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SIMULATION OF HUMAN CROWD BEHAVIOR IN EXTREME SITUATIONS

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Abstract: In this research work is presented the approach to modeling of the crowd behavior (ensemble) in extreme situations based on methods of an agent simulation. The main feature of the approach is the taking into account the dynamics of each agent in researched ensemble.

It is important to note, the effect of the full or partial losing of the orientation of an agent in extreme situations such as attacks, explosions, fires with a smoke screening, etc. was taken into account in the created model.

As a result of it, the "crowd effect" is being appeared. It is expressed by the "gravitating" or "antigravitating" of close located agents with the some probability depended on psychotype of an agent.

In the work is researched the effects related with the "turbulence of the crowd". There is simulated the activity of intellectual agent-rescuers. In the work is supposed own simulator of the "crowd effect" developed with using of Adobe Flash CS technology and the object-oriented programming language Action Script 3.0.

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1. Introduction

Now is observed the increasing of the interest in the agent-based simulation as the tool which allows to research possible states of the system as a result of interactions between agents.

There are many spheres of possible application of agent-based simulation methods, for example, modeling of transport streams, sociology, epidemiology, biology, etc. At the same time, it is very interesting to research the human behavior with the help of agent-based simulation methods, especially in unusual (no typical) conditions of the environment.

It should be noted that there are interesting papers in the field of socio-systems modeling, in particular, the following ([1]-[9]).

For instance, in the work [1] is researched the human behavior in the crowd, in particular, in a museum and the main idea focused on the effects of the separation of the crowd by persistence groups.

In the work [2] is researched the behavior of pedestrians with the using of agents modeling methods. The each agent tries to avoid possible collisions with other agents and it influences on the agents dynamics.

In the work [3] is researched the crowd behavior on the base of video data. The target of the researching is the seeking of methods which can increase the safety under moving of people in the crowd in extreme situations.

The works ([4]-[5]) are devoted to developing of the optimal model of an evacuation of people. The results of the investigation demonstrate the importance of a coordination of people activities under the evacuation.

Nevertheless, the problem of the researching of optimal methods of the control of the crowd dynamics in extreme situation is very topical despite existence of some works in the field of the simulation of the human crowd behavior.

Therefore, the developing of the special visual system based on the using of the agent simulation methods is timely. In particular, such system allows estimating the consequences of extreme situations for conditions of agents. Thus, the important feature of such system is the possibility of the forming the different scenarios of the evacuation of people with taking into account of differences in the behavior of agents in appropriate adverse events.

The aim of the work is to research the human crowd behavior in difficult conditions such as super-high density of agents ("crush"), the appearing of wave effect ("the turbulence of the crowd"), different extreme situations, etc. and to study the possibilities for the minimization of consequences of such situations for agents including using of passive and active (intellectual) tools of defenses.

It should be noted that there is used some methods of the adaptive control in the developed system. In particular, the behavior of intellectual agent-rescuers is based on a special procedure of the self-training. Such procedure can be also referred to the methods of the evolutionary computations. In the work [9] were described some approaches for the adaptive control of complex organization structures and demonstrated the using of evolutionary computations (such as genetic algorithms) for the optimal control.

2. Simulation of Human Crowd Behavior

It should be mentioned that the crowd is unstructured congestion of agents which do not have clear understanding of the generality of aims. Nevertheless, agents are linked between each other by the similarity of an emotional state and a common object of attention.

The circular reaction (increasing mutual directed emotional infection) and also rumors are main mechanisms of the crowd forming and developing of its specifics.

As a result of it there is being appeared well known the *“effect of the gravitating” of an agent to a group of other agents.*

Because of increasing of the density of agents in the crowd there is being appeared of a panic at some time. As a result of it there is being appeared the *“effect of the turbulence of the crowd”* when agents begin to panic and push to increase their personal areas [8].

At the same time, *strong waves of the compression* are being appeared in the crowd which can throw out the agents on some distances. After that, agents are being placed in the critical situation (for example, they can be thrown out on dangerous areas).

According to many observations [8], the behavior of people in extreme situations is described by the following:

- partial or full losing of the orientation in the space and time;
- high level of the “turbulence of the crowd”, that is consequence of the chaotic moving of agents in all directions under condition of high density of agents in the areas of appearing of extreme situations.
- targeting to the nearest exit of a placement if the visibility of the exit was not limited;
- targeting of moving in the direction of the nearest group of agents (“the effect of gravitating of the crowd”);

- targeting of moving in the direction of the nearest agent-rescuers if they is located in bounds of the visibility.

The main problem of the human crowd behavior in extreme situations is an appearing of a panic, losing of an orientation in a space and time and as a result of that, the difficulty of a timely evacuation.

Therefore, the task of the simulation of the human crowd behavior in extreme situations (such as attacks, explosions, fires with a smoke screening, etc.) is very timely.

2.1. Simulation of Human Crowd Behavior without Special Extreme Situations

The main problem is the supporting of free access to exits for agents and prevention of the crush and the "turbulence effect" under condition of the absence of special extreme situations (such as attacks, explosions, etc.).

Let's give a formal description of the model. The main assumption in the model is the considering only one type of a space of agents locations in the form of a one-floor building (simple placement) which has a rectangular form with two exits.

Initially each agent has limited own personal area. However, as a result of gradual increasing of the density of the crowd around an agent, its own personal area is firstly being compressed to the critical level (because of a panic), after that it is sharply being decompressed. As a result of it there is being appeared the "wave effect" expressed by the increasing of the pushing out the agents from the center of the crowd to sides.

