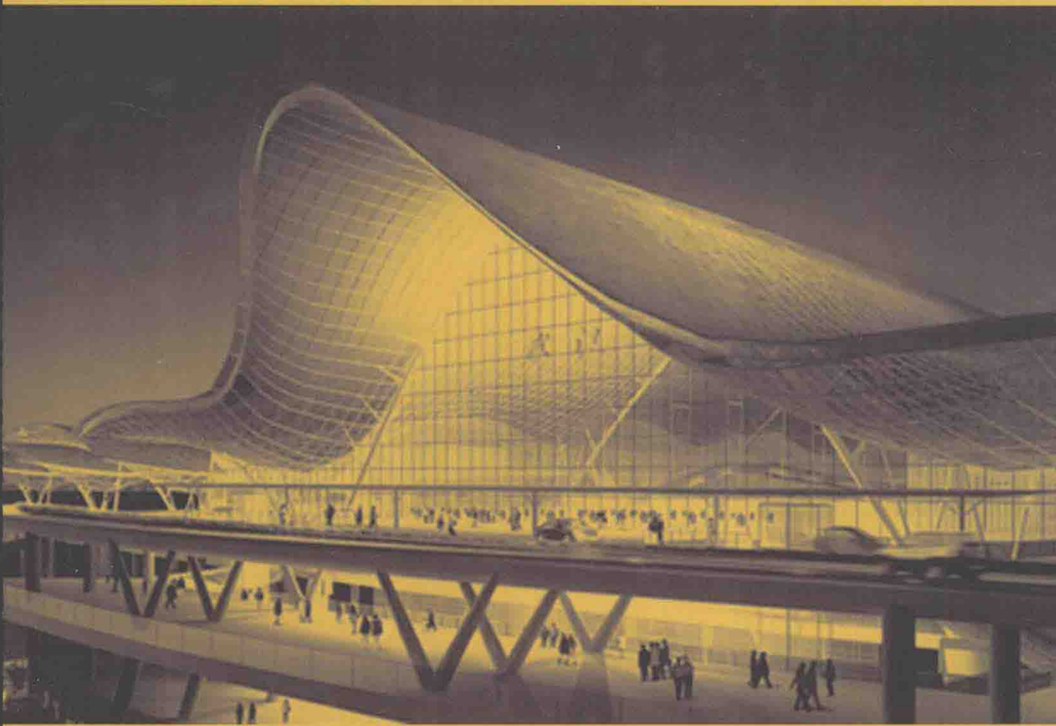

Civil Engineering and Urban Planning III

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Kouros Mohammadian
Konstadinos G. Goulias
Elif Cicek
Jieh-Jiuh Wang
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Civil Engineering and Urban Planning III

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A critical comparison between CPM and PERT with Monte Carlo simulation in project management and scheduling

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ABSTRACT: Project management and scheduling control are important issues in construction and management science. It has been proved that CPM and PERT are most suitable methods to solve the problem of project management and scheduling in practice. A very important problem has been neglected for a long time. The problem is how big the differences between CPM and PERT. The papers made a classic case of textbooks as an example and calculate parameters of all works. After 5000 times' simulation, the results showed that scheduling with PERT was not as optimistic as CPM, the scheduling risk is so big that we must find out the largest risk points. Through the sensitivity analysis, the work which has large influence could be found and should be treat as key control points. It is proved that PERT with Monte Carlo simulation was better to solve the problem of project management and scheduling. And, it is meaningful to compare CPM and PERT in project management and scheduling.

