V.V. Kholshchevnikov, D.A. Samoshin. "Modeling and reality of evacuation process". Proceedings of 13th International Conference "Interflam 2013". Royal Holloway College, University of London. UK, 2013, pp. 509-514

MODELING AND REALITY OF EVACUATION PROCESS

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Model is an image, a substitute of a real object (phenomenon, item or process). A real object, on the other hand, is an original, a prototype of this model. The model reproduces the original only with a certain precision that depends both on the level of person's knowledge of the properties of the original and on the capabilities to describe and reproduce them, as well as on the required fullness (detailing) of such reproduction. Regardless of this, in any case, they have to reproduce the essence of a real modeled process that is expressed in its established regularities, which determines the reliability of the results obtained on their basis.

Methodological peculiarity of modeling of movement of the flows of people is that two real objects are reproduced at the same:

1. The very flow of people, as a generality (system, multitude, mass) of people moving within its borders, in accordance with their inherent psychophysiological regularities;
2. The process of movement of the flow of people in general (mass of people as a system) through sections of different types and widths, that results in changes in the size (width and length) of the flow, and in some cases, even the quantity of the flow.

Modeling of the flow of people requires, above all, the observance of the identified regularities of connection between its parameters. Modeling of the movement process requires to reproduce in one way or another the changes of values of the parameters that occur after changes in the geometry of parts of the flow as a result of crossing the border of path sections of different width and type. These are so called kinematic regularities. The kinematic regularities of the flows of people were first developed by Professor Predtechenskiy V.M. in 1958 [1].

Several models of movement of the flow of people are possible depending on the completeness of records of kinematic regularities. The first one is the simple "Model of movement of homogenous flow of people", where the flow is considered as a rectangle, ignoring its head and closing parts. Parameters of movement of people (density D and travel speed V) within the section (i), occupied by them, are taken as equal. As can be seen, the model focuses on the change of flow parameters in general. This model, due to its simplicity, has been primarily implemented in Russian standardization: SNiP II-2-80 [2]. A more complete model, within the framework of analytical description of kinematics of movement of the flows of people, takes into account the changes of the parameters occurring between the structural parts of the flow: their re-formation, spreading and decompaction [3].

The mathematical calculations of the model were carried out practically by hand due to the absence of developed base of computer equipment; graphical methods that allow to receive graphics of movement of parts of the flow in time and corresponding charts of changes in the density of the flow at their path sections have been developed to illustrate the results of calculations. The combination of these operations was called a graphic-analytical method of calculation. The graphic-analytical calculation is "rather elementary in its essence, but it is labor-intensive" [3]. With the advent of computers there appeared a possibility to conduct a lot of arithmetic operations that are necessary to calculate the movement of the flows of people not by hand (using arithmometers, slide rules and graphical layouts), but with a computer. This step in the usage of computers to model the flows of people was associated with the automation of calculations of the analytical method.

Imitation modeling started to develop actively in the 70's of last century, due to the intensive development of computers and software methodology. The methodology of imitation modeling of complex systems is one of the most interesting directions in modeling of the flows of people. The capacity of modern computers, combined with the art of programming, makes it possible to imitate the movement of each person as an element constituting a complex system of the "flow of people" [4].

This creates an opportunity to consider all the stages of formation of the flow of people: from individual movement of each person to their gathering in a flow of increasing density (from individual to flow movement), i.e. - imitate individual movement of each pedestrian in the flow.

Despite the appealing abundance of possibilities of these programs, the question of trustworthiness of imitation of processes of people behavior in the flow with these programs remains unsolved. So, it is obvious that each of the authors of computer programs, taking the burden to "decompose the complex process of functioning of the system as a whole in the sequence of simple things and events" [5], interprets scientific description of real modeling object subjectively, without the necessary knowledge or objective data. Therefore, the researchers of the flows of people faced the problem to create the model of flow structure and behavior of people in it, that corresponds more with the actually observed process.

A flow of people is considered to be a stochastic process [6,7], connection regularities between the main parameters of which are described by a random elementary function:

$$V_D = V_0 \quad if \quad D \leq D_0 \qquad [1]$$

$$V_D = V_0 (1 - a \ln D / D_0) \quad if \quad D \geq D_0 \qquad [2]$$

In this formula: V_D is a speed of flow movement; V_0 is the random variable of speed of free movement of people in the flow that depends on physical and psychological state of people; D_0 is the threshold value of the density i.e. density does not affect the speed of movement of people; **a** is the coefficient of people’s adaptation to changes in the flow density while; D is the value of density of the flow of people.