At the same time, some agents can be destroyed as a result of the "turbulence of the crowd" and also because of the "crush", which is appeared when the density of the crowd significantly exceeds the critical level.

Further the following signs will be used:

- t – fast simulation time;
- $i = 1, 2, ..., I$ – index of agents (without agent-rescuers);
- $k = 1, 2, ..., K$ – index of agent-rescuers;
- $\{x_i(t), y_i(t)\}$, $\{x_k(t), y_k(t)\}$– coordinates of locations of usual agents and agent-rescuers at the time t, respectively;
- s_i, s_k – speeds of the moving of agents – *exogenous*;

- R_ξ – radius of ξ- column-obstacle ($\xi = 1, 2, ..., \Psi$)– *exogenous*;
- $r_i(t)$ – radius of "own personal area" of i-agent;
- $\tilde{r}$– radius of "own personal area" (that is the radius of action) of the agent-rescuer, which is a zone of the visibility of the agent regarding other agents - *exogenous*;
- $\{a_1, b_1\}$, $\{a_1, d_1\}$ – coordinates of tops of the first exit - *exogenous*;
- $\{a_2, b_2\}$, $\{a_2, d_2\}$ – coordinates of tops of the second exit – - *exogenous*;
    - $p(t)$– some probability formed by a random number generator in the range from 0 to 1 at the time t.

$dist_{i\xi}(t)$– distance between i-agent ($i = 1, 2, ..., I$) and ξ-column-obstacle ($\xi = 1, 2, ..., \Psi$) with coordinates $\{x_\xi, y_\xi\}$ located on the trajectory of i- agent at the time t (see fig. 1):

$$dist_{i\xi}(t) = \sqrt{(x_i(t) - x_\xi)^2 + (y_i(t) - y_\xi)^2}, \quad i = 1, 2, ..., I, \quad \xi = 1, 2, ..., \Psi. \quad (1)$$

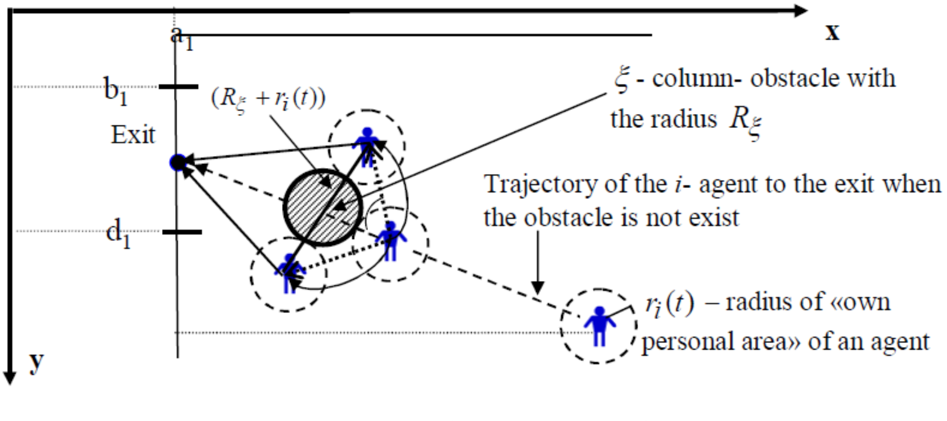


Figure 1: Possible trajectories of the moving of an agent to the exit under condition of having obstacles and the absence of special extreme situations

It should be noted that initial coordinates of agents is defined by the randomization. Besides, most of them are located inside the building and included to the potential zone of the attack.

Each i-agent has the own personal area with the radius $r_i(t) = f(\rho_i(t))$, where $\rho_i(t)$ - the density of people in the crowd regarding i-agent at the time t.

$$\rho_i(t) = \sum_{j=1}^{I}\left[1\left|\sqrt{(x_i(t)-x_j(t))^2+(y_i(t)-y_j(t))^2}\leq \bar{R} \text{ and } i\neq j \text{ and } st_j(t)\neq 1\right.\right] \tag{2}$$

$$i = 1,2,...,I, \quad j = 1,2,...,i-1,i+1,...I.$$

Here:

t – fast simulation time;

$st_i(t) = \{0,1,2\}$ – status of an agent (0 – live (normal), 1- destroyed, 2 –injured);

$\bar{R}$– fixed radius for the density estimation.

The distance between i-agent j-agent at the time t:

$$dist_{ij}(t) = \sqrt{(x_i(t)-x_j(t))^2+(y_i(t)-y_j(t))^2} \quad i,j = 1,2,...,I. \tag{3}$$

The own personal area of an agent at the time t:

$$r_i(t) = \begin{cases} r_1, \text{ if } \rho_i(t) \leq \bar{\rho}_1, \\ r_2, \text{ if } \bar{\rho}_1 < \rho_i(t) \leq \bar{\rho}_2, \\ r_3, \text{ if } \bar{\rho}_2 < \rho_i(t) \leq \bar{\rho}_3, \\ r_4, \text{ if } \bar{\rho}_3 < \rho_i(t) \leq \bar{\rho}_4; \end{cases} \tag{4}$$

Here:

$$r_1, r_2, r_3, r_4, \quad r_3 \ll r_2 \ll r_1 \ll r_4 \text{ – fixed radius;}$$

$\bar{\rho}_1, \bar{\rho}_2, \bar{\rho}_3, \quad \bar{\rho}_1 \ll \bar{\rho}_2 \ll \bar{\rho}_3$ – fixed boundary values of the crowd density.

