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Improving the Methodology for Ensuring Population Safety During Emergencies

Mamatov Nurbek Ziyodillaevich
Karshi State Technical University, Uzbekistan
sirojiddinmuradov0@gmail.com

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Abstract

This study analyzes the influence of the human factor, building architecture, technical means, and several other variables on the evacuation process, as well as the methodology for organizing population evacuation during emergencies. Particular attention is given to how these factors affect the efficiency and safety of movement along escape routes for different categories of the population, including vulnerable groups, within various types of buildings, structures, and residential areas. The evacuation methodology was refined and improved through computer-based simulations, which enabled the systematic evaluation and optimization of evacuation scenarios under conditions of heightened stress and risk.

Keywords: Emergencies; Evacuation Methodology; Human Factor; Technical Means; Vulnerable Groups; Escape Routes; Residential Areas

Introduction

Every year, hundreds of emergencies occur worldwide. The greatest risk during such situations is the failure to evacuate the population in a timely manner. Problems that arise during evacuation — blocked routes, poor management, and panic — often lead to catastrophic consequences.

In recent years, urbanization in our country has increased sharply, and the number of multi-story residential buildings has grown significantly. Organizing effective evacuation processes in such buildings during emergencies is not only a technical but also a social challenge. Experience shows that many buildings lack proper evacuation plans; evacuation routes often do not meet safety standards, and the population is unaware of proper behavior during emergencies.

In global practice, simulation modeling, mathematical calculations, automation of evacuation systems, and the implementation of specialized methodologies are proposed as solutions to this issue.

Degree of Study of the Topic: International organizations such as the World Health Organization (WHO), NFPA (National Fire Protection Association), and ISO have developed a number of international standards and recommendations for organizing evacuations.

Leading researchers —Ruggiero Lovreglio, Milad Haghani, Daniel Nilsson, as well as local scholars such as Bozorov S.E., Gaibnazarov S.B., Gulomjonov B., Nasriddinov J., Sadullaev S.B., Khodjakulov M., and Karimov Kh.S.— have conducted numerous studies to improve evacuation systems during emergencies.

Research Objective: To analyze existing methodologies for evacuating the population from residential buildings during emergencies and to improve them for greater safety and efficiency.

Research Tasks:

1. Analyze the evacuation system of residential buildings during emergencies;
2. Identify and classify the factors affecting the evacuation process;
3. Develop improved methodologies and recommendations to increase evacuation efficiency.

Methodology

The study employed analytical, comparative, simulation, expert evaluation, and systematic approaches. Practical drills were conducted to measure evacuation efficiency, evacuation time, crowd density, and the effectiveness of warning systems.

Results and Discussion

Due to increasing urbanization in recent years, the number of residents and high-rise residential buildings in cities has grown rapidly. Consequently, preparedness for emergencies in such structures has become a critical issue, especially in high-risk seismic zones (Tashkent, Fergana Valley, Andijan, Kashkadarya).

Although the "Construction Norms and Rules (QMQ)" stipulate safe evacuation routes, compliance in practice remains low. Older buildings often lack adequate evacuation paths, emergency exits, and warning systems. Fire protection systems are frequently malfunctioning or absent, and even new residential complexes sometimes violate technical safety standards.

Public awareness of emergency procedures is generally low, and evacuation drills are rarely conducted. Rapid warning systems operate mainly in central urban areas but are absent or inactive in remote regions.

Industrial buildings and production facilities are particularly vulnerable, facing risks such as:[3]

-fire (due to the presence of flammable chemicals);

-explosions (caused by gas, pressurized equipment, or combustible materials);

-poisoning (from toxic waste, smoke, or gases);

-mechanical injuries (from heavy machinery or high-voltage systems);

-technogenic accidents (equipment failure or system breakdowns).

Therefore, industrial facilities require stricter and more detailed evacuation plans than residential buildings.

In developed countries such as the USA, Japan, and Germany, separate evacuation plans are designed for each production zone. Quarterly evacuation drills are mandatory, employees are tested on their knowledge, and each worker receives a personal emergency instruction card. Advanced safety technologies are widely implemented.[5]

Evacuation- is the process of moving people to a safe location during emergencies, and its effectiveness depends on the evacuation methodology.

When planning and implementing an evacuation, the following factors should be taken into account:

Table 1. Factors Affecting the Evacuation Process

1	**Factor Group**	**Description**	**mpact**
2	Human factor	Psychological state, leadership, management	Major determinant of evacuation speed and efficiency
3	Building architecture	Exit routes, number of floors, internal layout	Determines movement convenience and safety
4	Technical means	Signaling, lighting, communication systems	Ensures alert and management during evacuation
5	Population size and structure	Density, vulnerable groups	Defines evacuation complexity and duration
6	Environment	Climate, external conditions, type of emergency	Alters evacuation conditions and effectiveness

Improvement Approaches. To improve the evacuation process, it is important to study and consider the above-mentioned factors in combination.

