Modeling People Behavior in Emergency Situations

Ilya I. Viksnin, Ruslan Gataullin, Alexandr Muradov, Ivan Danilov, Nikita Tursukov, Alexey Chechet
Saint-Petersburg National Research University of Information Technologies, Mechanics and Optics
Saint-Petersburg, Russia
wixnin@cit.ifmo.ru

Abstract—**A model of human behavior in emergency situations in confined spaces with a complex structure. A distinctive feature of this model is that the information influence of the behavior of agents in the group is individual. The level of exposure to the influence of the information agent depends on the type, based on some factors, such as location relative to the group members, the physical and functional characteristics of the individual membership. By the functional affiliation is meant the role of agent upon condition the absence of some external destructive influences. The proposed model describes four possible physical states of the agent: alive and active; alive and passive, wounded; received critical damage, unable to move; dead. The developed theoretical foundations models have been implemented in a software environment simulation by the example of incident in the club "Lame Horse" located in Perm, Russia, 05.12.2009. The experiments showed results corresponds to the actual outcome of the incident model operating results with considering the probability of deviations.**

I. Introduction

Nowadays simulations of emergency situations and behavior of people in critical life conditions go a long way. In the context of the destructive impact of external factors and the limited space, it is impossible to accurately analyze events based on traditional mathematical approaches. The behavior of individuals in a critical situation characterized by stochasticity decision-making, therefore it is often leading to disastrous consequences. Mortality statistics during a stampede in some situations [1] proves the importance of the development and future using of modeling techniques for the analysis of security restricted spaces of various events, such as fires, terrorist attacks, environmental and natural disasters, etc. It should be noted that the existing methods of analyzing fields with large concentrations of people using modern technologies aimed at solving private problems. These include a variety of system timing evacuation of people from buildings [2], warning and evacuation during fires [3], [4], automated fire extinguishing system [5], the use of modern equipment to extinguish fires [6], and others. However, in recent years more and more attention is paid to the use of modern information technologies in order to coordinate assistance in emergencies, predict emergencies.

In this regard, there is a growing number of organizations involved in the development of tools for modeling of emergency situations, in order to optimize the architectural features, both at the design stage, and existing solutions, in order to calculate the parameters of the damaging factors and building possible affected areas in consequence of an emergency and in order to respond to emergency situations of different nature.

Such a solution means assume at least the following tasks:

1) Forecast of possible emergencies and analysis of occurred emergencies.
2) Simulation of probable events and optimization of the "typical actions".
3) Planning interaction of people during an emergency.

At the heart of their solution on mathematical optimization models that take into account, among other things, psychological and social aspects of the behavior of poorly organized masses, using the computing power of modern technology, the solution of optimization problems and transport problems, as well as the study of the problems raised by. Such problems are described in [7] – [15] papers.

This paper presents a model of human behavior in emergency situations of different nature in a small space and in areas with different numbers of way outs, taking into account the physiological, psychological, social and informational aspects of external and internal exposure to individuals during the panic. A distinctive feature of this model is a different informational influence exerted by individuals in the process of evacuation. The influence of the information refers to a direct or indirect changing in the awareness of other members of the group on the environment.

Before the describing the model it is necessary to provide an analysis of existing approaches to modeling the behavior of the crowd in a panic and emergency situations, removing a number of restrictions on the subjects of the description, expanding the number of factors that characterize the behavior of individuals.The adequacy of the model is confirmed by the results of an experiment demonstrating the convergence of model data with incident in the club "Lame Horse" 05.12.2009, which confirms the efficiency of the developed model for analyzing and predicting the behavior of people in emergency situations.

The article is divided into seven parts. The second part describes the different approaches to the modeling of crowd in emergency situations. It is stated that these approaches do not consider the information factor, by which the agent is able to influence the progress of the situation. The third part examines the statement of the problem: it is described by a mathematical model, based on which the simulator will be built. The model of human behavior in emergency situations was considered in part IV: it describes the behaviors and different types of agents in detail. Part V is devoted to the impact of the information agents. Part VI describes the operation of the simulator models of the behavior of agents; this part also describes the data collecting and realization of experiments. Final part VII presents the results of experiments and conclusions, including plans for the further research.