It should be noted that if $\rho_i(t) > \bar{\rho}_4$ then $i-$agent is destroyed as a result of a “crush”. In this case the status of the agent $st_i(t) = 1$ in the model. Also, $i-$agent $(i = 1,2,...,I)$ is destroyed as a result of the “turbulence effect” if the agent is thrown out on walls (bounds). That is the case when expected coordinates of the agent coincide with the bounds of the placement having coordinates of walls $\{\underline{x}, \bar{x}, \underline{y}, \bar{y}\}$ or overstep them (that is possible only if “boundary” agents will be thrown out the walls, if: $x_i(t) \leq \underline{x}$ or $x_i(t) \geq \bar{x}$ or $y_i(t) \leq \underline{y}$ or $y_i(t) \geq \bar{y}$.

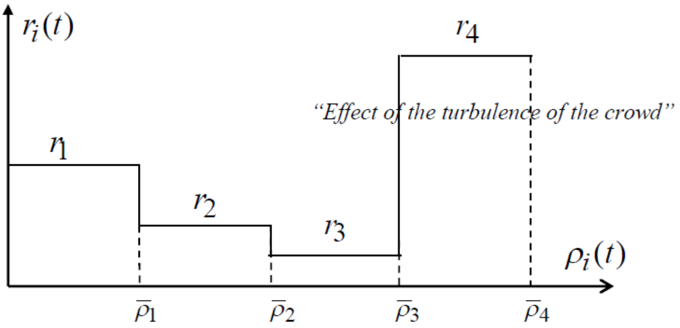


Figure 2: Dependency of own personal area of an agent on the crowd density $\rho_i(t)$

In the condition of the absence of extreme situations, dynamics of i-agent $(i = 1, 2, ..., I)$ is described by the following system of differential equations at the time t:

$$\frac{dx_i(t)}{dt} = \begin{cases} s_i \cos(\alpha_i), \text{if the condition I is true,} \\ s_i \cos(\alpha_i \pm \bar{\beta}_{i\xi}) + \frac{?_2}{dist_{i\xi}} \cos(\gamma_{i\xi}), \text{if the condition II is true,} \\ \frac{c_1}{dist_{ij}} \cos(\beta_{ij} \pm \bar{\beta}_{i\xi}) + \frac{?_2}{dist_{i\xi}} \cos(\gamma_{i\xi}), \text{ if the condition III is true,} \\ \frac{c_1}{dist_{ij}} \cos(\beta_{ij}), \text{if the condition IV is true,} \\ 0, \text{if the condition V is true,} \end{cases} \quad (5)$$

$$\frac{dy_i(t)}{dt} = \begin{cases} s_i \sin(\alpha_i), \text{if the condition I is true,} \\ s_i \sin(\alpha_i \pm \bar{\beta}_{i\xi}) + \frac{?_2}{dist_{i\xi}} \sin(\gamma_{i\xi}), \text{if the condition II is true,} \\ \frac{c_1}{dist_{ij}} \sin(\beta_{ij} \pm \bar{\beta}_{i\xi}) + \frac{?_2}{dist_{i\xi}} \sin(\gamma_{i\xi}), \text{ if the condition III is true,} \\ \frac{c_1}{dist_{ij}} \sin(\beta_{ij}), \text{if the condition IV is true,} \\ 0, \text{if the condition V is true;} \end{cases} \quad (6)$$

where:

I. $dist_{i\xi}(t) > (R_\xi + r_i(t))$ for all $\xi = 1, 2, ..., \psi$ and $dist_{ij}(t) > (r_i(t) + r_j(t))$ for all $j = 1, 2, ..., i-1, i+1, ..., I$ and $st_i(t) \neq 1$,

II. $dist_{i\xi}(t) \leq (R_\xi + r_i(t))$ for the nearest $\xi = 1, 2, ..., \Psi$ and $dist_{ij}(t) > (r_i(t) + r_j(t))$ for all $j = 1, 2, ..., i-1, i+1, ..., I$ and $st_i(t) \neq 1$,

III. $dist_{ij}(t) \le (r_i(t) + r_j(t))$ for the nearest $j = 1, 2, ..., i-1, i+1, ..., I$ and $dist_{i\xi}(t) \le (R_\xi + r_i(t))$ for the nearest $\xi = 1, 2, ..., \Psi$ and $st_i(t) \ne 1$ and $st_j(t) \ne 1$,

IV. $dist_{ij}(t) \le (r_i(t) + r_j(t))$ for the nearest $j = 1, 2, ..., i-1, i+1, ..., I$ and $dist_{i\xi}(t) > (R_\xi + r_i(t))$ for all $\xi = 1, 2, ..., \Psi$ and $st_i(t) \ne 1$ and $st_j(t) \ne 1$,

V. $dist_{i\xi}(t) < (R_\xi + r_i(t))$ for all $\xi = 1, 2, ..., \Psi$ or $dist_{ij}(t) < (r_i(t) + r_j(t))$ for all $j = 1, 2, ..., i-1, i+1, ..., I$ or $st_i(t) = 0$.