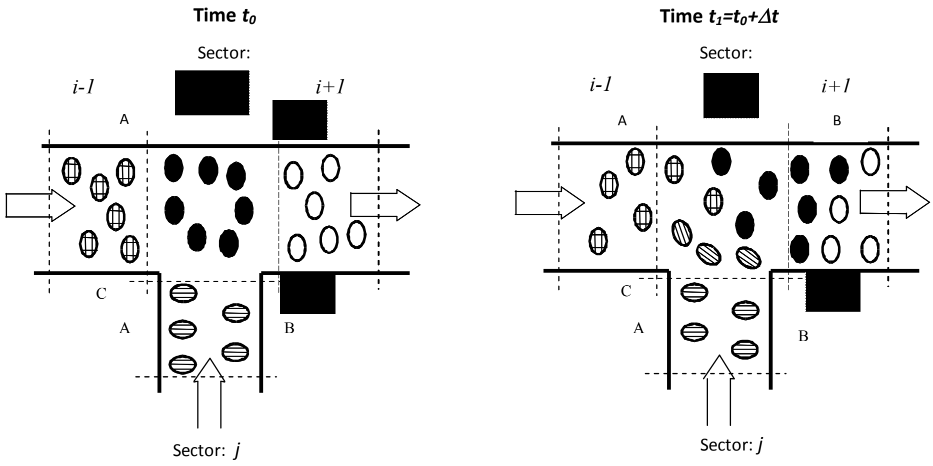
The results of more than 100 series of experiments and field observations conducted both in Russia and abroad, in buildings of various application with the flows of people of all age groups (from pre-school children to the elderly and disabled people), showed the invariance of the identified regularity. The values of the coefficients of determination that describe the closeness of connection between the analyzed parameters of the flow in each of the sets are above 0,95. This relation is also truth for so called vulnerable population: children[8], elderly[9] and disabled people [10]. Parameters of V_0, a, D_0 used for more than 30 years in Russian Building Codes for evacuation calculations is given in Table 1.

Table. 1.
Parameters of V_0, a, D_0 applied in Russian Building Codes for evacuation calculations

Route type	V_0, m/min		a	D_0, persons/m^2
	Design value	Range		
Horizontal (indoors)	100	90-120	0,407	0,69
Horizontal (outdoors)			0,295	0,51
Door			0,295	0,65
Stair downwards			0,400	0,89
Stair upwards	60	55-75	0,305	0,67

Establishment of psychophysically grounded connection between parameters of the flow of people enabled the development of the imitation-stochastic model of its movement that considers the changes in the state of the flow at consecutive (in small time intervals Δt) moments of time (Fig. 1). Unlike some existing models it doesn’t have any kinematic regularities. However, they appear as a result of modeling and corresponds to the observation of the real process.

Figure. 1.
Changes in the state of the flow of people at consecutive moments of time



In this model the entire building is sub-divided into elements of floor space with the lenths Δl equal to 0.5m – 1.0 m and with the width of the route. At time t_o the number of people in the first elementary section is determined: $N_i^{t_o}$. If the width of the pathway section is b_i the density of flow is:

$$D_i^{to} = \frac{N_i^{to}}{b_i \Delta l} \quad [3]$$

These $N_i^{t_o}$ people go along the elementary sector *i* with travel speed *V*. Analogical statements are on previous *i-1,* on the next *i+1* sector and on the elemental sector *j* adjoining to the *i*. After the lapse of Δt in the instance of time $t_1 = t_0 + \Delta t$ pedestrians move from sector *i* to a next sector *i+1*, Figure 3. These occupants will be designated as $N_{i,i+1}^{t_i}$. From $N_i^{t_o}$ of people placed in a sector *i* at the instant t_0, this sector will contain only $N_i^{t_o}$ - $N_{i,i+1}^{t_i}$ persons after the lapse of Δt . But this number will be added by the people passed from the previous sectors *i-1* and *j* during this time Δt , $N_{i-1,i}^{t_i}$ and $N_{j,i}^{t_1}$ respectively. Thus the flow density at the sector *i* can be written as following:

$$D_i^{t_1} = \frac{N_i^{t_0} - N_{i,i+1}^{t_1} + N_{i-1,i}^{t_1} + N_{j,i}^{t_1}}{b_i \Delta l} \quad [4]$$