II. Approaches to modelling the human behavior in conditions of emergency situations

Existing models for describing the movement of the crowd in an emergency situation (ES), specializing in the analysis of the following aspects:

- The mathematical model of the motion of the crowd and decision-making;
- Physical factors affecting the behavior and decision-making;
- Psychological and sociological factors that affect the movement of the crowd and the behavior of individuals in the crowd.

The current level of development of scientific-methodical apparatus provides considerable advantages in the field of creation of mathematical models of the crowd movement in terms of closed extensive areas with multiple outputs and complex internal structure. However, existing models have a number of significant disadvantages.

In [15] paper is considered a mathematical model, based on the laws of molecular dynamics and behaviors of Helbing panicking crowds. The authors described a system of 4N ordinary differential equations, which is complemented by the initial conditions and the geometry of the placement. The main advantage of this model is a decision-making algorithm by the agent during the search of exit from the premises: the algorithm considers only a given probability and the proximity of the output, however, shows adequate results and relatively realistic model. The disadvantage of this model is that the researchers did not consider this aspect of decision-making, as the "herd mentality". There was not described the safe way to achieve the goal of an agent. Besides, the model is not accounting for the psychological factors influencing the behavior of agents.

In papers [8], [9], [10] is detailed some of the aspects described above. This work is also based on molecular dynamics and models of panicking Helbing crowds. A distinctive feature is the presence of some additional factors in crowd behavior, likely stampede and turbulence, which play an important role in modeling the behavior of people in emergency situations. The disadvantages of this model is that the behavior of agents and crowds were not taken into account by any psychological factors, moreover, the work has not present the results of experiments in real conditions, i.e it is not represented practical application of the model to real-life situations.

Articles from most of researchers have an important drawback – they are not considered an information factor crowd movement. Under the information refers to factors originating from the environment to the individual. In the general case, this information is divided into two main groups: useful information, allowing the individual to make the right decision in determining your future actions, and destructive information, preventing the individual to make the right decision, which ultimately can lead to negative consequences, including death. The informational factors in the simulation of an emergency situation will more accurately determine the results and consequences of an event and develop a set of measures to mitigate the damage from realization events.

III. Statement of the problem of modeling the behavior of people in emergency situations

The problem of modeling the behavior of people in emergency situations is to get the dynamics and the general scheme of moving of the entire group on the basis of detailed traffic patterns of each individual. Under the scheme of motion on an average log change in time of the subject position (movement trajectory), as well as change the set of attributes that characterize his behavior and condition. Every individual in emergency situations characterized by the following factors:

- lack of completeness of knowledge about the environment and about other members of the band;
- lack of ability to predict changes in the environment;
- a choice of non-optimal route to achieve the goal of a plurality of routes;
- little formalized behavior due to the subjectivity of the environmental assessment and the individual's own state;
- penchant for choosing the path of movement, on the basis of the average trajectory other individuals of the group.

The presence of such a scheme will assess the damage caused by the disaster and to prepare the effects system that can reduce or completely eliminate the negative effects.

Considering the disaster as a set of time intervals

$$T = \{t_0, t_{1 \dots} t_n\},$$

we can assume the existence of a system according to the state of the element (individual) at the moment of time t_i from its state in previous times. Under the condition of an individual is a set of variable attributes:

$$P = \{P_0, P_1, \dots, P_m\},$$

and characterizing the physical condition of the individual and of the environment:

$$P = P_{inf} \cup P_{con}.$$

Such attributes include: physical damage, the availability of information on the rest of the band and the knowledge of finding a safe place, etc.

Each individual at any given time decides the optimal route solve task of moving to a safe place with the limited knowledge about the environment:

$$M_{ij} = f(P_{ij}, E_{ij}),$$

where E_{ij} is environment, the well-known to i-th individual in the j-th point in time, P_{ij} - a set of properties of i-th individual on j-th time.

Under the optimal route is understood as a route in which a set of individual properties characterizing his physical condition will be most similar to a set of similar properties at the initial time (at the beginning of disaster):

$$\frac{n(P_{i0} \cap P_{in})}{n(P_{i0} \cup P_{in})} \rightarrow 1.$$

However, for each individual, this indicator is calculated on the basis of the limited knowledge of a limited area surrounding environment, thus, the decision may not be optimal from the point of view of the complete evacuation of the individual.

