PSYCHOPHYSICAL RELATION LAWS FOR PEDESTRIAN FLOWS PARAMETERS

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ABSTRACT

The book of Vsevolod Predtechenskii and Anatoliy Milinskii "Planning for foot traffic in buildings" [1] is well-known for specialists researching human behaviour in fire and pedestrian flow movement. An extensive observations and theoretical studies of human flow was carried out during last 40 years and this led to the further development and correction of the pedestrian flow theory.

We would like to acquaint you with some results obtained during last time, first of all, about human movement, as one of the form of human behavior and also discuss statistical treatment of empirical database and theoretical construction, describing relations between travel speed, density of flow and emotion state of people in a flow [2].

GENERAL PRINCIPAL OF TRAVEL SPEED ANALYSIS

The main indicator of motional activity of a crowd moving simultaneously on the same route in the same direction as its reaction to the conditions of the environment is the speed of the human flow. It is well-known that the velocity of the human flow (V) depends on the type of routes (j), the density of flow (D), and the level of emotional state (e). In other words the velocity is the function of these factors and its value at the i section of the route can be represented as $V^{e}_{j,Di}$. The purpose of the field observations and experiments is to establish the relation between the human flow velocity and an other multiple factors. The flow velocity is defined by the mean values of individual travel speed V_n of N people moving on a particular section of route, i.e.:

$$V^{e}_{j,Di} = \sum_{1}^{n} V_n / N. \qquad [1]$$

In the Russia at the beginning of 80's there were carried out more than seventy series of observations of human flow in various type of buildings on the different route types (horizontal, door openings, stairs ascent and descent) and special experiments. These results are shown in Figure 1a-1c. The total number of values "the travel speed – the density" was about 25 000.

All this data as well as similar data found in foreign studies and known in Russia by that time (Figure 2) was dispersed in numerous literary publications and scientific reports and was never analyzed side by side. The need to analyze them together arouse due to the development of the State Building Code at the end of the 70s "SNiP II-2-80 "Fire Safety of Buildings and Structures". They prescribed to establish estimated relations between characteristics of human flows for each route type for forecasting human flow movement during evacuation in new buildings.

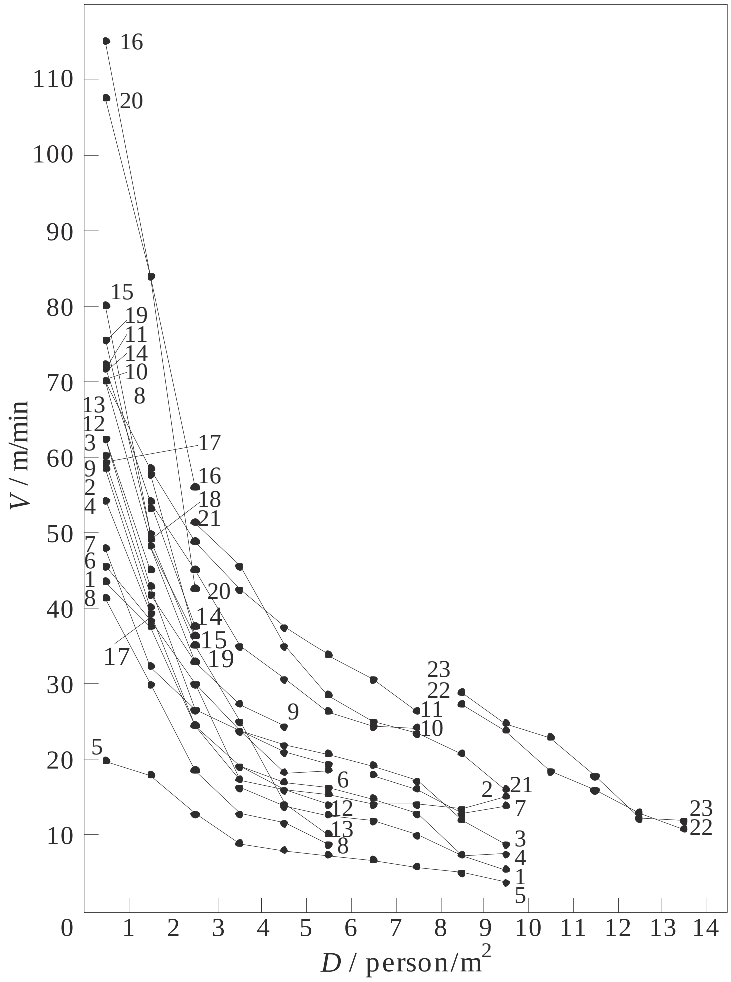


Fig. 1a. Empirical relationships between travel speed of human flow and density which was obtained at the end of 70's (horizontal plane)

***Type of buildings**: theatres, cinemas - 1, 5; universities – 2; industrial – 3; transport structures – 4, 13,14; sports – 6; other – 7; trade – 8;*
schools: senior group – 9, middle group – 10, young group – 11;
***Streets**: shopping street – 12; transport junction – 15, 16, 18;*
***Industrial units**: 19; **Underground stations**: 20, 21; **Experiment**: 22, 23.*

The multitude of empirical relationships $V_{j,D}=\varphi(D)$ for each route type provoked an attempt to try and to unite them. As the sample f observable values V_n in each density interval was known for each series of field observations, that is why numeral characteristics of distributions for respective sampling population were defined for each of them: the mean value - $m(V_{j,D})$ and the dispersion $S^2_{V_D}$. The nature of empirical distributions is illustrated by the bar charts given on Figure 3.