The angle of the direction of the moving of i-agent to the exit

$$\alpha_i = \begin{cases} \arctan\left(\frac{(d_1+b_1)/2 - y_i(t)}{a_1 - x_i(t)}\right), \ if p(1) \ge 0.5, \\ \arctan\left(\frac{(d_2+b_2)/2 - y_i(t)}{a_2 - x_i(t)}\right), if p(1) < 0.5, \end{cases} . \tag{7}$$

The angle of the bypassing of i-agent around ξ- column-obstacle

$$\bar{\beta}_{i\xi} = \pi/4 + \left|\arctan\left(\frac{y_\xi(t) + (R_\xi + r_i(t))\sin(\pi/4) - y_i(t)}{x_\xi(t) + (R_\xi + r_i(t))\cos(\pi/4) - x_i(t)}\right)\right|. \tag{8}$$

The angle of the rebound of i-agent from ξ- column-obstacle

$$\gamma_{i\xi} = \pi + \arctan\left(\frac{y_\xi(t) - y_i(t)}{x_\xi(t) - x_i(t)}\right). \tag{9}$$

The angle of the rebound of i-agent from the nearest j-agent

$$\beta_{ij} = \pi + \arctan\left(\frac{y_j(t) - y_i(t)}{x_j(t) - x_i(t)}\right),$$

$$i = 1, 2, ..., I, \quad j = 1, 2, ..., i-1, i+1, ..., I, \quad \xi = 1, 2, ..., \Psi \quad . \tag{10}$$

2.2. Simulation of Human Crowd Behavior under Appearing of Extreme Situations

Under appearing of extreme situations all agents are separated by three groups depending on locating in the zone of the attack.

So:

if $\sqrt{(x_i - g)^2 + (y_i - f)^2} \le z_1$, then the agent is destroyed ($st_i = 1$),

if $\sqrt{z_1 < (x_i - g)^2 + (y_i - f)^2} \le z_2$, then the agent is injured ($st_i = 2$),

if $\sqrt{(x_i - g)^2 + (y_i - f)^2} > z_2$, then the agent is normal ($st_i = 0$).

Here, $\{g, f\}$ – known coordinates of the attack ("center of exposition"); z_1 – radius of full destroying; z_2 – radius of the attack when agents become injured.

The difference between the injured agents and normal agents, in the frame of such model, is that the first group has lesser speed of the moving.

After appearing the extreme situations, agent-rescuers having own "gravitating radiuses" R_k can be directed at the destroying zone for the evacuation of disoriented agents. Here, $R_k$is the radius of the zone of the visibility of agent-rescuers for other agents in a smoked placement.

$dist_{ik}(t)$ is the distance between i-agent and k-agent-rescuer at the moment t:

$$dist_{ik}(t) = \sqrt{(x_i(t) - \tilde{x}_k(t))^2 + (y_i(t) - \tilde{y}_k(t))^2}, \tag{11}$$
$$i = 1, 2, ..., I, \quad k = 1, 2, ..., K.$$

If any agent-rescuer will reach the zone of the visibility of i-agent , that is $dist_{ik} \leq R_k$, then i-agent will move in the direction of k-agent-rescuer having coordinates $\{\tilde{x}_k, \tilde{y}_k\}$. At the same time, the last one will move in the direction of the nearest exit. So, the agent-rescuer keeps its orientation in a space by a choosing of the optimal way.

If any agent-rescuer will not reach the zone of the visibility of i-agent, that is $dist_{ik} > R_k$, then i-agent will move in the direction of the nearest $j-$agent $(j = 1, 2, ..., i-1, i+1, ..., I)$ having coordinates $\{x_j, y_j\}$ or in the opposite direction (it depends on a psychotype of the agent).

Thus the "effect of gravitating of the crowd" will be realized. Let's sign $\tilde{p}_i(t)$- the probability of the influence of the "gravitating effect" on i-agent.

As a whole the dynamics of injured and normal agents $(i = 1, 2, ..., I)$ can be described by the following system of differential equations taking into account the more chaotic moving of agents under condition of extreme situations:

$$\frac{dx_i(t)}{dt} =$$
$$\begin{cases} s_i \cos(\alpha_i), \text{ if the condition I is true,} \\ s_i \cos(\omega_i), \text{ if the condition II is true,} \\ s_i \cos(\alpha_i \pm \bar{\beta}_{i\xi}) + \frac{c_2}{dist_{i\xi}} \cos(\gamma_{i\xi}), \text{ if the condition III is true,} \\ \frac{c_1}{dist_{ij}} \cos(\beta_{ij} \pm \bar{\beta}_{i\xi}) + \frac{c_2}{dist_{i\xi}} \cos(\gamma_{i\xi}), \text{ if the condition IV is true,} \\ \frac{c_1}{dist_{ij}} \cos(\beta_{ij}), \text{ if the condition V is true,} \\ 0, \text{ if the condition VI is true,} \end{cases} \tag{12}$$

$$\frac{dy_i(t)}{dt} =$$

$$\begin{cases} s_i \sin(\alpha_i), \text{ if the condition I is true,} \\ s_i \sin(\alpha_i), \text{ if the condition II is true,} \\ s_i \sin(\alpha_i \pm \bar{\beta}_{i\xi}) + \frac{c_2}{dist_{i\xi}} \sin(\gamma_{i\xi}), \text{ if the condition III is true,} \\ \frac{c_1}{dist_{ij}} \sin(\beta_{ij} \pm \bar{\beta}_{i\xi}) + \frac{c_2}{dist_{i\xi}} \sin(\gamma_{i\xi}), \text{ if the condition IV is true,} \\ \frac{c_1}{dist_{ij}} \sin(\beta_{ij}), \text{ if the condition V is true,} \\ 0, \text{ if the condition VI is true,} \end{cases} \tag{13}$$

where

I. $dist_{i\xi}(t) > (R_\xi + r_i(t))$ for all $\xi = 1, 2, ..., \psi$ and $dist_{ij}(t) > (r_i(t) + r_j(t))$ for all $j = 1, 2, ..., i-1, i+1, ..., I$ and $st_i(t) \neq 1$ and $\tilde{p}_i(t) \leq 0.1$.

