Simulation Model of Emergency Evacuation in Case of Fire in a Nightclub

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Abstract. The article is devoted to studying the problem of ensuring people safety and security in case of fires in nightclubs. It is proposed to use the agent-based modeling for estimating evacuation time period, which allows to take into account in the model the following factors: club visitors alcohol intoxication, as well as panic and crush accompanying evacuation process. Based on a Saint Petersburg club example, evacuation model was developed using the AnyLogic simulation modelling system. Two probable evacuation scenarios were considered to estimate time period required for the nightclub visitors evacuation. Results obtained showed that in the said nightclub high risk to human life and health was present.

1. Introduction

Nowadays, reducing the risk of fires down to a socially acceptable level is an important problem. The number of people perished and injured during fires is the most important indicator, which demonstrates effectiveness of the fire safety system [1, 2].

Characteristic feature of modern construction is an increase in the number of buildings with a massive presence of people. In case of fire in these buildings, death of a large number of people is possible [3, 4]. The problem of people safety in case of fires in nightclubs is particularly topical. The number of such places is rapidly increasing; in particular, they are popular among young people. And often fires in nightclubs are accompanied by serious damage [5-7].

For example, large-scale fires in nightclubs in Russia are well known. On the night of March 25, 2007, a fire broke out in the “911” Club premises in Moscow. The club hosted a theatrical fire show, which employed alcohol. During a routine performance, a jar, where there were about two liters of alcohol, ignited, after which the scene caught fire. There were no windows in the club; and because of panic crush at the exit occurred. The fire area amounted to more than 100 m². When the fire started, there were about 150 people in the club. As the fire result, 4 women and 6 men perished; 8 people were hospitalized.

July 2, 2009 a fire broke in “Diagilev” nightclub in Moscow (Figure 1). In 15 minutes after ignition the roof of the club collapsed. The fire spread over an area of 1,500 m². Two people were hospitalized with burns. The building completely burned out. The cause of the fire was non-observance of the fire safety rules, which resulted in a short circuit in the electrical wiring.

The most terrible fire broke out on December 5, 2009 in the “Lame Horse” nightclub in Perm (Figure 2). When pyrotechnics was used in the “Lame Horse” nightclub, club decor and plastic in the ceiling ignited. When the fire started, there were about 400 people in the premises. With the ignition,
the lights went out in the club; the window openings were closed. Though there was one emergency exit, most visitors tried to leave the club through the main exit creating a serious crush. In total, this fire killed 156 people. Most of the victims died from poisoning with highly toxic smoke, many died from burns [8].

![Figure 1. Consequences of fire in the “911” Club (Moscow, March 25, 2007).](image1)

![Figure 2. Consequences of a fire the “Lame Horse” club (Perm, December 5, 2009).](image2)

People safety ensuring in case of fires in nightclubs is complicated by the following factors:
- large people concentration in clubs could lead to significant delay in leaving to a safe zone, and therefore to onset of panic;
- club visitors alcohol intoxication could lead to their inadequate behavior in an emergency situation, which could prevent rapid evacuation;
- fires are characterized by rapid spread throughout the entire nightclubs;
- high probability of collapse of the ceilings suspended over the dance floor and in other places of people mass gathering.

The problem of ensuring people safety in case of fires in nightclubs remains topical nowadays. The given article considers issues connected to evaluation of time required to ensure people evacuation in case of fire in nightclubs.

2. Methods

Escape time to reach a safe zone is the most important indicator reflecting the people safety level in a nightclub in the event of fire. The most important problems of people behavior in fire conditions include: panic, spatial loss of orientation, impossibility of quick and timely evacuation [9]. To estimate evacuation time, it is necessary to use simulation methods. It is required to build a model of a crowd of people movement in premises space, as they are exposed to panic.

Studying the crowd behavior based on the complex systems mathematical models started quite recently. First publication on this topic appeared in Nature journal in 2000 [10], and a number of characteristic phenomena was identified there, such as traffic jams and new people involvement in panic observed in a real panicked crowd, which were reproduced for the first time using mathematical modeling. Following this work, similar models were proposed by other authors in literature [11-13] examining various aspects of possible model complications.

Analysis of the given works demonstrated that the crowd group dynamics could be successfully modeled. Simulation models creation is one of the effective tools in studying the ongoing processes. The given simulation method makes it possible to consider a wider range of alternatives, improve decisions quality and predict consequences thereof.

According to numerous observations [14], people behavior in emergency situations is characterized by the following factors:
- partial or complete loss of orientation in space and in time;
- high degree of crowd turbulence, i.e. chaotic movement in all directions in case of people high density in the fire ignition areas;
- significant slowdown in movement speed, for example, caused by injuries, alcoholic intoxication, significant people density in a crowd, etc.;
- tendency to reach the nearest exit out of the premise, provided that the exit is within sight;
- tendency to move in direction of the nearest group of people (crowd attraction effect);
- tendency to move in direction of the nearest rescuers, in case they are present within sight.