The presence of all those characteristics gives an opportunity, based on the statistical analysis, to unite various series to a general sample. According to the methodology of mathematical statistics, to achieve this purpose they have to be homogeneous, i.e. they should not have significant differences in mean values and dispersions at all the density intervals.

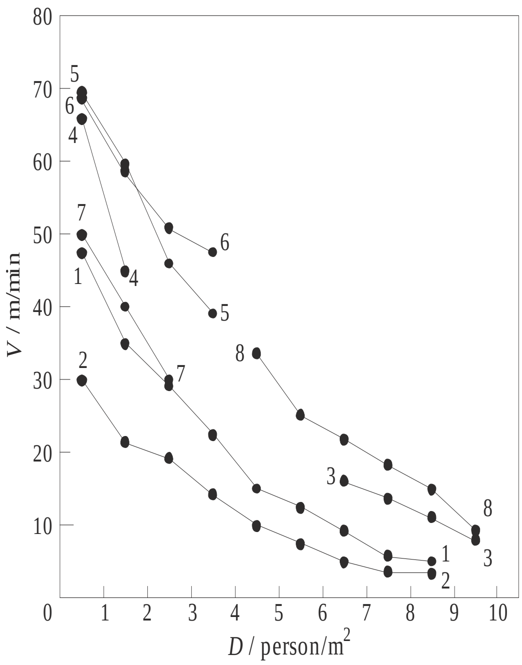


Fig. 1b. Empirical relationships between travel speed of human flow and density which was obtained at the end of 70's (stairs downwards)
Type of buildings*: multipurpose – 1; sports -2, 3; universities – 4; schools: middle group – 5, young group – 6;* ***Streets****: transport junction –*