It needs to develop a model, that possible for the most similar to reality and describe the existing features of the behavior of the individual, based on the principles described above.

IV. THE MODEL OF HUMAN BEHAVIOR IN EMERGENCY SITUATIONS

The basis of the developed model is a model of social forces by D. Helbing and P. Molnar [14]. Selection of the optimal route is based on the individual movements of environmental knowledge: the proximity of the output, the number of agents in the crowd near the exit, availability of information on available outputs, availability of information on other outputs. At any time the agent recalculates the route based on the changing information environment.

To solve this problem the model was expanded as follows:

- introduced ordinal metric is the physical condition of the individual;
- added algorithms for physical interaction between people;
- added psychosocial aspects.

Under the physical condition of an individual is meant the ability of individuals to be active:

- alive and active (A);
- alive and passive, wounded, movement is restricted (P);
- received critical damage, unable to move (K);
- dead (M).

Category A and P is the individual capacity for independent movement in the space, but differ in the speed of movement and resistance to external influences. In such cases, we can say that the behavior of the agents is almost completely described using the model presented in [14]. By category means no ability to move without any external influence in an individual, which may ultimately lead to death (the transition to the category M). Individuals whose condition applies to category M, can change the trajectory of the movement of other categories of individuals.

Algorithms for the physical interaction of individuals, in addition to the classical model of Helbing algorithms include algorithms stampede and turbulence. The basis of these algorithms is momentum. Impulse agents considered in the collision in the model with each other and depend on the mass, velocity and direction of movement of the simulated agent.

Finding the pulse:

$$P_n = m_n * \acute{V_n} = |P| = m * V \quad (1)$$

where P_n is pedestrian pulse, m_n is pedestrian weight, V_n is pedestrian speed at the time moment.

Based on (1) is the angle of interaction of individuals:

$$cos\alpha = \frac{\acute{P_1} * \acute{P_2}}{|\acute{P_1}| * |\acute{P_2}|} \quad (2)$$

Starting from (1) and (2), the interaction force equation:

$$\acute{F} = |P_1|^2 + |P_2|^2 + 2 * |P_1| * |P_2| * cos\alpha \quad (3)$$

The strength of the interaction of agents with each other is calculated by the formula:

$$\acute{F} = \acute{F_1} + \acute{F_2} \quad (4)$$

Coefficient of the powers distribution can be calculated based on (3) and (4):

$$\frac{F_1}{F_2} = \frac{P_1}{P_2} = \gamma \quad (5)$$

This force is divided into the stampede resistance coefficient (ω) adopted in this study as a constant $(\omega = 1000)$. The total damage to the two individuals is defined as the square of the number:

$$D = \left(\frac{F}{\omega}\right)^2 \quad (6)$$

After that, the damage to one individual is determined based on distribution coefficient:

$$D * \gamma = D_1 \quad (7)$$

$$D - D_1 = D_2 \quad (8)$$

At the core of the psychosocial aspect is the division of people (agents) into types:

- visitors: trying to leave the disaster;
- staff: trying to leave the disaster, they have great knowledge about the environment at time t_0;

- saboteurs: building a route on the basis of misconceptions about the environment both at the time t_0, and at other times.

Individuals assigned to the staff, can improve survival rates in emergency situations, as they have more knowledge about the specifics of environmental protection not at the time of emergency. After the information about the additional possible route, nearby agents begin to follow him, even if it turned out they didn't know. Saboteurs are capable of going to accidentally change or averaged vector crowd movement that will change the motion vector of an individual, and it can lead to poor survival rates. The agent accepts the saboteur as the staff and begins to follow him to the additional output, which may or may not exist, so some people following the saboteur become trapped. In general, when a staff in the area of an individual's sight, not a staff, the latter expands the list of possible follow routes by adding new probable escape route. At any time, an individual selects the best escape route, based on a set of inherent properties and their knowledge about the environment, including - his notion of capacity output capacity, dimension of the group before the release of the data, hindering evacuation. However, in a situation where an individual discovers that all this time moved to a nonexistent door and found myself in a room surrounded by fire, he is making a decision not to go through it, which is equivalent to suicide, and the hope of salvation remains in the room.