1 INTRODUCTION

Schedule, quality and cost are three key goals in construction project management. As everyone knows, quality and cost are largely determined by schedule of a project. So, how to define the schedule of a project has become a very important and popular issue in construction project management. Generally speaking, there have been some important methods to define the schedule of a project such as CPM, PERT, GERT, VERT, SCERT, ID and some improvements in themselves. For example, someone combined fuzzy with CPM in order to get better results on schedule control [1]. Some one used fuzzy to make sure the probability instead of traditional triangular distribution [2]. As the development and application of computer technology, large-scale calculation became a reality gradually. Simulation and Monte Carlo by computer became more and more popular on this issue [3]. Monte Carlo simulation was a very good way to solve uncertain problem especially the problem such as construction schedule management [4]. The theoretical basis of Monte Carlo was law of large numbers and the central-limit theorem, the practice method of it was repeated sampling and high-speed computation. GERT was a good method to solve the problem such as quite uncertain. For example, when you don't know the relationships and time parameters of all works, GERT will be a better choice for you [5~6]. VERT (Venture Evaluation and Review Techniques) was used on problem of defining the risk and venture. SCERT (Synergistic Contingency Evaluation and Response Techniques) was a method to solve the problem of evaluation on uncertain [7].

As everyone knows, construction procedures were defined in construction management, so, the relationships between procedures are defined. For example, if someone wants to produce reinforced concrete, the order of 'template support', 'assembling reinforcement', 'concreting' and 'maintenance reinforced concrete' were couldn't be changed, everybody must do it according to the order or it would be cause lots of problems. Another problem was the time parameters of all procedures. According to CPM, duration of every work was certain parameter, for example, duration of template support was 3 days etc. In practice, duration was impossible to know accurately before we do the work, so, 3 days was an estimation number. In reality, some factors such as construction efficiency and construction conditions would influence duration time a lot. The results of doing template support may be 3.12 days or 2.87 days. MCCAULLEY, JW introduce the two methods in 1969 [13]. Some researchers discuss how to define the parameters with CPM and PERT [8~9]. Lots of researcher used the two methods in many subjects [10]. But, few researchers pay close attention to how much difference between PERT and CPM, especially on the same project.

2 METHOD

2.1 *Get the AOA network*

According to practice and relationships between the procedures of project, draw the network by AOA rule correctly.

2.2 *Calculate the network by CPM*

Firstly, calculate parameters of all procedures. There are 6 time parameters need to be calculate in the method. They are ES (Earliest Start), EF (Earliest Finish), LS (Latest Start), LF (Latest Finish), TF (Total Float), FF (Free Float). According to the calculation rule of CPM. Secondly, define the critical path. According to CPM, critical path was combined by the procedures whose durations were the maximum. Thirdly, find out the key procedures and promote specific measures to ensure key procedures complete on schedule.

2.3 *Calculate the network by PERT*

Firstly, define the distribution and parameters of all procedures by Delphi Method. In practice, during time was impossible to know accurately before we do the work, so, 3 days was an estimation number. In reality, some factors such as construction efficiency and construction conditions would influence during time. The result of doing support template was 3.12 days or 2.87 days maybe. According to lots of construction practice, during time of works in construction fit 3 distributions as triangular distribution, normal distribution and beta PERT- distribution. Their functions and parameters were shown in Table 1. And then, define the parameters with Delphi Method. Secondly, find all path of the network. As the duration of all procedures was not defined, so, it was probably that some un-critical path would become into critical path. So, it is necessary to list all path of the work and calculate the duration respectively. Thirdly, simulate all paths by Monte Carlo Method. After finishing the Delphi questionnaire survey and define the parameters of selective distribution, we need to do Monte Carlo simulation by repeated sampling. According to Law of Large Numbers, the number of sampling times should be at least 1000~5000 and even more. Fourthly, analyze the simulation results.

2.4 *Compare the results and make decision*

After the simulation by Monte Carlo, compare the results with CPM, and check the differences between two results. The first is checking the total duration of construction and judge whether it meet the requirement. The second is to find the work which had biggest change after the comparison. The works was key control points during the construction procedure. The third is to check whether the critical path change or not and define the new one if there was a changing.

3 CASE STUDY

3.1 *Get the AOA network*

The network program was shown in Fig. 1. The name and duration of works were shown above and below of the arrow respectively. For example, the name of work 1–2 was A, and the duration was 6 days.

3.2 *Calculate the network by PERT*

According to CPM method, all parameters of works had been calculated and shown in Fig. 1, the parameters icon was shown at the top right corner in Fig. 2.

According to the results, total duration of the project was 36 days. There were 2 critical paths in the network, one is A-B-E-H-J, and another is A-C-F-H-J. Procedure B and C are most important procedures.