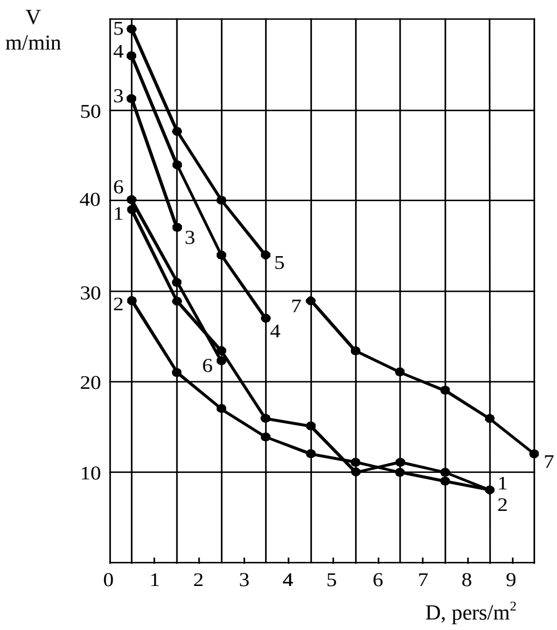


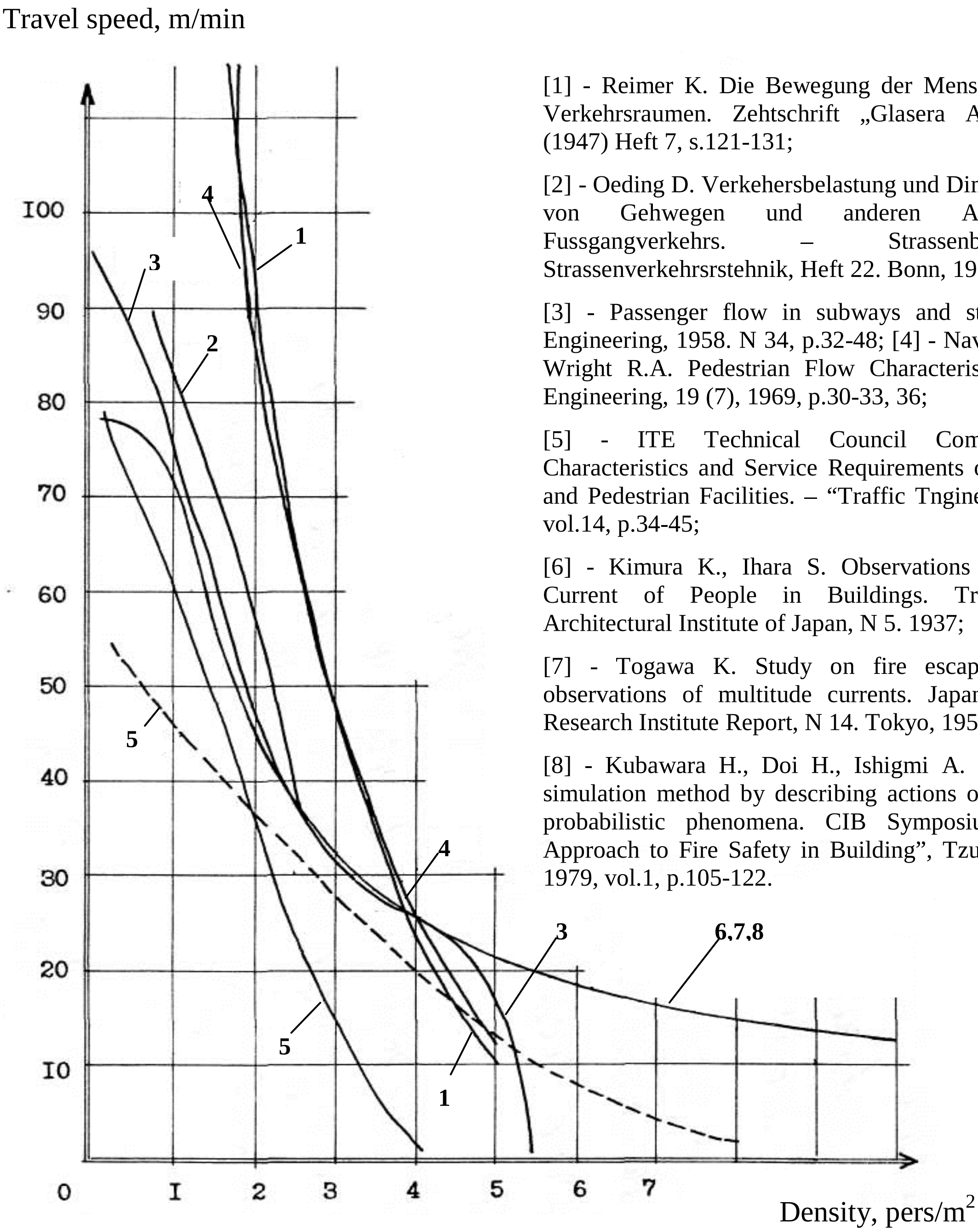
Fig. 1c. Empirical relationships between travel speed of human flow and density which was obtained at the end of 70's (stairs upwards)
Type of buildings*: multipurpose – 1; sports -2; universities – 3; schools: middle group – 4, young group – 5;* ***Streets****: transport junction – 6;* ***Experiment****: 7.*

The given analysis [3,4] in general does not provide any basis for the correct unifying of statistical data of separate series to establish general relationship $V_{j,D}=\varphi$ (D). Meanwhile, even a quick look at the charts showing empirical relations is enough to understand that they illustrate the general tendency of a change in the velocity of human flow movement when its density is increased. Here we clearly have "a feeling" that there exists a certain "inner law paving its way through the randomness and regulating it" [5]. This figurative expression helps for better understanding that each series of field observations and experiments is one of isolated cases of a random process manifestation; that is a human flow by its nature. Consequently, a mathematical expression of relations between its parameters should be sought for in the class of random rather than determinate functions*.

Such understanding of a process and required form for its mathematical description leads to a understanding that there is a need for a change in the methodology of processing empirical data. The essence of this changes can be expressed briefly in the terms of the theory of probability and mathematical statistics: "it is pointless to hunt after the equations that would give exact equality for each pair of numbers (X_i , Y_i). The later mistake is what most experimenters are apt to commit – having plotted several obtained points they take as a graph of y against x a smooth curve passing through those plotted points! Thus, the method of interpolation from the given points cannot be applied in the theory of random values "[6, p.224]. Such method with its "preciseness", in fact, "tones

* The relation between travel speed and density of flow according to Prof Predtechenskii [1]
$V=(112D^4 - 380D^3 + 434D^2 - 217D + 57)\, m$ **,** where m:
for horizontal plane - $m = 1$;
for door opening - $m = 1{,}7 + 0{,}13 \sin (6{,}03\, D - 0{,}12)$;
for stairs downward - $m=0{,}775+0{,}44\, e^{-0{,}39\, D} \sin (5{,}61\, D – 0{,}224)$;
for stairs downward - $m = 0{,}785 + 0{,}9e^{3.45D} \cdot \sin 15{,}7D$, if $0 < D < 0{,}6$ and
$m = 0{,}785 - 0{,}1 \sin(7{,}85D + 1{,}57)$ if $0{,}6> D = 0{,}92$.

down” the expression of the desired “inner law” manifesting itself though accidents. The mathematical formula that we fit to approximate empirical data “only then gets a real value when it is adequate to the inner relations between the inner phenomena or at least expresses those relations with sufficient degree of approximation…That is why when plotting a regression line a researcher should clearly see the inner relations that can determine the relationship in this precise form” [7, p.126].