It is also necessary to note the presence of threats such as smoke, fire and other emergency elements that can change the physical state of the individual.

V. INFORMATIONAL INFLUENCE OF AGENTS

The authors consider several possible types of agents based on the information on the impact of the group of agents. In general, there are three main types of agents:

- Providing the usual influence;
- Providing good informational influence;
- Providing destructive informational influence.

Average impact is information influence on the behavior of the agent group, which can not significantly alter the average motion group. By increasing the amount of this type of agent, moving on similar or identical paths possible mass change trajectory group of agents. However, this requires a significant number of agents that have the effect of normal information. Within the framework of this example, agents are usual visitors.

Agents that have positive impact information are able to reduce the effects of an emergency. This effect is achieved by the high awareness of environmental agents. Thus, this type of agents is able to find another solution to avoid any damage caused by the implementation of an emergency. These types of agents in this example the "Lame Horse" can be attributed to the local employees who are aware of the presence of the other on the free exit. Consequently, they may leave the room in another way.

Also worth noting is the degree of influence on the group of agents in this category. Unlike ordinary influence, this category can significantly change the direction of movement as a small part of the group, as well as a large number of agents. This effect is achieved due to the presence of some distinctive features characterizing agents belonging to this category. The form of the employee places can serve as an example of such a distinguishing feature.

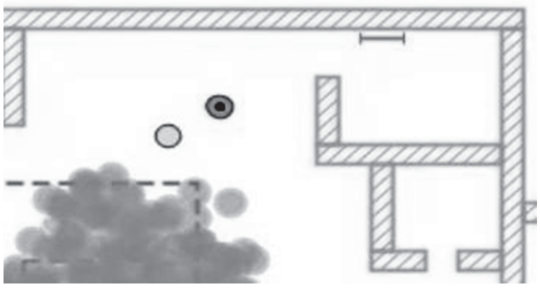

Fig. 9. Positive influence of a knowledgeable agent to the conventional agent

Agents that have destructive impact information also can significantly modify the behavior of a group of agents, but the information that agents are watching their actions will be destructive. Under the destructive information be understood the information that has a negative effect on the properties of the agent, subjected to its influence. In the proposed model, a negative influence on the properties meant the deterioration of human vital signs. The destructive effects of both agents may be provided intentionally and randomly. Under random refers to those actions which are carried out to perform individual tasks the agent, and the other members of the group interpreted the wrong actions of the agent. Figure 10 shows an example of a possible destructive informational influence, when an agent moves to a closed room during a fire and it is followed by neutral agents.

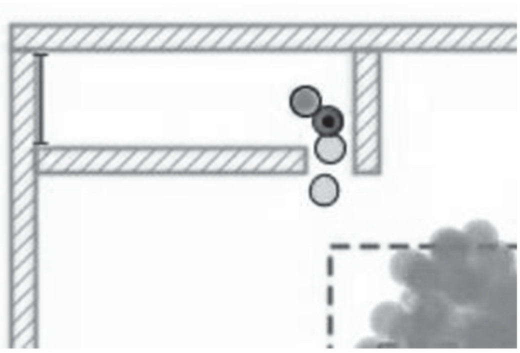

Fig. 10. Possible destructive informational influence

The developed simulator uses the following algorithm behavior of neutral agents. The agent starts a movement for the agent of the second or third category, which saw the first. Thus, other agents of these categories, appearing in its scope can not change the trajectory of a given agent first seen. Agents of the second category are beginning to move to the emergency exit at the time of start of the event. At the same time, this category is able to determine which of the outputs of the movement more preferably (less distance, less people, etc.) and to move toward him. From the viewpoint of changing the physical state of all the agents are characterized by the rules described above.

VI. Experimental verification of the developed methods

To check the adequacy of the model experiment on the dynamics modeling and outcome of emergency, which occurred December 5, 2009 in the club "Lame Horse" located in Perm, Russia [18]. The adequacy of the model is confirmed by conducting experiments based on real situations.

Damaging factors is presented entities "Smoke" and "Fire". The spread of smoke and fire is based on GOST R 54081-2010 [17], which define the standards for the simulation of fire in a confined space.