II. $dist_{i\xi}(t) > (R_\xi + r_i(t))$ for all $\xi = 1, 2, ..., \psi$ and $dist_{ij}(t) > (r_i(t) + r_j(t))$ for all $j = 1, 2, ..., i-1, i+1, ..., I$ and $st_i(t) \neq 1$ and $\tilde{p}_i(t) > 0.1$.

III. $dist_{i\xi}(t) \leq (R_\xi + r_i(t))$ for the nearest $\xi = 1, 2, ..., \Psi$ and $dist_{ij}(t) > (r_i(t) + r_j(t))$ for all $j = 1, 2, ..., i-1, i+1, ..., I$ and $st_i(t) \neq 1$.

IV. $dist_{ij}(t) \leq (r_i(t) + r_j(t))$ for the nearest $j = 1, 2, ..., i-1, i+1, ..., I$ and $dist_{i\xi}(t) \leq (R_\xi + r_i(t))$ for the nearest $\xi = 1, 2, ..., \Psi$ and $st_i(t) \neq 1$ and $st_j(t) \neq 1$.

V. $dist_{ij}(t) \leq (r_i(t) + r_j(t))$ for the nearest $j = 1, 2, ..., i-1, i+1, ..., I$ and $dist_{i\xi}(t) > (R_\xi + r_i(t))$ for all $\xi = 1, 2, ..., \Psi$ and $st_i(t) \neq 1$ and $st_j(t) \neq 1$.

VI. $dist_{i\xi}(t) < (R_\xi + r_i(t))$ for all $\xi = 1, 2, ..., \Psi$ or $dist_{ij}(t) < (r_i(t) + r_j(t))$ for all $j = 1, 2, ..., i-1, i+1, ..., I$ or $st_i(t) = 0$.

The angle of the direction of moving of i-agent to the exit

$$\alpha_i = \begin{cases} \arctan\left(\frac{(d_1+b_1)/2 - y_i(t)}{a_1 - x_i(t)}\right), & \text{if} \quad p(1) \geq 0.5, \\ \arctan\left(\frac{(d_2+b_2)/2 - y_i(t)}{a_2 - x_i(t)}\right), & \text{if} \quad p(1) < 0.5. \end{cases} \tag{14}$$

The angle of the bypassing of i-agent around ξ- column-obstacle

$$\bar{\beta}_{i\xi} = \pi/4 + \left| \arctan\left(\frac{y_\xi(t) + (R_\xi + r_i(t))\sin(\pi/4) - y_i(t)}{x_\xi(t) + (R_\xi + r_i(t))\cos(\pi/4) - x_i(t)}\right) \right|. \tag{15}$$

The angle of the rebound of i-agent from ξ- column-obstacle

$$\gamma_{i\xi} = \pi + \arctan\left(\frac{y_\xi(t) - y_i(t)}{x_\xi(t) - x_i(t)}\right). \tag{16}$$

The angle of the rebound of i-agent from the nearest j-agent

$$\beta_{ij} = \pi + \arctan\left(\frac{y_j(t) - y_i(t)}{x_j(t) - x_i(t)}\right). \tag{17}$$

The angle of the direction of moving of i-agent to the nearest j-agent or to the nearest k-agent-rescuer

$$\omega_i = \begin{cases} \arctan\left(\frac{y_j(t)-y_i(t)}{x_j(t)-x_i(t)}\right), & \text{if the condition VII is true,} \\ \pi + \arctan\left(\frac{y_j(t)-y_i(t)}{x_j(t)-x_i(t)}\right), & \text{if the condition VIII is true,} \\ \arctan\left(\frac{\tilde{y}_k(t)-y_i(t)}{\tilde{x}_k(t)-x_i(t)}\right), & \text{if the condition IX is true;} \end{cases} \tag{18}$$

where:

VII. $\tilde{p}_i(t) > 0.1$ and $dist_{ik} > R_k$ for all $i = 1, 2, ..., I,\ j = 1, 2, ..., i-1, i+1, ...I,\ k = 1, 2, ..., K$,

VIII. $\tilde{p}_i(t) \leq 0.1$ and $dist_{ik} > R_k$ for all $i = 1, 2, ..., I,\ j = 1, 2, ..., i-1, i+1, ...I,\ k = 1, 2, ..., K$,

IX. $dist_{ik} \leq R_k$ for all $i = 1, 2, ..., I,\ k = 1, 2, ..., K$.

Here, ω_i – the angle which is defined by the moving of an agent in the direction of an agent-rescuer (under condition that it has reached the zone of the visibility) or in the direction of the nearest agent or in the opposite direction.

It should be noted that the time of the evacuation for agents is not usually limited under conditions of the absence of extreme situations.

In this case the using of passive tools of the security such as column-obstacles will be fully reasonable.

However the time of the evacuation for agents will be limited in extreme situations (for example, exploits). That is the critical factor for the system.

Therefore, the using of intellectual agent-rescuers having the opportunity to identify the fields of the high crowd density in a placement and move to them by shortest trajectories is needed. Such agent-rescuers can also move between columns, reach the far zones which are located “behind the obstacles”, etc.