[1] - Reimer K. Die Bewegung der Menschenmasen in Verkehrsraumen. Zehtschrift „Glasera Annlen“, N71 (1947) Heft 7, s.121-131;

[2] - Oeding D. Verkehersbelastung und Dimensionierung von Gehwegen und anderen Aulagen der Fussgangverkehrs. – Strassenbau und Strassenverkehrsrstehnik, Heft 22. Bonn, 1963;

[3] - Passenger flow in subways and stain-comes. – Engineering, 1958. N 34, p.32-48; [4] - Navin F.P.D. and Wright R.A. Pedestrian Flow Characteristics. –Traffic Engineering, 19 (7), 1969, p.30-33, 36;

[5] - ITE Technical Council Committee 5-R. Characteristics and Service Requirements of Pedestrians and Pedestrian Facilities. – “Traffic Tngineering”, 1976, vol.14, p.34-45;

[6] - Kimura K., Ihara S. Observations of Multitude Current of People in Buildings. Transaction of Architectural Institute of Japan, N 5. 1937;

[7] - Togawa K. Study on fire escapes based on observations of multitude currents. Japanese Building Research Institute Report, N 14. Tokyo, 1955;

[8] - Kubawara H., Doi H., Ishigmi A. A fire-escape simulation method by describing actions of evacuees as probabilistic phenomena. CIB Symposium “Systems Approach to Fire Safety in Building”, Tzukuba (Japan), 1979, vol.1, p.105-122.

Figure 2. Relationship between travel speed of human flow and density according to international authors’ data (numbers on the curves correspond to the references on the right part of the picture)

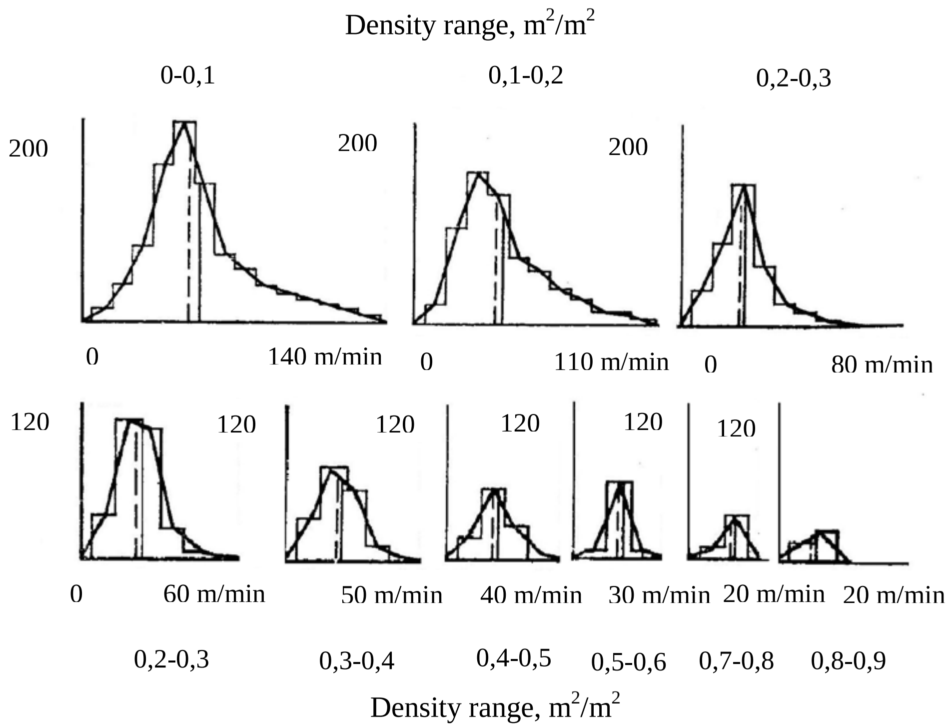


Figure 3. Histograms and polynomial distributions of travel speed value in various density interval on horizontal route (dot line - median, solid line – mean values)

None of the studies describing the movement of people in a flow succeeds in finding “the inner relations” that can determine the relation between the velocity and density of human flow in the form of mathematical expression. At best we can observe some attempts [1] to take into account the influence of physical state of the people comprising the flow and their psychological state by way of calculating empirical coefficient of “the flow composition” and the conditions of movement. Those coefficients are calculated as the ratio of average values of flow velocity obtained during the series of observations to the average values of velocity in the other series carried out earlier and taken for no clear reason as the main one. Apparently, this approach does not explain “the inner relations” determining the nature of the relation between these parameters but just demonstrates the understating of a need to somehow reflect their influence on the formation of the desired relations.