Fire (saturated big grey circles on Fig.11) can spread to the unallocated space of the room, as well as combustible materials, which are defined in the description of the room configuration. Additional features model that ensures compliance with the conditions of the experimental conditions, the actual situation is the possibility of taking into account the velocity of propagation of fire on various materials. For this we introduce the corresponding coefficient.

The smoke (big grey circles on Fig.11) like fire, can take a free point in space and has a virulence factor determined filling the room features and characteristics of the material exposed to fire.

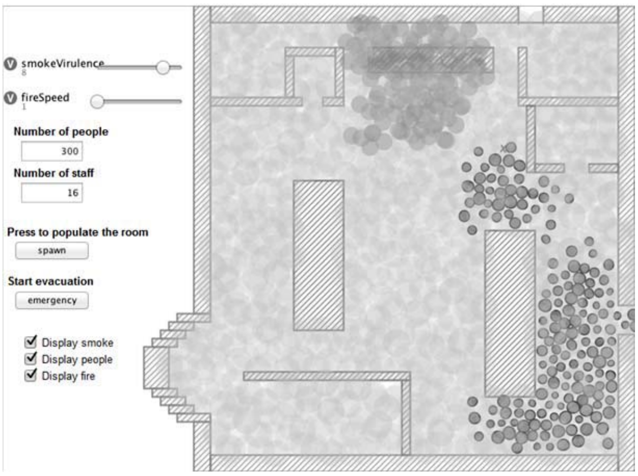

Fig. 11. Demonstration of the smoke and fire spread

Agents such as "staff" represent individuals who initially knew about the fire exit from the room (on Fig. 12 staff agents are marked as circles with a dot in the center). Staff affected by the decision on the choice of output for conventional agents as follows: if the agents can see that the staff is running not in the main exit, they would likely to trust him and follow him, trying to see any way out. The number of staff is set on initialization of the experiment.

Features of the simulator allow representing statistical graphs in real time. The diagram (Fig. 13) shows the dependence of the number of agents in various states over time (over the number of simulation steps). Number of dead agents is indicated with beige, the number of “still inside” agents is indicated with grey, and the number of unharmed agents is denoted with black.

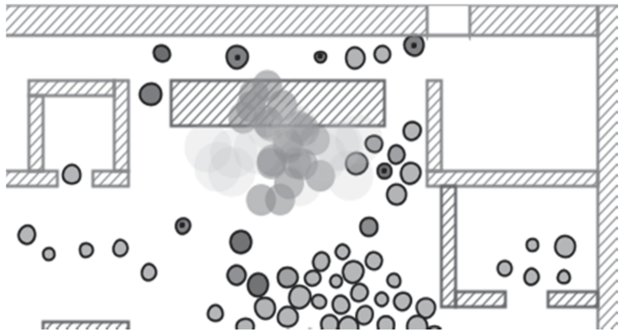

Fig. 12. Demonstration of the agents following by «staff-type» agents

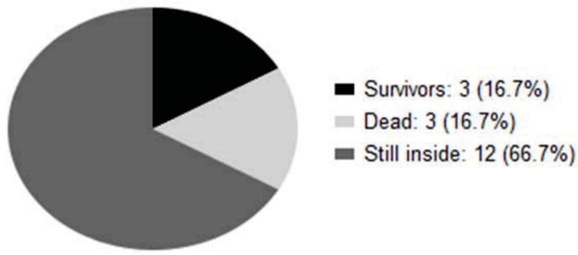

Fig. 13. Phase diagram of the agents’ states during the simulation

The second graph (Fig. 14) shows the extent of the resulting smoke and fire damage over time. The graph is also showing the extent of the damage done by effects of stampede. From the data of the graph revealed that the damage resulting from the fire people is disproportionately less than the damage caused to the smoke.

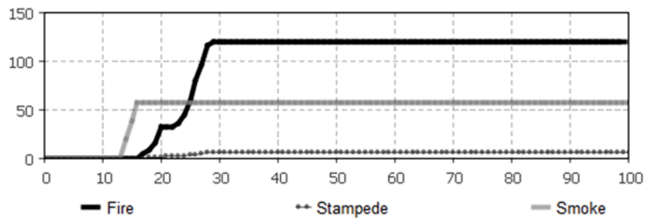

Fig. 14. Graph of the damage taken by agents during the simulation

VII. Results and conclusions

The model results after a large number of experiments have shown results that are comparable with the real. In a real situation of the 300 visitors of the club 111 people died on the spot and another 45 died in hospitals, with a serious burns and toxic smoke poisoning. In the developed model the number of dead and injured survivors, who received critical damage, is in the range of ± 10% of the actual number. Such a variation in the number of deceased and injured survivors is caused by the peculiarities of each unique situation (probabilistic nature of the model), as the exit from the room rate is also driven by the size of a particular individual and the size of individuals, standing in front of them.