The most promising approach to evacuation simulation modeling taking into account possibility of panic is the agent-based approach. In agent-based modeling, system under examination consists of many agents, who interact with each other based on certain rules. System behavior integral regularities are formed by interactions of individual agents. Rules of agent behavior could be changed during simulation, in particular, as a result of training.

The most important advantage of agent-based modeling is that this model could be developed without any knowledge of global dependencies. One could know very little about system properties at the global level; but understanding individual logic of each agent behavior, we could build a system model and derive global properties based thereon. This means that the given approach could make it possible to take into account individual psychophysiological behavior features of each agent in case of fire in order to estimate evacuation time.

Agent-based models could help identify critical points in time, after which extreme consequences would become of irreversible character.

To develop a simulation model for people evacuation from a nightclub in the event of fire, the AnyLogic simulation modeling system was used [15-18]. AnyLogic is a tool based on languages and methods adopted in the complex information systems development practices [19, 20].

Building plan of one of the nightclubs in Saint Petersburg, as well as statistical data on the club attendance during public events were used as the model basis. The club visitors’ number on certain dates amounted to about 1,000 people.

![Figure 3. Agents’ behavior diagram.](image)

At the first stage of modeling, AnyLogic space marking tools were employed to create the building plan layout, which was later used to simulate the crowd movement directions. Next, a diagram of agents’ movement in the nightclub was prepared both in the normal mode and in the event of fire (Figure 3), as well as a diagram of agents’ state that reflects the agents’ behavior rules in an emergency situation. Depending on the current situation, agents' behavior rules and agents’ interrelations in a crowd, an agent is able to react to external influences in a certain way.

At a certain point, evacuation process is activated in the model in accordance with the behavior diagram and the agents’ state.

Simulation model development and further experiments with it were carried out to determine people evacuation time from the nightclub using the existing evacuation plans with various scenarios [21, 22].
3. Results and discussion

When conducting experiments with the developed model, it is possible to observe potential “chaotic” dynamics among all the agents. Besides, evacuation process global characteristics could be estimated, as each agent makes his own contribution to the created structure. To simulate individual cognitive processes based on the created agents’ state diagram, each agent should constantly assess the current situation and make decisions based on his rules of decision making and interacting with other agents.

In the visualization mode, the AnyLogic simulation modelling system allows to observe flow density in the nightclub different premises, which is very important, since evacuation could be accompanied by panic and crush. During simulation it appears possible to observe the dynamics of changes in the number of agents in the building, their speed and coordinates of each agent. Besides, statistical data on all evacuation exits from the nightclub building is collected.

Two probable evacuation scenarios were considered in the event of fire.

**Scenario 1.** Evacuation was carried out using the main and emergency evacuation exits (Figure 4).

![Figure 4. People evacuation process using two emergency exits.](image)

Dynamics of the number of people staying in the club premises is automatically displayed on the corresponding chart (Figure 5). All agents are trying to leave the building as quickly as possible and are moving to the nearest exit in accordance with the created model of their agent-based behavior. Studies demonstrated that the evacuation time would be about 11 minutes.

![Figure 5. Dynamics of the number of people staying in the nightclub premises under scenario 1.](image)
Scenario 2. Evacuation was carried out through a single main emergency exit. This emergency exit was blocked by dangerous fire factors (Figure 6).

According to this scenario, evacuation time increased to 19 minutes (Figure 7).

![Figure 6. People evacuation process using a single emergency exit.](image)

![Figure 7. Dynamics of the number of people staying in the nightclub premises under scenario 2.](image)

This paper was not aimed at assessing the fire hazardous factors exposure time to nightclub visitors. But analyzing fires that actually occurred in nightclubs suggests making a conclusion that such time is significantly lower than the time required for safe evacuation. Results obtained allow to conclude that a potentially occurring fire in the studied nightclub could lead to a significant number of perished people.

4. Conclusion

Analysis performed makes it possible to conclude that visitors’ evacuation in the event of fires in nightclubs is one of the most important factors ensuring minimization in the number of perished and injured. Evaluation of time and probability of visitors’ evacuation from nightclubs should be carried out using mathematical modeling methods, since conducting real experiments with such objects is often impossible or is completely unethical.

Fires in such premises are often accompanied by injuries and death. First of all, this applies to rapidly developing fires in confined space, which pose a real danger to people within a few minutes after ignition and are characterized by intense effect of dangerous fire factors on people. Calculations performed on the of one of the Saint Petersburg nightclubs example showed that the evacuation time
in case of fire would constitute from 11 to 19 minutes, which becomes a very high risk to life and health of club visitors.

