraine is extremely high – more than 5 thousand people annually. It is known that most of them die in residential buildings with a height of up to 5 floors and with III-V degrees of fire resistance of the building itself (i.e., in buildings that are the least structurally protected from fire). The reason for their death is an underestimation of the danger of fire and unpreparedness to act in the event of its occurrence. In other words, the death of people is facilitated by the lack of the necessary planning of measures and the inability to perform the actions necessary to ensure safety [1].

The need to improve calculation methods aimed at assessing the safety of people during a fire necessitates the development of algorithms for modeling the evacuation process, which, in turn, requires a large amount of factual material and its statistical processing.

Thus, an analysis of the state of the above problems leads to the need to clarify the existing methodology for the safe evacuation of people. In the modern world with the active development of computer technology and information technologies, solving problems in many areas of activity can be solved by automating various processes. Modern information systems can also be actively used in the field of occupational health and safety.

Analysis of recent research and publications. Domestic and foreign authors consider various aspects of modeling the evacuation of people from buildings, from mathematical modeling of human flow to the development of software tools and analysis of specific cases of evacuation from buildings of various types.

In his work, Emelyanenko A. [1] considers both classical mathematical models and modern software products that allow for detailed modeling of evacuation processes, taking into account various factors, such as the geometry of the room, the number of people, their physical characteristics, etc.

Khlevnoy D. [2] the author considers a comprehensive approach to calculating the time of evacuation of people from public premises. He proposes to use for this purpose a combination of mathematical methods for modeling the movement of human flows and modern information technologies, such as computer modeling systems and geographic information systems. The author notes that such an approach allows for more accurate and realistic results.

The authors of the book on computer modeling of fires and evacuation of buildings [3] consider various modeling methods, such as fluid flow models, agent-oriented models and hybrid models. They also discuss the verification and validation of the models, as well as their application to building design and evacuation planning.

In [4], the authors propose an agent-based model for modeling the evacuation of large crowds in complex buildings. They show that this model can be used to study the influence of various factors, such as building layout and human behavior, on evacuation times.

Thus, the scientific literature has devoted much attention to the problem of human evacuation and approaches to its solution. However, the use of these approaches for calculating evacuation times still requires methodological development and modification.

The aim of research. The purpose of the study is to develop a methodology for calculating the evacuation time of people from a public building in the event of an emergency for its application in an information system.

Methods, subject and object of research. The object of the study is the process of calculating the evacuation time of people from public buildings.

The subject of the study is modern mathematical methods for calculating the evacuation time of people in the event of an emergency.

Proposed mathematical model. Let consider the methodology for determining the estimated time of evacuation of people from premises and buildings.

The estimated time of evacuation of people tp from premises and buildings is established by calculating the time of movement of one or more human flows through evacuation exits from the most remote places of accommodation of people. When calculating, the entire path of movement of the human flow is divided into sections (passage, corridor, doorway, staircase, vestibule) with a length and width δi. The initial sections are passages between workplaces, equipment, rows of chairs, etc. [5-8].

When determining the estimated time, the length and width of each section of the evacuation route are taken according to the project. The length of the path along staircases, as well as ramps, is measured along the length of the march. The length of the path in the doorway is taken equal to zero. An opening located in a wall with a thickness of more than 0.7 m, as well as a vestibule, should be considered as independent sections of the horizontal path, having a finite length l_i.

Estimated evacuation time t_p should be defined as the sum of the time of movement of the human flow along individual sections of the path t_i according to the formula (1):

$$t_p = t_1 + t_2 + t_3 +, ...- + t_i, \tag{1}$$

where t_1 – time of movement of the human flow in the first (initial) section, min;

$t_1, t_2, t_3, ..., t_i$ – time of movement of the human flow on each subsequent section of the path after the first, min.

The time of movement of the human flow in the first section t_i, min, is calculated by the formula (2):

$$t_1 = \frac{l_1}{v_1}, \tag{2}$$

where l_1 – length of the first section of the path, m;

v_1 – speed of movement of the human flow along the horizontal path in the first section, m/min (determined according to Table 1 depending on the density *D).*

The density of human flow on the first section of the path D_1 is calculated by the formula (3):

$$D_1 = \frac{N_1 \cdot f}{l_1 \cdot \delta_1}, \tag{3}$$

where N_1 – number of people in the first area, people;

f – the average area of the horizontal projection of a person, m^2, which is taken to be equal to 0.100 – an adult in home clothes; 0.125 – an adult in winter clothes;

δ_1 – width of the first section of the path, m.

Table 1

Intensity and speed of human flow at different points on evacuation routes depending on density

Flow density *D*, m²/m²	Horizontal path		Doorway, Intensity *q*, m/min	Stairs down		Stairs up	
	Velocity *v*, m/min	Intensity *q*, m/min		Velocity *v*, m/min	Intensity *q*, m/min	Velocity *v*, m/min	Intensity *q*, m/min
0,01	100	1,0	1,0	100	1,0	60	0,6
0,05	100	5,0	5,0	100	5,0	60	3,0
0,10	80	8,0	8,7	95	9,5	53	5,3
0,20	60	12,0	13,4	68	13,6	40	8,0
0,30	47	14,1	16,5	52	16,6	32	9,6
0,40	40	16,0	18,4	40	16,0	26	10,4
0,50	33	16,5	19,6	31	15,6	22	11,0
0,60	28	16,3	19,05	24,5	14,1	18,5	10,75
0,70	23	16,1	18,5	18	12,6	15	10,5
0,80	19	15,2	17,3	13	10,4	13	10,4
0,90 и більше	15	13,5	8,5	8	7,2	11	9,9

The speed v_1 of the human flow on the sections of the path following the first one is taken according to Table 1, depending on the intensity of the human flow on each of these sections of the path, which is calculated for all sections of the path, including doorways, by the formula (4):

$$q_i = \frac{q_{i-1} \cdot \delta_{i-1}}{\delta_i}, \tag{4}$$

where δ_i, δ_{i-1} – width of the analyzed i-th and previous section of the path, m;

q_i, q_{i-1} – intensity of human flow movement on the analyzed i-th and previous sections of the path, m/min (the intensity of human flow movement on the first section of the path $q = q_{i-1}$ is determined according to Table 1 by the value of D_1, which is calculated by the formula (3)).