Based on these results it can be concluded that the developed tool can be used to analyze real emergency, to investigate the incident with a large number of victims, as well as to analyze the strengths and weaknesses of the premises in terms of fire safety.

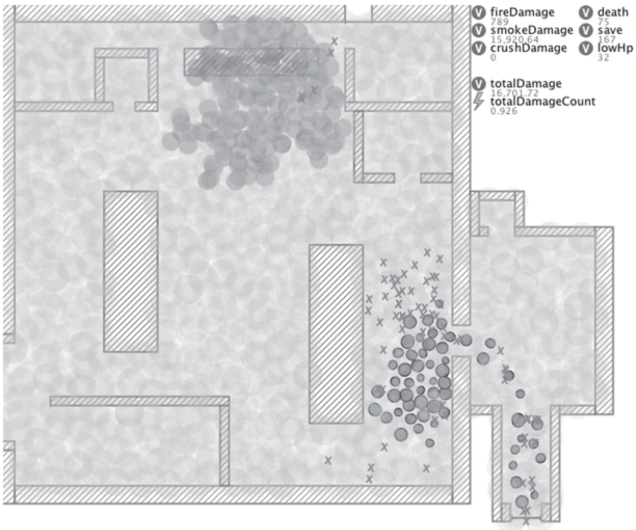

Fig. 15. Final state of the evacuation\

Further development of the model can be associated with an increase in the number of the types of agents to adapt the models of information interaction of the elements of well-organized systems in poorly organized systems. Further research will focus on the improvement of the model followed by bringing structure to the heterogeneous. The model of various infrastructure facilities will be built (plaques, indicators etc.): thus will estimate the influence of such information signs on the possibility of saving humans. It will put the question of how effective is this kind of signs in the problem of the evacuation of people in emergencies.

REFERENCES

[1] List of the dead in Lame Horse club, Web: http://permloshad.narod.ru

[2] S. Kutsenko, "Overview of software systems for the calculation of time to evacuate people from buildings and the construction", 2013

[3] T. Korhonen, S. Hostikka, O. Keski-Rahkonen, "A proposal for the goals and new techniques of modelling pedestrian evacuation in fires", 2005

[4] E.N. Mirkin, A.G. Sergeev, "Modern automated fire extinguishing systems", 2015

[5] Y.P. Klyuchko, Kh.Sh. Gasanov, N.V. Krynsky, "Analysis of the application of thermal imagers for fire extinguishing", 2014

[6] V.V. Shaptala, Y. Vetrov, E.G. Kovaleva, "Simulation of operational management in emergencies", 2016

[7] N.N. Severin, Y. Vetrov, A.I. Kudinov, "Modeling of emergencies universities", 2015

[8] A.S. Akopov, L.A. Beklaryan, "The agent-based model of crowd behavior in emergency situations", 2015

[9] A.S. Akopov, L.A. Beklaryan, "Modeling the behavior of the crowd on the basis of the intellectual dynamics of interacting agents", 2015

[10] A.S. Akopov, L.A. Beklaryan, "The psychology of human behavior in extreme conditions", 2015

[11] J. Izquierdo, I. Montalvo, R. Pérez, V.S. Fuertes, "Forecasting pedestrian evacuation times by using swarm intelligence", 2009

[12] C. Burstedde, K. Klauck, A. Schadschneider, "Simulation of pedestrian dynamics using a two-dimensional cellular automaton", 2001

[13] D. Helbing, P. Molnár, "Social force model for pedestrian dynamics", 1995

[14] D. Helbing, D. Brockmann, T. Chadefaux, "Saving Human Lives: What Complexity Science and Information Systems can Contribute", 2014

[15] A.M. Aptukov, D.A. Bratsun, "Modeling group dynamics of the crowd, the panic in the confined space", 2009