AN IMPACT OF FLOW DENSITY ON TRAVEL SPEED

An impact of random realization of the movement process makes it difficult to identify underlying essence of relationship between parameters. The fact that travel speed detected during all field observations is formed not only under the influence of density, but also as a result of emotional and psychological state of people have in the observed situation, for example, comfortable movement after the theater play or increased activity during rush hour in the morning in the public transport. Consequently, the way to neutralize this factor should be found.

The classification of the movement of people during changing the flow density (Table 1 in accordance with [1]) pointed to such capability.

Table 1. Classification of movement with increasing density of flow

Density, persons/m^2					
0–0,05	0,05–1,5	1,5–4	4–7	7–9	> 9
Individual	**Flow**				
Free movement	Free movement in a flow	Without contacting obstacles	With contacting obstacles	With force impact	
				Body compression	Body deformation

The physical nature of different travel speed depends on two factors: the length of the step and the movement pace. The density of the flow from this point of view has an effect in that it deprives a pedestrian of a space necessary to walk with a full step. However, with a density of people in a flow about 1 pers/m^2 there is some space for walking with the full step but a person is proceeding with a speed less than the speed of free movement when there are no other people around. In this interval of density the distance between people forced to decrease the speed of a person because it limits a person's capacity to maneuver with an intention to overtake or avoid a collision with the other people. If, on the other hand, he decides to overtake a preceding person he will have to either increase his speed significantly or conversely slow down abruptly to avoid a collision or go ahead, all this would provoke physical and psychological rebuff from the people around and will not be enjoyable for the overtaking person himself. It is apparent that the density of the flow is perceived by a person not only as the limitation of the physical space but as something more complex - a set of physical and physchological factors whose intensity of impact on a person increases as the flow density grows and it is not clear to what extent.

The listed effects of human impacts that are associated with density changing, show that density is a synthesizing factor of different aspects of environment impact on people. Actually it is impossible to determine the physical impact of this factor: whether – "the number of visible heads in front of", or – invisible below the chest area of unoccupied way, whether -"something" physical non-specific, which, however, identify the certain physical reaction - changing travel speed in the flow. From this point of view we can say that the density of human flow is relative, convenient for researchers, physical "carrier" of complex psycho-physical environment effects.

The name itself "free individual movement" suggests that in this interval the density (D_0) has no effect on travel speed. On the interval from 0 to D_0 the velocity of people in the flow ($V^e_{j,0}$) depends on a physical ability and emotional and psychological state, because "a person even without psychological pressure from others people infects with their behaviour submit and follows it" [8].

This fairly obvious conclusion allows to determine at least statistical tendency of density influence on travel speed, introducing $\Delta V^e_{j,Di}$, that reflects travel speed changes in various density intervals:

$$\Delta V^e_{j,Di} = V^e_{j,0} - V^e_{j,Di} \qquad [2]$$

Apparently, the absolute values of the variable $\Delta V^e_{j,Di}$ depend on the emotional state of people and will differ in different series of field observations with the same values of flow density. In order to bring out one general trend of a speed change under the impact of density, one has to resort to relative values:

$$R^{EMP}_{j,Di} = (V^{э}_{j,o} - V^{э}_{j,Di}) / V^{э}_{j,o} = \varphi(D) \qquad [3]$$

This give us an opportunity to get an understanding of a general trend in a reaction (R) of people to the increasing impact of human flow density. From the formulas [2] and [3] it follows that the common relation of travel speed can be written as:

$$V^{э}_{j,Di} = V^{э}_{j,o}(1 - R^{EMP}_{j,Di}). \qquad [4]$$

Empirical values of $R^{EMP}_{j,Di}$ were determined at all the intervals of human flow density for all the field series.

One has to look for a relation R = φ(D) in the context of one of the psychophysical laws describing the quantitative relationship between physical characteristics of a stimulus and the intensity of a sensation as a response to this stimulus. As the result of the analysis of the most general psychophysical laws (the Weber–Fechner law [9] and Steven's law [10]), the Weber–Fechner law was used to approximate empirical relationship $R^{EMP}_{j,Di} = \varphi(D)$ [2]. This choice was justified because it was proved [11] that it is true for the cases where the increment size of the impact is not clearly perceivable and only its general level has a practical value, just as in human flow:

$$R^{T}_{j,Di} = a_j \ln \frac{D_i}{D_{0j}}. \quad [5]$$

Here the coefficient a_j is interpreted as the indicator of adaptation of the mixed human flow to the movement of the J-type route. The example of approximation of empirical values of R obtained on the basis of series of field observations on horizontal routes is given on Figure 4. The values of a_j and D_{0j} for various route types presented in Table 2.