3.3 *Calculate the network by PERT*

Define the duration of works by beta PERT distribution with Delphi Method, though 3 rounds questionnaire, the results was shown in Table 1. Do Monte Carlo simulation with Excel and @Risk soft wares. The distribution of all parameters were PERT, the iterations of simulation was 5000, the simulation was 1.

4 RESULTS

There are 4 paths in PERT network; they are A-B-E-H-J, A-C-F-H-J, A-D-I-J and A-C-F-GI-J. The total duration of network is equal to the maximum of the 4 paths'. The simulation results was shown in Fig. 3.

According to the results, in the condition of PERT, total duration has changed from 36 days with CPM into

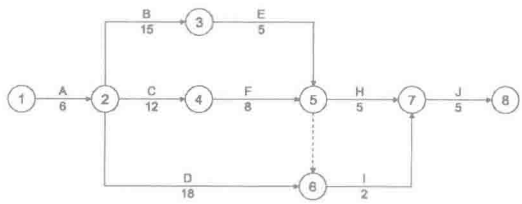

Figure 1. The AOA network and duration of all procedures.

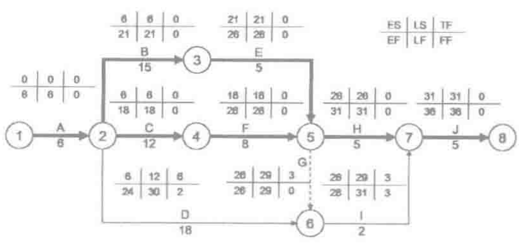

Figure 2. The CPM network program and its parameters calculation results.

a distribution of Lognormal. The mean of distribution was 36.4440; the probability of total duration between 34.54 and 38.35 was 90%. So, the manager should consider the probability of total duration under 36days. The result was shown in Fig. 4. The probability was 35.3%. It means the manager has a big risk to finish the work within 36 days.

The simulation results of 4 paths was shown in Fig. 5, total duration of path A-B-E-H-J and A-D-I-J were in accordance with Weibull distribution; total duration of path A-C-F-H-J was in accordance with Lognormal distribution and total duration of path

Table 1. PERT parameters of works estimated by Delphi Method

Parameters	Minimum	Most likely	Maximum
A	4.9	6.33	8.3
B	12.5	14.97	17.3
C	9.8	11.84	13.65
D	16.5	18.22	20
E	3.85	4.81	6
F	7.2	8.27	10
G	3.85	4.81	6
H	1.2	2.1	3
I	3.85	4.81	6
J	4.9	6.33	8.3

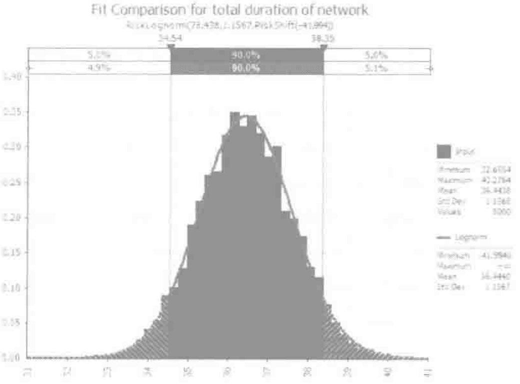

Figure 3. The simulation results of total duration of network.

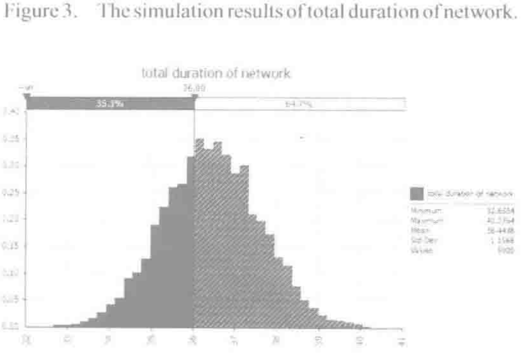

Figure 4. The simulation result of probability of total duration within 36 days.