So, intellectual agent-rescuers have the ability to identify the coordinates of the centers of the sectors of the high crowd density and range them by the value of the density and choose higher-priority of them (by decreasing) on the each rescue iteration.

So, intellectual agent-rescuers have the ability to identify the coordinates of the centers of the sectors of the high crowd density and sort them by decreasing

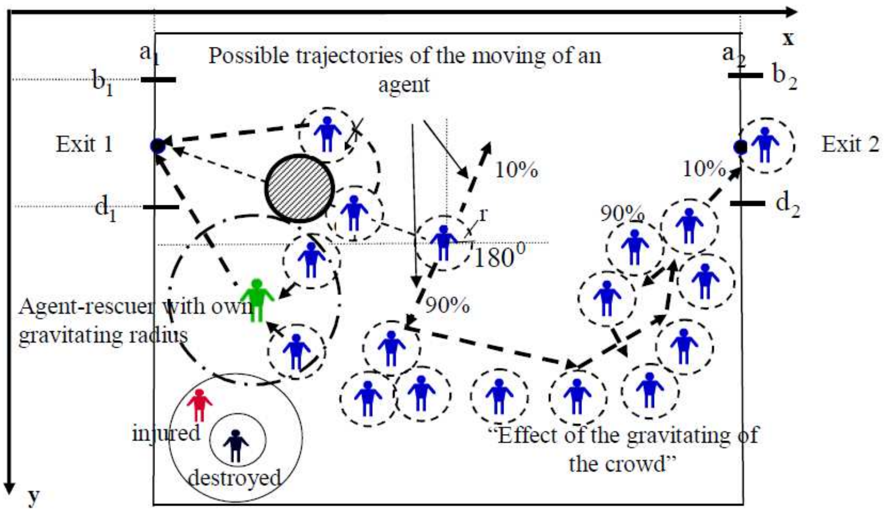


Figure 3: Possible trajectories of the moving of agents under extreme conditions

of the value of the crowd density and choose higher-priority sectors on the each rescue iteration.

At the same time, such agent-rescuers are being self-trained. In particular, they estimate the success of each rescue iteration (for example, by the ratio of the amount of evacuated agents to all agents at the destroyed zone) and use this information under choosing of high-priority sectors and adjusting own parameters (such as speed, time of stopping, etc.).

Also each agent-rescuer takes into account the trajectory of the moving of other agent-rescuers for the exception of problems related to the possible duplication of the "gravitational centers" and the disorientation of agents.

The common procedure of the activity of agent-rescuers is the following:

- **Step 1.** The closed placement divides into $n-$sectors having equal size $(n = 1, 2, ..., N)$. Next, the crowd density is being estimated and sorted in all $n-$sectors.

- **Step 2.** Each $k-$agent-rescuer $(k = 1, 2, ..., K)$ moves in one from $n-$sectors (in order of decreasing of the crowd density that is relative importance of sectors for agent-rescuers) if the trajectory of $k-$agent-rescuer is not crossing with trajectories of other agent-rescuers.

- **Step 3.** When $k-$agent-rescuer ($k = 1, 2, ..., K$) has reached the center of n-sector the ratio of the amount of normal and injured agents (having lesser speed) to all agents in the sector is being estimated. If the most part of agents in the sector is normal (no injured), then k-agent-rescuer having own standard speed immediately moves to the nearest exit of the placement and simultaneously draws the attention of evacuated agents ("gravitates" agents). If the most part of agents in the sector is injured, then k-agent-rescuer stops and waits in the center of the sector to give the possibility for injured agents to come nearer to k-agent-rescuer. After that k-agent-rescuer having own speed which equals the speed of injured agents moves to the nearest exit of the placement.
- **Step 4.** After going out of k-agent-rescuer from the placement, the amount of successfully evacuated agents from n-sector ($n = 1, 2, ..., N$) is being estimated and remembered. If the share of evacuated agents in the common amount of agents of $n-$sector has not decreased in the comparison with the previous rescue iteration, then the behavior (own speed, the algorithm of the selection of sectors, etc.) of k-agent-rescuer does not change. Otherwise, the behavior of of k-agent-rescuer will be corrected by the changing of some parameters (such as own speed, the time of waiting, the algorithm of the selection of sectors, etc.).
- **Step 5.** Return to the **Step 2** while all normal and injured agents are not evacuated or the time of the evacuation is not exceeded.

Here is shown the example of the trajectory of the moving of an agent-rescuer under the condition of the presence of some column-obstacles (Figure 4).

3. Results of the Simulation

It should be noted that the special simulator was developed with the help of objective-oriented program language Action Script 3.0 and Adobe Flash CS technology.

The simulator is intended for the modeling of the crowd behavior in extreme situations. At the same time, the possibility of the variation of different parameters of the system (such as the amount of agents, the amount and the localization of column-obstacles, radiuses of columns, the probability of the "gravitation" of agent to the crowd, the amount of agent-rescuers, sizes of exits, etc.) is supported in the system.