The evaluation of correlation tightness between the given values was performed using theoretical correlation relation, which values were: for horizontal routes within buildings - 0,99; for horizontal routes outside the buildings - 0.984; stairs descent - 0.985; stairs ascent - 0.996. Determination coefficient (square of theoretical correlation ratio) shows that at a fixed level of emotional state, more than 97% of total variance of travel speed on all kinds of routs determines by the density of human flow.

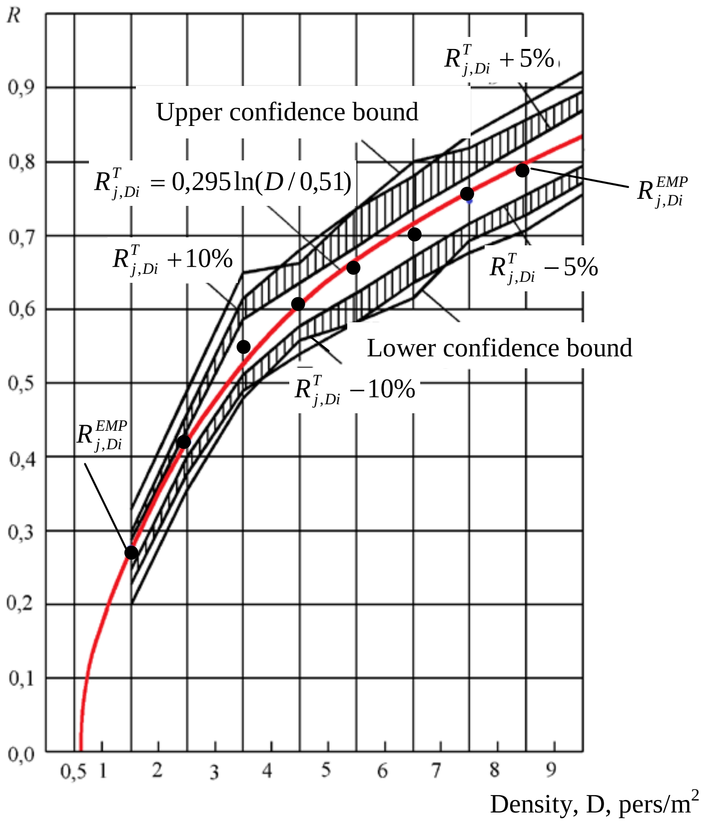


Figure 4. An approximation of empirical relation $R^{EMP}_{j,Di}$ by the theoretical function $R^{T}_{j,Di}$.

▥ - an area of 5 to 10% deviations from $R^{T}_{j,Di}$.

Table 2. Values of a_j and D_{0j} for each route type

Route type	a_j	D_{0j}, person/m2
Horizontal outdoors	0,407	0,69
Horizontal indoors	0,295	0,51
Door aperture	0,295	0,65
Stair downwards	0,400	0,89
Stair upwards	0,305	0,67

This approach enables us to describe the relationship between the parameters of the human flow as a stochastic process in the form of elementary random function.

$$V^{e}_{D,j} = V^{e}_{0,j}\,[1-a_j \ln(D/D_{0,j})]. \qquad [6]$$

Elementary random function is product of a random value of free travel speed of human flow on non-random function (in the parentheses) which describes effect of its density.

TRAVEL SPEED AND EMOTIONAL STATE OF PEOPLE

Statistical analysis showed that at the first interval of density travel speeds values are homogeneous and might be combined. Moreover, travel speed values might be grouped into three - four speed intervals of free movement. An analysis of the experiments conditions suggests the identity of the psychological stress of the situations. However, we can't say more because scaling of psychological tension of the situation is limited by a scale: comfortable movement, movement under normal conditions and in conditions of approaching emergency (because of absence of observation in real emergency situations).

Physical activity indicators and emotional state levels that were scaled in relative units and can be obtained from data [12] that psychologists used for information emotional states modeling. However, there is no sufficient data to establish the relation between sped and degrees of psychological tension of evacuees.

The scale of levels can be represented in relative units (from 0 to 1) and has the following conceptual description. The first stage ($0<e<0,3$) is connected with the development of weak signals about a possible danger. At this stage a body is adjusting, preparing to face with an expected danger. The second stage ($0,3<e<0,7$) should be called "energetic actions" because this stage is associated with a state of heightened activity that goes along with the behaviour aimed at eliminating the danger. When it is not possible to eliminate the danger and there is a sense of helplessness at the face of impending danger then the third stage comes ($0,7<e<1$), this stage is characterized by a lack of activity and beyond-the-control listlessness.

However, there is no sufficient data to establish this correspondence as regards movement of people in situations having various degrees of psychological tension.

Nevertheless, it is obvious that in the statistical distribution the maximum values of travel speed are more associated with the people who are in increased emotional state. This led to an idea to use statistical theory of extreme sample values [12] for predicting their possible meanings in the extreme, not observable, but possible situations (Emergency situations). It should be considered that the maximum value of sample cannot exceed twice its mean value [13].