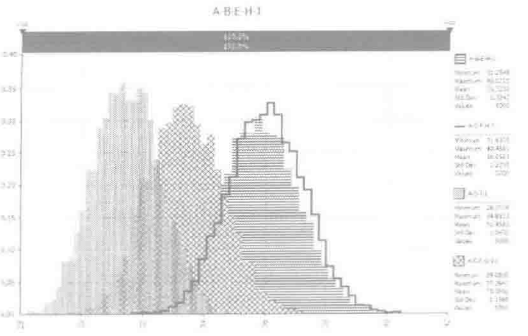

Figure 5. The comparison of total duration between 4 paths.

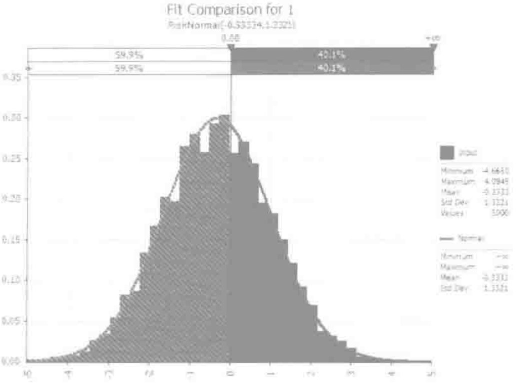

Figure 6. The simulation results of total duration of path A-B-E-H-J minus Path A-C-F-H-J.

A-C-F-G-I-J was in accordance with Beta General distribution.

According to the results, Path A-C-F-H-J was most likely be the critical path in the network, but the total duration of path A-B-E-H-J was longer than Path A-C-F-H-J in some area. It means that path A-B-E-H-J maybe was the critical path the same. The problem is what the probability for that probability is. We use total duration of path A-B-E-H-J minus total duration of Path A-C-F-H-J and simulate the results with 5000 times. The results was shown in Fig. 6.

According to the results, total duration of path A-B-E-H-J minus Path A-C-F-H-J was in accordance with Normal distribution. The probability of total duration of path A-B-E-H-J longer than Path A-C-F-H-J was 40.1%. It means the manager should prepare that path A-B-E-H-J was also become critical path the same. So, the next problem was which procedure should the manager to care about especially? There were 4 different procedures in two paths; they were B, C, E, and F. We made a sensitivity analysis with procedure B, C, E, and F, and find out which procedure would influence the result most. The result was shown in Fig. 7.

According to the results, work B has greatest influence in the network; the next order was C, F and E. The order is the same as their durations' order. So, it

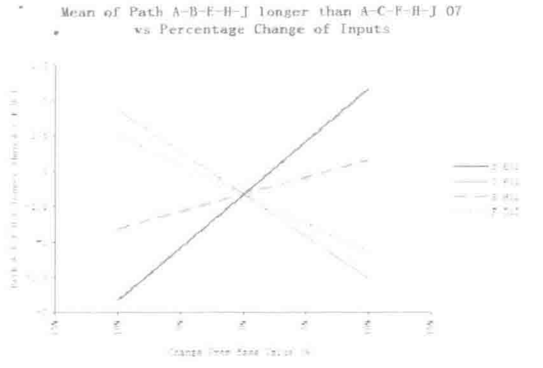

Figure 7. The sensitivity analysis results of procedure B, C, E, and F.

was very necessary to control the works in order to control the total duration.

5 CONCLUSION

It is proved that Monte Carlo simulation was a very good method to solve the problem on uncertain. In construction management practice, more and more people realized that the problem of schedule management and risk control need uncertain tools to do it. With Monte Carlo simulation, there are 3 points need to be pay attention to. The first is to make clear the problem you want to solve. The second is to make sure and define the duration parameters with scientific and reasonable method such as Delphi or something else. In practice, expert engineers, scholars, project managers and professors are good information channel to obtain the useful information. The last is to do simulation as much as possible, the times be better 1000 times at least.

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A discrete-continuous agent model for fire evacuation modeling from multistory buildings

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ABSTRACT: In the paper a discrete-continuous model of pedestrian movement is presented. The model is implemented in SigmaEva evacuation module that is a part of "SigmaFS" software for fire safety engineering applications. Some case study of fire evacuation simulation is presented. This work has got partial financial support by the Integration project of SB RAS, number 49/2012.