Solving the problem of ensuring people safety in case of fires in nightclubs, bars and restaurants requires development of scientifically based special fire safety requirements for this kind of premises in emergency situations, taking into account peculiarities in the behavior of people who are using alcohol.

5. References

[1] Gwynne S, Galea E R, Owen M, Lawrence P J, Filippidis L 1999 A review of the methodologies used in the computer simulation of evacuation from the built environment Building and environment 34(6) pp 741-749

[2] Matveev A V 2018 The model of the process of emergency evacuation from the building while using the self-rescue equipment in case of the fire ARPN Journal of Engineering and Applied Sciences 13(15) pp 4535-4542

[3] Matveev A V, Scherbakov O V, Artamonov V S, Maximov A V, Podruzhkina T A 2017 Evaluation models of effectiveness of hose rescue equipment used in evacuation of people from high-rise buildings Journal of Engineering and Applied Sciences 12(20) pp 5190-5195

[4] Matveev A V, Scherbakov O V, Maximov A V, Matveev V V 2017 Theoretical basis for designing integrated security systems of potentially hazardous facilities International Journal of Applied Engineering Research 12(22) pp 12357-12361

[5] Grosshandler W, Bryner N, Madrzykowski D, Kuntz K 2005 Report of the technical investigation of The Station Nightclub fire: appendices NIST NCSTAR 2: Vol 1

[6] Atiyeh B 2013 Brazilian kiss nightclub disaster Annals of burns and fire disasters 26(1) p 3

[7] Galea E R, Wang Z, Veeraswamy A, Jia F, Lawrence P J, Ewer J 2008 Coupled fire/evacuation analysis of the Nightclub fire Fire Safety Science 9 pp 465-476 doi:10.3801/IAFSS.FSS.9-465

[8] Strick J 2014 Development of Safety Measures for Nightclubs LUTFDG/TVBB

[9] Matveev A V, Popivchak I I 2018 Staff safety management of nuclear power plants in the fire National Security and Strategic Planning 3 pp 92-101 doi: 10.37468/2307-1400-2018-3-92-101

[10] Helbing D, Farkas I, Vicsek T 2000 Simulating dynamical features of escape panic Nature 407 pp 487-490

[11] Hoogendoorn S 2004 Pedestrian flow modeling by adaptive control Transp. Res. Rec 1878 pp 95-103

[12] Antonini G, Bierlaire M, Weber M 2006 Discrete choice models of pedestrian walking behavior Trans. Res. Part B 40 pp 667-687

[13] Yu W, Johansson A 2008 Modeling crowd turbulence by many-particle simulations Phys. Rev. 76 pp 46105-46116

[14] Helbing D, Johansson L, Al-Abdeen N Z 2007 Crowd turbulence: The physics of crowd disasters The International Conference on Nonlinear Mechanics (ICNM-V) (Shanghai) pp 967-969

[15] Macal C M, North M J 2010 Tutorial on agent-based modelling and simulation J. of simulation 4(3) pp 151-162

[16] Avdeeva M, Uzun O, Borodkina Y 2020 Simulation of the evacuation process at various economic facilities using the Anylogic software product In E3S Web of Conferences 175 p 11031

[17] Shariff G N, Yong J C, Salleh N 2019 Risk Assessment of building fire evacuation with stochastic obstructed emergency exit In 4th International Conference and Workshops on Recent Advances and Innovations in Engineering pp 1-5 doi: 10.1109/ICRAIE47735.2019.9037753

[18] Mahmood I, Nadeem T, Bibi F, Hu X 2019 Analyzing emergency evacuation strategies for large buildings using crowd simulation framework In Winter Simulation Conference (WSC) pp 3116-3127 doi: 10.1109/WSC40007.2019.9004906

[19] Gao H, Medjdoub B, Luo H, Zhong H, Zhong B, Sheng D 2020 Building evacuation time optimization using constraint-based design approach Sustainable cities and society 52 doi: 10.1016/j.scs.2019.101839
[20] Haoxiang G, Yuling H, Jingwan L 2020 Model framework of emergency evacuation system based on multi-paradigm modeling In Chinese Control And Decision Conference pp 2565-2570

[21] Xin J, Huang C 2013 Fire risk analysis of residential buildings based on scenario clusters and its application in fire risk management Fire Safety Journal 62 pp 72-78 doi: 10.1016/j.firesaf.2013.09.022

[22] Chen J, Liu D, Namilae S, Lee S, Thropp J E, Seong Y 2019 Effects of exit doors and number of passengers on airport evacuation efficiency using agent based simulation International Journal of Aviation, Aeronautics, and Aerospace 6(5) doi: 10.15394/ijaaa.2019.1418