The travel speed of the occupants of sector *i* at time t_1 is then a function of the density of the flow in sector *i* and is calculated according to [1] and [2]. This process is repeated for all of the occupied sectors. Variations in the density of the flow in different sectors of the route at different times reflects the process of flow adjustment including flow spread. As shown, the variation in flow density is a result of the different numbers of occupants passing through the connected sectors of the route. In general, the number of occupants moving from sectors *i* to sector *i+1* is:

$$N_{i,i+1}^{t_1} = D_i^{t_o} b_i V_{pass} \Delta t \quad [5]$$

where V_{pass} is the speed of the occupants passing through the sector bounded, eg, by A-A, B-B, C-C (V_A, V_B and V_C respectively). If occupants enter a narrower elementary sector, eg, a door opening a width correction is necessary. From field observations deviations in flow trajectory were established, ie, pedestrians on the outer fringes of the flow altered their trajectories when forced to diverge and converge by 30° and 45° respectively.

Conceptually for the purposes of modeling pedestrian flow it is reasonable to assume a wedge shaped flow moving forwards into the adjacent sector with a flow speed of V_i^{to}. If the density of the flow in the sector ahead is above certain limits the flow of the migrating occupants will decelerate. Thus the speed V_{pass} of passing through the boundary of adjacent sectors can be taken as:

$$V_{pass} = \begin{cases} V_i^{t_0}, & if \quad D_{i+1}^{t_0} \le D_{q_{\max}}; \\ V_{i+1}^{t_0}, & if \quad D_{i+1}^{t_0} \succ D_{q_{\max}}; \end{cases} \qquad [6]$$

where $D_{q_{\max}}$ is the value of density corresponding to the maximum intensity of the flow and it is approximately equal to 4-5 persons per square meter [7]. If $V_{pass} = V_{i+1}^{t_0}$ the number of occupants remaining in sector i increases while the number moving to sector i from sectors $i-1$ and j remains the same. Under this condition the flow density for sector i will increase and thus flow density will quickly (5-7 seconds) approach $D_{\max}$. When $D_{i+1}^{t_0} = D_{\max}$ there is congestion in the flow. If at some instant of time t_k the flow density reaches its maximum value such that it cannot increase further there will be congestion of $\Delta N_{i-1,i}^{t_k}$ and $\Delta N_{j,i}^{t_k}$ people, who cannot move from one sector to the next. During a next time step t_{k+1}, some people will leave sector i. It means, that $N_{i-1,i}^{t_{k+1}}$ and $N_{j,i}^{t_{k+1}}$ people from sectors $i-1$ and j will be able to move to sector i. Their contributions with respect to flow into sector i at t_{k+1} is proportional to the width of the sectors $i-1$ and j. For the general case the ratio of their contributions can be expressed as:

$$\frac{N_{i-1,i}^{t_{k+1}}}{N_{j\tilde{o}\, i}^{t_{k+1}}} = \frac{D_{i-1}^{t_{k+1}} V_{i-1}^{t_{k+1}} b_{i-1}}{D_j^{t_{k+1}} V_j^{t_{k+1}} b_j} \qquad [7]$$

The correspondence of the imitation model with the real process of flow movement was repeatedly tested by field observations. One of the examples of comparison of results [11] is shown on Fig. 2. The model is implemented by software product Analysis of Movement Of The Flows Of People, Probability - Version V 2.0 - «ADLPV-2.0». - State Standard of Russia. № RUCTI05.IT00220.

Figure. 2.
Change of the number of people passing through the cross section of the path at consecutive moments of time, example of the underground passenger hall

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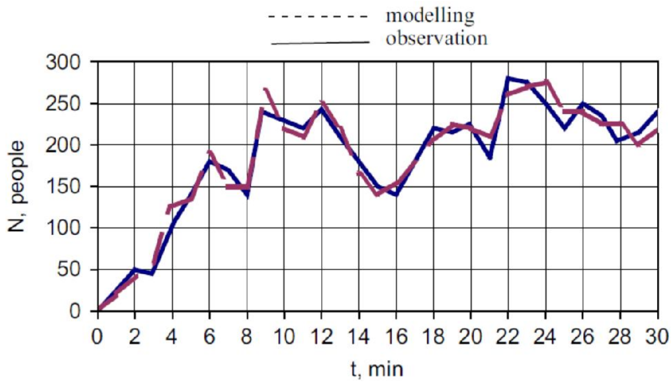

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