Keywords: evacuation, multistory buildings, fire safety, simulation.

1 INTRODUCTION

Modeling of pedestrian dynamics is actual problem at present days. Simulations are used in many fields from organization of mass events to fire safety of buildings, ships, aircrafts. The main task of applying such simulations is to estimate evacuation time in different scenarios to provide safe conditions for visitors, passengers in emergency situations.

Different approaches from the social force model based on differential equations to stochastic CA models are developed; see Schadschneider et al. 2009 and references therein. They reproduce many collective properties including lane formation, oscillations of the direction at bottlenecks, the so-called "faster-is-slower" effect.

The most popular approach from practical applications is individual one mining that each person is considered as individual agent, and a model gives coordinates of each person. Each person may be assigned with individual properties: free movement speed, evacuation starting time, projection size, evacuation way. This allows to solve variety of evacuation tasks, including fire evacuation tasks.

At present time there are two main approaches to simulate individual people movement: continuous and discrete. There was developed a discrete-continuous model SIgMA.DC (Kirik et al. 2014) which was motivated by advantages of the continuity of a modeling space and the intuitive clarity of update rules in discrete models. In this model agents move in a continuous space (in this sense model is continuous), but the number of directions for the particle to move is limited and predetermined by a user (in this sense model is discrete). So in the model a size of the modelling space is considered as it is (it is very important for such narrow places as doors). At the same time mathematics of the model is simpler comparing with continuous models.

The article is organized as follows. In the next section, model is presented. It is followed by the case study section when some fire evacuation example is considered under different initial conditions and conclusion.

2 DESCRIPTION OF THE MODEL

2.1 *Space and initial conditions*

A continuous modeling space $\Omega \in R^2$ and an infrastructure (obstacles) are known. (Here and below under "obstacle" we mean only walls, furniture. Agents are never called "obstacle".) There is a unified coordinate system, and all data are given in this system. Agents may move in a free space. To orient in the space agents use the static floor field S, Schadschneider & Seyfried (2009). The nearest exit is assumed as a target point.

Shape of each agent is disk with diameter d_i, $i = \overline{1,N}$, N – number of agents, $\vec{x}_i(0) = (x_i^1(0), x_i^2(0))$, $i = \overline{1,N}$ – the initial positions of agents mining coordinates of disks centers (it is supposed that they are coordinates of body's mass center projection). Each agent is assigned with the free movement speed v_i^0, $i = \overline{1,N}$, the square of projection. We assume that the free movement speed is random normal distributed value with some mathematical expectation and variation, Kholshevnikov & Samoshin (2009). It is supposed that while moving people do not exceed maximal speed (the free movement speed), and persons control speed according to a local density.

Each time step t each agent i may move in one of predetermined directions $\vec{e}_i(t) \in \{\vec{e}^{\alpha}(t), \alpha = \overline{1,q}\}$, q – number of directions, model parameter (here a set of directions uniformly distributed around the circle $\{\vec{e}^{\alpha}(t), \alpha = \overline{1,q}\} = \{(\cos\frac{2\pi}{q}\alpha, \sin\frac{2\pi}{q}\alpha), \alpha = \overline{1,q}\}$

is considered). Agents whocross target line leave the modeling space.

2.2 *Preliminary calculations*

To model directed movement the "map" which stores the information on the shortest distance to the nearest exit is used. This distance is measured in meters, [m]. Such map is saved in the static floor field S imported from a floor field Cellular Automata approach which provides pedestrians with information about ways to exits, Schadschneider & Seyfried (2009). This field increases radially from the exit and it is zero in the exit(s) line(s), Kirik et al. 2011. It is not changeable with time and is independent on the presence of the particles. To calculate the field S the modeling space $\Omega \in R^2$ is covered by a discrete orthogonal grid with cells 10–40 cm in size, and, the Dijkstra's algorithm with 16-nodes pattern is used, for instance. A distance to the exit from arbitrary point is given by bidirectional interpolation among nearest nodes.