If the value of q_i, which is determined by formula (4), is less than or equal to q_{max}, then the time of movement along the track section t_i, min, is equal to:

$$t_i = \frac{l_i}{v_i} \tag{5}$$

In this case, the value of q_{max} (m/min) should be taken equal to:

– 16.5 – for horizontal paths;
– 19.6 – for doorways;
– 16.0 – for stairs down;
– 11.0 – for stairs up.

If the value of q_i, which is determined by formula (4), is greater than q_{max}, then the width δ of a given section of the path should be increased by such a value that the condition is met

$$q_i \le q_{max} \tag{6}$$

If condition (6) cannot be fulfilled, the intensity and speed of human flow through the area are determined according to the table with a value of D = 0.9 and more. In this case, the delay time of people’s movement due to the resulting crowding should be taken into account.

The intensity of movement in a doorway with a flow density of 0.9 and more, which is equal to 8.5 m/min, is set for a doorway with a width of 1.6 m and more, and for a doorway with a smaller width δ, the intensity of movement should be determined by the formula (7):

$$q = 2{,}5 + 3{,}75 \cdot \delta \qquad (7)$$

When two or more human flows merge at the beginning of section i (Figure 1), the traffic intensity q_i, m/min, is calculated by the formula (8):

$$q_i = \frac{\sum q_{i-1} \cdot \delta_{i-1}}{\delta_i}, \qquad (8)$$

where q_{i-1} – intensity of human traffic flows merging at the beginning of section i, m/min;
δ_{i-1} – width of the merging path section, m;
δ_i – width of the road section under consideration, m.

Fig. 1. Input data

If the value of qi determined by the formula (7) is greater than q_{max}, then the width δ_i of this section of the path should be increased by such a value that condition (6) is met. In this case, the travel time along section i is determined by the formula (5).

Based on the mathematical model, a software product has been developed that allows solving the problem of calculating the time of people from any building.

Let us consider an example of calculating the evacuation time of people from 3 floors of the second building of the DSMA. The developed software product allows solving the calculation problem under different conditions:

1. using the central staircase, assuming that the others are inaccessible;
2. using the side staircase, assuming that the central staircase is inaccessible;
3. using all three staircases available in the building (the human flow is divided into proportional sections).

For calculations, the database already contains the necessary reference data, which reflect the dependence of the speed and intensity of people's movement in different sections depending on the density of the human flow at the initial level of movement. For the calculation, it is necessary to fill in the list of available sections along the evacuation route.

Figure 2 shows the calculation of additional values, which involves recalculating the intensity of human traffic depending on the presence/absence of doorways, and also takes into account their width in accordance with established safety standards.

Fig. 2. Calculation of baseline values

After performing the necessary calculations, the user can view the resulting evacuation diagram with the indicated color markers for each of the studied areas. The performed calculation can be exported to an Excel file.

A similar calculation is performed for the evacuation options using the side stairs, assuming that the central stairs are inaccessible, as well as for the option using all three stairs available in the building (the human flow is divided into proportional sections).

After entering the data into the database, an analysis of the evacuation time depending on the number of stairs used can be performed. Figure 3 presents the results.

The resulting diagram shows that the fastest evacuation option is possible using three staircases.

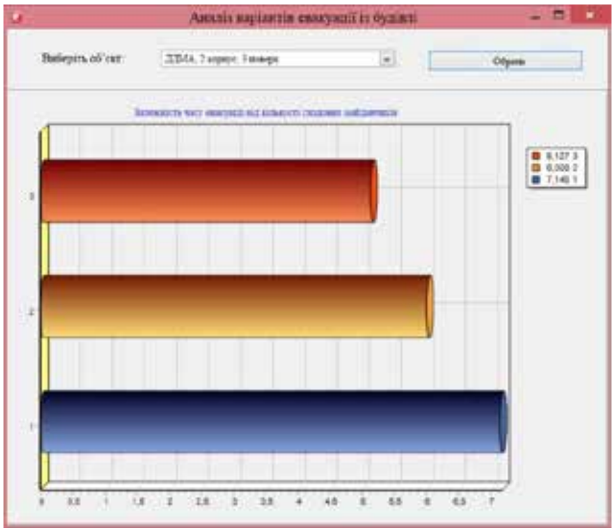

Fig. 3. Analysis of evacuation time depending on the number of staircases

Conclusions. Research into the principles of evacuation and analysis of methods for calculating evacuation time from buildings have shown that the most effective approach to automating this area is to use the human flow method. This method is based on calculating the density and intensity of movement of groups of people in various areas, such as horizontal paths, stairs and doorways, which allows taking into account the real conditions of people’s movement during evacuation. The use of mathematical methods and information technologies to calculate evacuation time helps to increase the accuracy and efficiency of forecasting, which is critically important for making informed decisions on evacuation management and minimizing the possible consequences of emergencies. Further research in this direction can be aimed at developing more complex models that take into account additional factors, such as the psychological state of people, the presence of obstacles, and others.

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