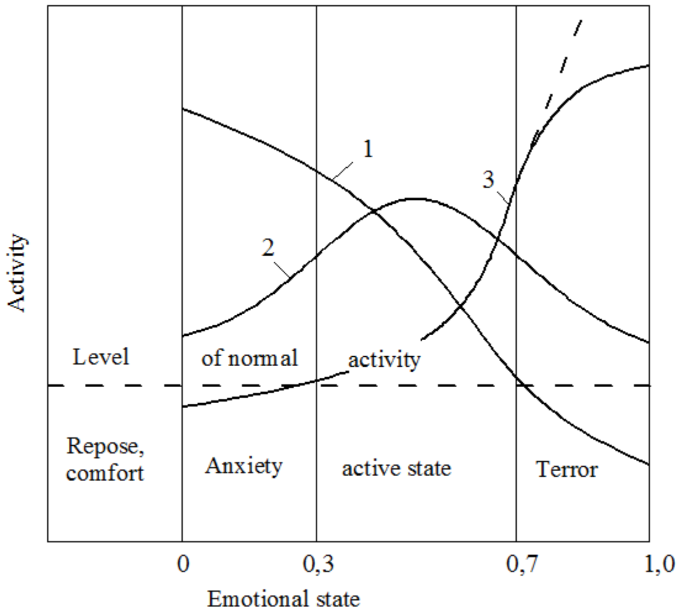


Figure 5. The influence of emotional state on the level of activity:1 – attention; 2 – management; 3 – movement.

The example of established categories of movement of mixed human flow on the horizontal routes is shown on Figure 6. The intervals of categories of movement of mixed composition human flow on all types of routes were calculated, Table 3.

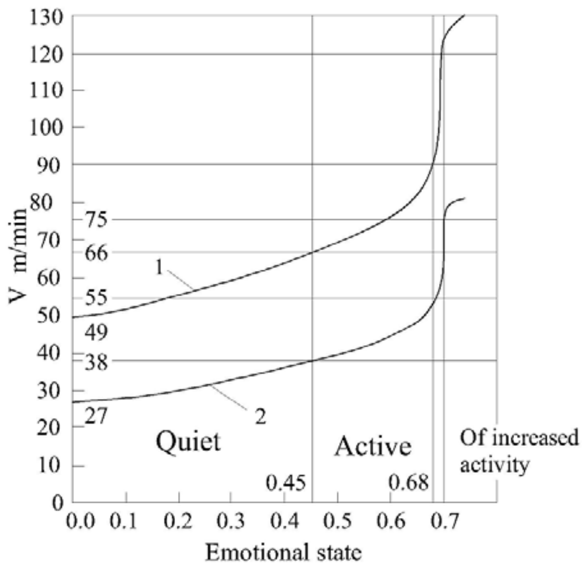


Figure 6. The relation between free travel speed and emotional state level: 1 – horizontal plane, door opening and stairs downwards; 2 – stairs upwards.

Table 3. Categories of movement, emotional state level, and unimpeded travel velocity

Categories of movement	Level of emotional state	Unimpeded travel velocity, V_0, m/min	
		Horizontal route, door opening, stair downwards	Stair upwards
Comfortable	0,00	<49.0	<27.0
Quiet	0,45	49.0-66.0	27.0-38.0
Active	0,68	66.0-90.0	38.0-55.0
Of increased activity	0,70	90.0-120.0	55.0-75.0

Thus, all the values that compose formula [6] are determined. Their values for the category of heightened activity are used in normative documents in Russia both for the purposes of standardization of evacuation parameters in case of fire [15,16] and planning evacuation routes and exits in the Construction Standards and Regulations [17, 18].

It is interesting to analyze the manifestation of the established relations of human flow speed changes that depends on the flow density in the international studies. However, it is rather difficult to accomplish this due to the lack of exact data as well as due to the uncertainty that the methods were used to carry out field observations and statistical processing of the results. It is absolutely obvious that the graphs given on Figure 2 might be inaccurate due to the quality of published diagrams.

However, it is just as well obvious that they demonstrate both qualitative and quantitative similarity to empirical relations established in Russia. Thus, the data obtained by Japanese researchers during field observations can be approximated by the established relations [6] with a high degree of accuracy with the values $V^e_{j,0}$=80m/min and a_j and $D_{0,j}$ for horizontal routes equal to the data given in Table 2; whereas the data of observations in London underground (up to 5 per/m²) is described by the very similar relationship ($V^e_{j,0}$=88m/min) that was established during the extensive studies at the stations and transfer hubs of Moscow underground transport system [19,20]: $V=106,2\cdot[1-0,4\ln(D/0,56)]$.