2.3 *Movement equation*

A movement equation for each agent is derived from a finite-difference expression of velocity $v(t)\vec{e}(t) \approx (\vec{x}(t) - \vec{x}(t - \Delta t))/\Delta t$. This expression allows to present the new position of the agent as a function of the previous position and current velocity of the agent. Thus for each time t the coordinates of i-th agent are given by the formula:

$$\vec{x}_i(t) = \vec{x}_i(t - \Delta t) + v_i(t)\,\vec{e}_i(t)\,\Delta t, \quad i = \overline{1, N}, \qquad (1)$$

where $\vec{x}_i(t - \Delta t)$ denotes the particle's position at time $(t - \Delta t)$; $v_i(t)$, [m/s], is the particle's speed; $\vec{e}_i(t)$ is the unit direction vector. The time shift $\Delta t = 0.25$, [s] is assumed to be fixed, Figure 1.

Unknown values in (1) for each time step for each particle are the speed $v_i(t)$ and the direction $\vec{e}_i(t)$. A value of the speed is obtained from experimental data (fundamental diagram), for example, Kholshevnikov & Samoshin (2009), in accordance with a local density. The direction $\vec{e}_i(t)$ of the next step is proposed to be stochastic with the probabilities distribution calculated, this idea adopted from the discrete CA approach.

2.4 *Choosing movement direction*

This discrete-continuous model was inspired by a previously presented stochastic CA FF model, Kirik et al. 2011. All predetermined directions for each agent each time step are assigned with some probabilities to move, and the direction is chosen according to the probability distribution obtained.

Personal probabilities to move in each direction each time step have contributions: a) the main driven force (given by the destination point), b) an interaction with other pedestrians, c) an interaction with

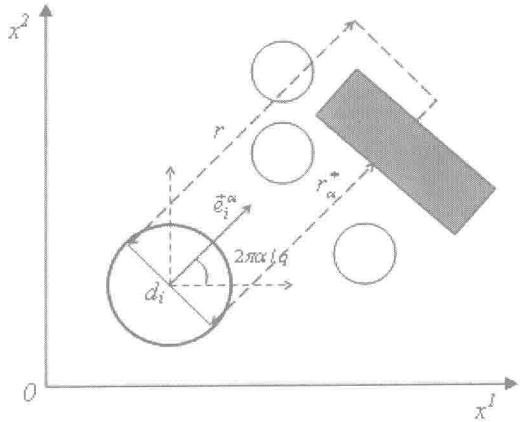

Figure 1. Scheme of visibility area of particle in direction $\vec{e}_i^{\,\alpha}(t)$.

an infrastructure (non movable obstacles). The highest probability (mainly with value > 0.9) is given to the direction that has most preferable conditions for movement considering other agents and obstacles and strategy of the people movement (the shortest path and/or the shortest time).

2.5 *Choosing movement direction*

Let i-th agent has gotcoordinate $\vec{x}_i(t - \Delta t)$. The probability to move from this position to the direction $\vec{e}^{\alpha}(t) = (\cos\frac{2\pi}{q}\alpha, \sin\frac{2\pi}{q}\alpha)$, $\alpha = \overline{1, q}$ during next time step is the following:

$$p_\alpha^i(t) = \frac{\hat{p}_\alpha^i(t)}{Norm} = \frac{\exp\left(-k_W^i\left(1 - \frac{r_\alpha^*}{r}\right)1(\Delta S_\alpha)\right)\exp\left(-k_P^i F(r_\alpha^*)\right)\exp\left(k_S^i \Delta S_\alpha\right)}{Norm} W\left(r_\alpha^* - \frac{d_i}{2}\right), \qquad (2)$$

where $Norm = \sum_{\alpha=1}^{q} \hat{p}_\alpha^i(t)$.

The visibility radius r ($r \geq \max\{d_i/2\}$), [m], is model parameter representing the maximum distance at which people and obstacles influence on the probability in the given direction. Obstacles can reduce visibility radius r to value r_α^* (see Figure 1). The people's density $F(r_\alpha^*) \in [0, 1]$ is estimated in the visibility area, see Kirik et al. 2014. Function $1(\cdot)$ is Heaviside unit step function. There are model parameters: $k_S^i > 0$ – field S-sensitive parameter; $k_W^i > k_S^i$ – wall-sensitive parameter; $k_P^i > 0$ – density-sensitive parameter. Information on parameters one can find in Kirik et al. 2011, Kirik et al. 2014.