For example, apan—in regions frequently affected by earthquakes and tsunamis—has developed special evacuation routes and multifunctional evacuation centers, where regular training sessions are conducted.

In the United States, according to the NFPA 101 standards, building evacuation systems are automated, and strict requirements for emergency preparedness are enforced, which helps reduce casualties during fires and other emergencies.

The European Union widely applies integrated information systems and evacuation models in emergency management. Evacuation plans are regularly updated, and new technologies are continuously introduced [5].

During their research, the authors studied numerous scientific works aimed at optimizing evacuation processes in emergencies. Based on the findings of these sources, the most effective solutions for improving evacuation efficiency were identified:

1. Studies show that simulation considering the psychological state of people and regular public training significantly reduce evacuation time. Therefore, it is necessary to expand educational programs and conduct systematic drills.

2. Simulation results indicate that increasing the number and width of exits accelerates evacuation. Furthermore, simple interior layouts and clearly marked evacuation signs are essential.

3. Computer simulations and mathematical methods are used for modeling. These models help determine evacuation time, movement speed, and dependence on exit route configurations.

Formula for calculating total evacuation time:

$$T = \frac{H}{F} \qquad (1)$$

where: H—total number of people evacuated, F—flow rate (people/second).

The flow of people is a standard indicator that represents the number of individuals evacuated from a specific location within a certain period of time:

$$Q = \frac{N}{t} \qquad (2)$$

where: N — total number of people to be evacuated, t — evacuation time (in minutes or hours).

Thus, for effective evacuation planning, it is necessary to consider factors such as evacuation time, number and dimensions of exit routes, number of people, and crowd density within the building.

Maximum evacuation time:

$F = S \cdot \upsilon \cdot \varrho$ (3)

where: S — width of the exit (m) ·υ — movement speed (m/s), ϱ — crowd density (people/m^2).

Example: If (N = 300) people, the exit width (S = 1.2 , m), the movement speed (υ = 1.0 , m/s), and the crowd density (ϱ = 1.5 , people/m^2), then:

$F = 1.2 \cdot 1.0 \cdot 1.5 = 1.8$, people/second

This means that 1.8 people can be evacuated per second through the exit route.

Now, let's calculate T:

(T = H/F=300 / 1.8 = 166.7 ,s = 2.78 ,min .

Hence, 300 people can be evacuated in approximately 2 minutes and 47 seconds through a 1.2 m exit.

If $Q \leq F$ — evacuation is efficient;

If ($Q > F$) — congestion and risk of delay occur.

To ensure the continuity of the evacuation process, optimizing the exit routes is advisable as follows [1]:

-the number of routes should be sufficient and distributed evenly;

- each exit route should be clearly marked and visible;

-there should be special exit routes suitable for vulnerable groups, such as people with disabilities and the elderly;

-they should be equipped with technical means.

1. Human factor approach– enhance psychological preparedness, improve communication, leadership, and coordination.

2. Architectural and engineering solutions – optimize evacuation routes, upgrade ventilation and smoke removal systems, ensure accessibility for vulnerable groups.

3. Technical and automated systems – improve alarm systems, develop mobile and interactive evacuation guides, use real-time monitoring and control sensors.

4. Planning and testing – verify evacuation plans through computer simulations and conduct regular drills.

To strengthen the emergency protection system using the improved methodology, it is necessary to implement the above practical recommendations step by step. These recommendations are aimed at increasing public safety and ensuring a prompt and effective response to emergencies, while serving as a basis for integrating state policy and community engagement.

An experimental simulation conducted in a 10-story residential building demonstrated that the improved methodology reduced evacuation time by 20%, enhanced real-time information delivery, and improved inclusivity for all population groups.

Formula for total warning time:

$T_{total} = T_{detection} + T_{alert}$ (4)

For example: $T_{detection} = 30$,s , $T_{alert} = 20$,s ,

($T_{total} = 30+20 = 50$,seconds . Thus, people receive warning about danger after 50 seconds.

Based on the obtained data and conducted tests, the following conclusions can be drawn:

The process of evacuating people from residential buildings during emergencies is a significant and complex issue, in which various factors—including building architecture, human factors, technical means, population size, and community social characteristics—must be taken into account.

It should be noted that existing evacuation systems are often ineffective due to information shortages, outdated technical equipment in buildings, and low preparedness among the population. Therefore, to establish and implement an effective evacuation system for residential buildings, a comprehensive approach combining technical, organizational, and social measures is required. This approach should allow for a significant acceleration of the evacuation process and an increase in safety levels, based on computer simulations and international best practices, confirming the need to develop an improved methodology.

Recommendations

1. Modernize the technical infrastructure;
2. Develop information and communication systems;
3. Pay special attention to the elderly, disabled, and vulnerable groups;
4. Support scientific research and innovation in evacuation technologies.

These recommendations will strengthen emergency preparedness in residential buildings, enhance safety, and contribute significantly to the protection of human life.

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