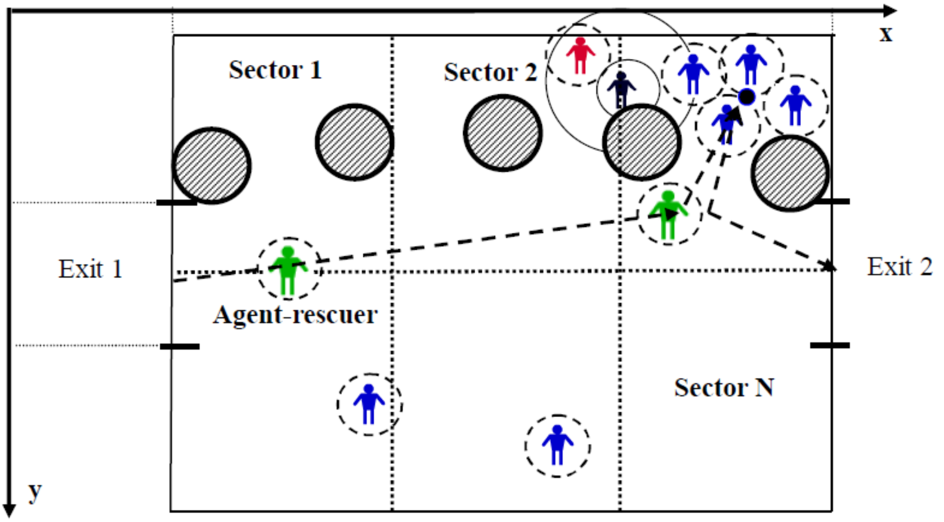


Figure 4: Possible trajectory of the moving of an agent-rescuer in extreme situations

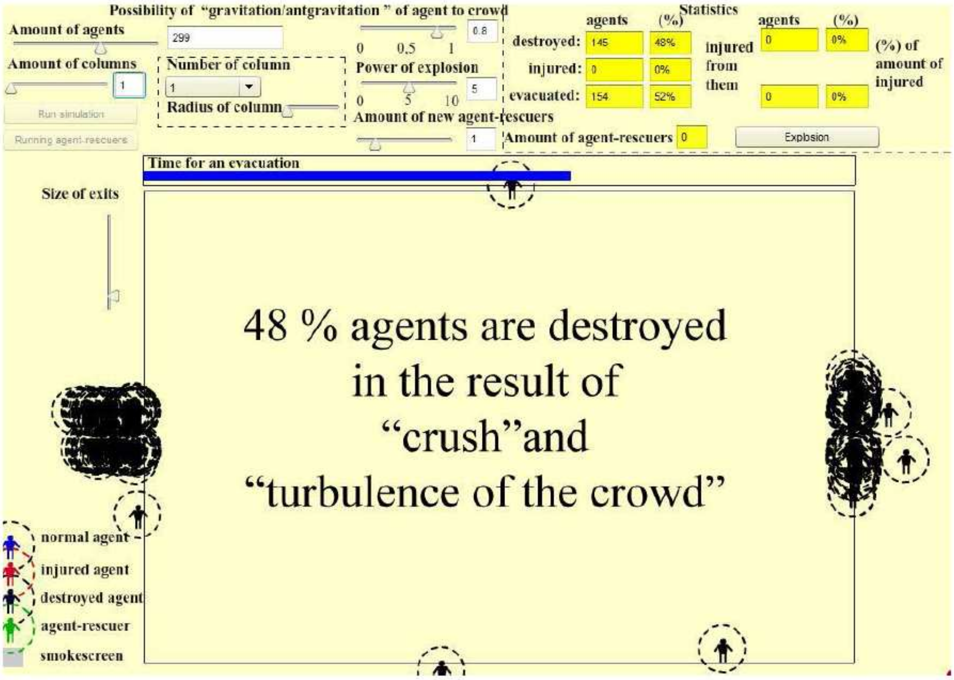
It should be noted that main statistics are calculated in the simulation process. They include such information as the amount of destroyed (normal, injured) agents (in percent), the amount of evacuated agents and other data.

The results of the crowd simulation without using of column-obstacles are represented on the Figure 5. Destroyed agents are marked by black.

The fragment of the effect of the “turbulence of the crowd” is illustrated on Figure 6.

In the result of researches which were completed with the help of the developed simulator, there was registered that the 43% – 50% agents are being destroyed even under the absence of special extreme situations, because of, the crowd density is superhigh. The effect is being appeared when the amount of agents simultaneously moving to exits of the closed placement is enough large (in particular, 300 and more agents on the area which is approximately equaled to 100 – 150 m2) and the throughput of exits is a relatively small (not more 2 agents per one passing through the exit), see Figures 5-6.

However, it is possible to use the column-obstacles which are allocated by the special way in the closed placement. In particular, they should be placed along walls with the next contraction near the exits. It allows minimizing the impact of effects of the “turbulence of the crowd” and the “crush” in the result of forced separating of human streams and to decrease the amount of destroyed



Possibility of "gravitation/antgravitation" of agent to crowd: 0.8

Amount of agents: 299

Amount of columns: 1

Number of column: 1

Power of explosion: 5

Amount of new agent-rescuers: 1

Statistics

destroyed: agents 145, (%) 48%

injured: agents 0, (%) 0%

evacuated: agents 154, (%) 52%

injured from them: agents 0, (%) 0%; (%) of amount of injured: agents 0, (%) 0%

Amount of agent-rescuers: 0

48 % agents are destroyed in the result of "crush"and "turbulence of the crowd"

Figure 5: Results of the crowd simulation without using of column-obstacles (destroyed agents are marked by a black)

agents approximately *in four times* (Figure 7).