$\Delta S_\alpha = S(t - \Delta t) - S_\alpha$, where $S(t - \Delta t)$ – static floor field in the coordinate $\vec{x}_i(t - \Delta t)$, S_α – static floor field in the coordinate $\vec{x} = \vec{x}_i(t - \Delta t) + 0.1\vec{e}_i^{\,\alpha}(t)$. With ΔS_α moving to the target point is controlled.

Function $W(r_{\alpha}^{*} - \frac{d_i}{2}) = \begin{cases} 1, & r_{\alpha}^{*} - \frac{d_i}{2} > w; \\ 0, & r_{\alpha}^{*} - \frac{d_i}{2} \leq w \end{cases}$ controls approaching to obstacles[1], model parameter $0 \leq w \leq 0.1$, [m], – coefficient of inadherence to obstacles.

If $Norm = 0$ than particle does not leave present position[2]. If $Norm \neq 0$ than required direction $\vec{e}_i(t)$ is considered as discrete random value with distribution that is given by transition probabilities obtained. Exact direction $\vec{e}_i(t) = \vec{e}_i^{\hat{\alpha}}(t) = \left(\cos \frac{2\pi}{q}\hat{\alpha}, \sin \frac{2\pi}{q}\hat{\alpha}\right)$ is determined in accordance with standard procedure for discrete random values.

As in cellular automata models a parallel update is used here. Decision rules to choose direction and final conflict resolution procedure are presented in (Kirik et al. 2011, Kirik et al. 2014).

2.6 *Speed calculation*

Person's speed is density dependent (Kholshevnikov & Samoshin (2009), Schadschneider et al. 2009). We assume that only conditions in front of the person influence on speed. It is motivated by a front line effect (that is very well pronounced while flow moves in open boundary conditions) in a dense people mass when front line people move with free movement velocity while middle part is waiting a free space available for movement. As a result it leads to a diffusion of the flow. Otherwise simulation will be slower then real process. Thus only density $F(r_{\hat{\alpha}}^{*})$ in direction chosen $\vec{e}_i(t) = \vec{e}_i^{\hat{\alpha}}(t)$ is required to determine speed. According [3, 4] current speed of the agent is

$$v_i(t) = v_i^{\hat{\alpha}}(t) = \begin{cases} v_i^0(1 - a_j \ln \frac{F(r_{\hat{\alpha}}^{*})}{F^0}), & F(r_{\hat{\alpha}}^{*}) > F^0; \\ v_i^0, & F(r_{\hat{\alpha}}^{*}) \leq F^0, \end{cases} \qquad (3)$$

where F^0 – limit people density until which free people movement is possible (density does not influence on speed of people movement); $a_1 = 0.295$ is for horizontal way; $a_2 = 0.4$, for down stairs; $a_3 = 0.305$, for upstairs.

Numerical procedures that is used to estimate local density is presented in Kirik et al. 2014. Area where density is determined is reduced by direction chosen and visibility area, see Figure 1.

3 SIMULATION

The model presented was realized in the computer program module SigmaEva©. There was performed validation of the module under open and periodic boundary conditions with fundamental diagram (the specific flow versus the density), Kirik et al. 2014.

The validation shown good dynamical properties: maintaining the speed according to local "directed" density, initial density and free movement speed maintains approximately till 0.5 [pers/m], flow diffusion realizes if it is possible, a model full flow rises with the bottleneck width increasing. A comparison with experimental data (Kholshevnikov & Samoshin (2009), Schadschneider et al. 2009, Seyfried et al. 2009) says model results are within an existing conception of the speed-density dependence.

The module SigmaEva is a part of software SigmaFS©. This software consist of 3D-building editor, CFD (computational fluid dynamics) simulation module for modeling of spreading of dangerous fire factors, simulation module for evacuation modeling, and 3D-visualization module.

SigmaFS is a tool for simulations that may be used in many fields from organization of mass events to fire safety of buildings, ships, aircrafts. One may vary a combustible material and its mass, places of fire, systems of smoke removal, pressurization systems, doors conditions, number of people, their initial positions, individual properties (free movement speed, evacuation starting time, projection size, evacuation way), furniture positions.

The main task of applying such simulations is to estimate evacuation time in different scenarios in order to provide safe conditions for visitors, passengers in emergency situations.

Let us consider and compare two evacuation scenarios from a school under fire conditions. According to both scenarios people evacuate from 3-store building using nearest stairways (Stw) number 1 and 2 and exits 4 and 2 correspondingly. A fire started in a marked room, Figure 2. While simulating it was assumed that doors in corridors were open.

The difference in scenarios is in initial conditions concerning a delay of the starting evacuation: 30 and 120 seconds later than the fire started.

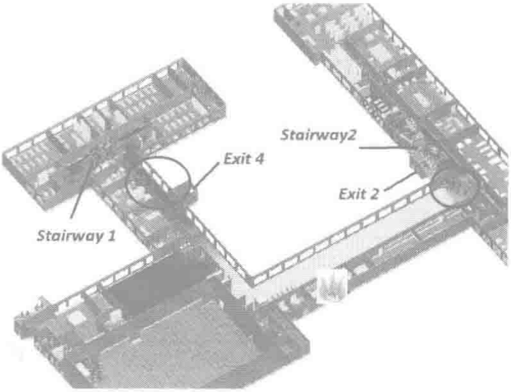

Figure 2. Fire position, exits and stairways in 3-store school building.

[1] Note, function $W(\cdot)$ "works" with nonmovable obstacles only.

[2] Actually this situation is impossible. Only function $W(\cdot)$ may give (mathematical) zero to probability. If $Norm = 0$ then particle is surrounded by obstacles from all directions.

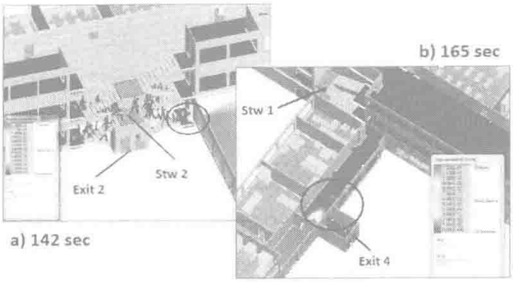

Figure 3. Evacuation from a school building under fire conditions, an evacuation stated 30 seconds later then the fire started.

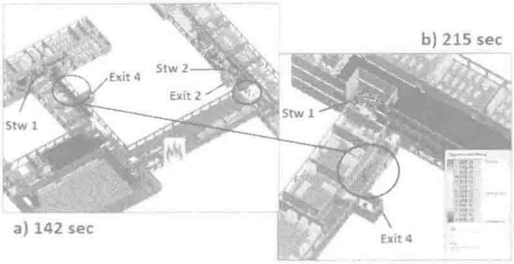

Figure 4. Evacuation from school building under fire conditions, evacuation stated 120 seconds later then fire started.

Fire conditions in the pictures are presented as a 2D-slice for height 1.7 m over a floor that is extracted from 3D-simulation of smoke. Blue color is for safe areas for people health, red color is for dangerous areas (boundary value is from the Russian fire safety legislation).

Joint simulation of the evacuation and the fire spread helps to show and estimate dangerous consequences of some initial conditions. Here the evacuation start delay is considered. In Figures 3 and 4 the most important areas are marked.

For the case of 120 second delay one can see that people moving to exit 2 are in risk area on 142 second. People moving to exit 4 are in a dangerous area on 215 second. Over 100 people evacuated in unsafe conditions if they start with 120 seconds delay.

If people start 30 seconds after fire started they evacuate in comfortable conditions, Figure 3.

4 CONCLUSION

These scenarios were simulated in educational purposes and are a part of special software – fire safety simulator. The idea is to show influence of different conditions on evacuation result.

Such comparative simulation with some parameters may be used for many purposes – evacuation plans design, an investigating of different conditions of building operating, a building safety design, etc.

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