4. Conclusion

- If the amount of agents in the closed placement simultaneously moving to exits is enough large (for example, 300 and more agents on the area which is approximately equaled to 100 – 150 m2) and the throughput of exits is a relatively small (not more 2 agents per one passing through the exit), then 43% – 50% agents are being destroyed even under the absence of special extreme situations in the result of the effects of the "crush" and the "turbulence of the crowd".
- Under the absence of extreme situations (when the time for an evacuation is not limited) the using of column-obstacles which are placed by the special way (along walls with the next contraction near the exits) in the closed placement allows minimizing the impact of the effects of the

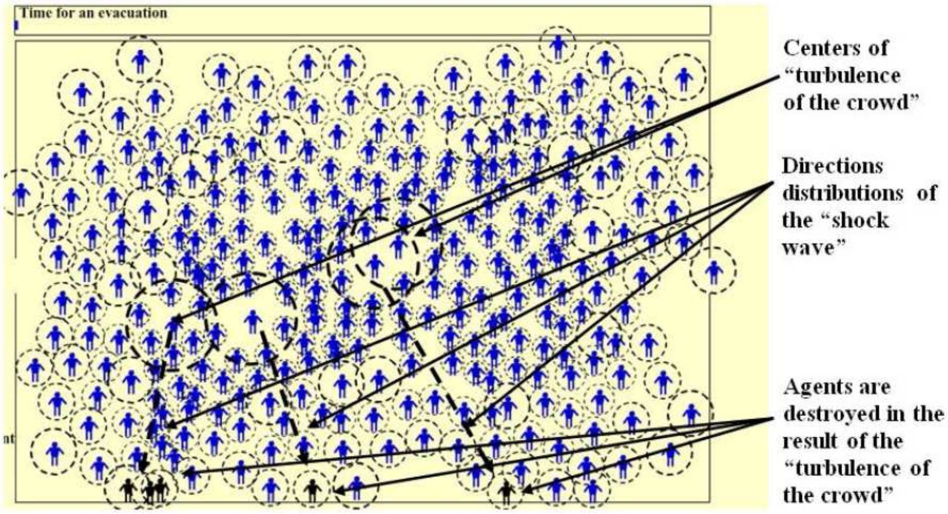
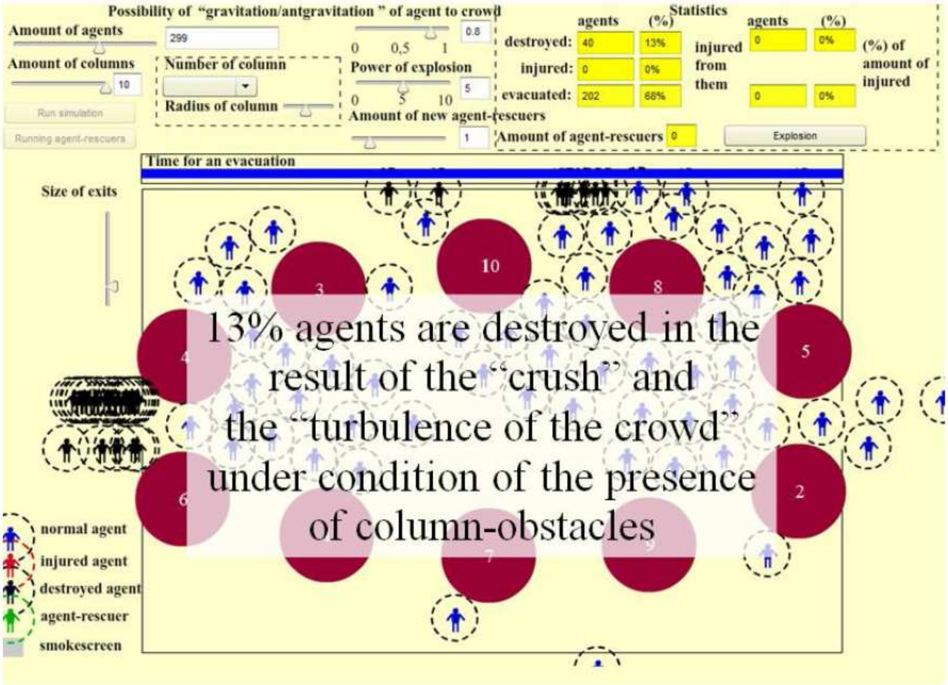


Figure 6: Illustration of the effect of the "turbulence of the crowd"

"crush" and the "turbulence of the crowd" and to decrease the amount of destroyed agents approximately in four times.

- Intellectual agent-rescuers should be used in extreme situations when the time for an evacuation is limited. Such agent-rescuers are being self-trained. In particular, they estimate the success of each rescue iteration (for example, by the ratio of the amount of evacuated agents to all agents at the destroyed zone) and use this information under choosing of high-priority sectors and adjusting own parameters (such as speed, time of stopping, etc.).

Finally, the agent-based modeling allows researching the crowd behavior to develop different scenarios of an evacuation in extreme situations. Besides, it allows studying the possibilities for the minimization of consequences of such situations for agents including using of passive and active (intellectual) tools of defenses.



Possibility of "gravitation/antgravitation " of agent to crowd: 0.8

Amount of agents: 299

Amount of columns: 10

Power of explosion: 5

Amount of new agent-rescuers: 1

Statistics

	agents	(%)	injured from them agents	(%)
destroyed:	40	13%	0	0%
injured:	0	0%		
evacuated:	202	68%	0	0%

(%) of amount of injured

Amount of agent-rescuers: 0

13% agents are destroyed in the result of the "crush" and the "turbulence of the crowd" under condition of the presence of column-obstacles

Figure 7: Results of the crowd simulation under the presence of column-obstacles separating the crowd

Acknowledgments

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