AN APPLICATION OF ESTABLISHED LAW FOR VULNERABLE POPULATIONS

According to the World Report on Disabilities, the total number of disabled people in the world is about one billion. Obviously, the distinct physical peculiarities of disabled people affect their mobility abilities. In the result of special study [21,22] disabled people were divided on 4 groups according to their movement characteristics: M1 – healthy adults and people with hearing limitations; M2 - elderly people, disabled people with artificial limb, with loss of sight, people with mental problems; M3 - disabled people with travel aids such as sticks, crutches. M4 - people moving on manual wheel-chairs. It was established, that the parameters of their movement is described by the same relationship [6] but with different values of the variables, Table 4. These data are included in the Russian Building Code SNiP 35-01-2001 “Accessibility of Buildings and Structures for the People with Disabilities”.

A special attention was also paid to research pedestrian movement of children and adolescents of various age. The movement of people studying at university in normal condition were analyzed in the studies [23,24]. These data was included into the general empirical database (see Figure 1) and was also analyzed separately [2]. The data under the conditions similar to emergency was observed during experiments [25,26].

The pedestrian movement of young kids (3-7 years old) are of a particular interest [27,28]. First of all, because as a result of the field observations and game experiments with children the significant database was collected – about 4000 counts of travel speed-density relation. These values were obtained in junior, middle and senior age groups with different levels of their emotional state and during the movement on horizontal routes through doorways, upstairs and downstairs. Secondly, because at this age a psychophysiological model of the own body is formed, called in psychophysiology “body scheme”. This “body scheme” is “orienting” on the movement task under certain conditions and makes it possible for the other parts of the body to feel the speed in a sensory form. At this stage the main motor skills are formed and motion experience is being accumulated. However, even at this age (Table 5), the relations between the parameters of human flow are governed by the same relations [6] when the values of theoretical correlative ratio are higher than 0,95.

Thus, the analysis of differentiated relations between characteristics of the human flow for various age groups which typical for buildings of different functional usage shows that they have common relationship which can be described as function [6].

Table 4. The values a_j and $D_{0\,j}$ for different mobile groups of disabled people (for fire evacuation conditions)

Mobility group	Parameters	A value of parameters depending upon route type		
		Horizontal	Stairs down	Stairs up
M2 Elderly people, disabled people with artificial limb, with loss of sight, people with mental problem.	V_0, m/min a_j D_0, pers/m^2	30 0,335 0,675	30 0,346 0,695	20 0,348 0,63
M3 Disabled people with travel aids such as sticks, crutches.	V_0, m/min a_j D_0, pers/m^2	70 0,350 0,34	20 0,454 0,693	25 0,347 0,40
M4 People moving on manual wheel-chairs	V_0, m/min a_j D_0, pers/m^2	60 0,399 0,14	- - -	- - -

Note 1. M1 group – healthy adults and people with hearing limitations. The parameters of their movement age given in the Table 2.

Note 2. Recent studies reveled that this classification need a further research. For instance, filed studies and statistical data treatment showed that elderly people should be classified at least by 4 groups: 1) without movement aids: 2) with 1 handhold; 3) with 2 handholds; 4) moving on wheel-chair without assistance [29].

Table 5. The values a_j and $D_{0\,j}$ for pre-school children (for fire evacuation conditions)

Mobility group	Parameters	A value of parameters depending upon route type		
		Horizontal	Stairs down	Stairs up
Pre-school children	V_0, m/min a_j D_0, pers/m^2	60 0,275 0,78	47 0,19 0,64	47 0,275 0,76

CONCLUSIONS

An analysis and generalization of multi-thousand statistical Russian and international data of various series of observations and experiments of pedestrian flow movement, revealed that pedestrian flow should be considered as a random process (in terms of theory of probability)> Instead of set of separate empirical relations [1], the general law for V=f(D) as a random function was established [formulae 6]. This relation due to its high validity is being used for more then 30 years for evacuation routes design, evacuation time calculation and fire risk assessment.

REFERENCES

1. Predtechenskii V.M., Milinskii AI. Planning for foot traffic flow in buildings. Revised and updated edition. Moscow: Stroiizdat; 1969; Predtechenskii V.M., Milinskii A.I.. Personenstrome in Gebauden - Berechnungsmehoden fur die Projektierung. Koln Braunsfeld, 1971; Predtechenskii V.M., Milinskii A.I..Evakuace osobs budov. – Cescoslovensky Svaz Pozarni Ochrany. Praha, 1972; Predtechenskii V.M., Milinskii A.I.. Planning for the foot traffic flow in buildings. New Delhi, 1978; Predtechenskii V.M., Milinskii A.I. Planning for foot traffic flow in buildings. Revised and updated edition. Moscow: Stroiizdat; 1979.
2. Kholshevnikov V.V., Shields T.J., Boyce K.E, Samoshin D.A. Recent developments in pedestrian flow theory and research in Russia. Fire Safety Journal, vol. 43 (2008), pp. 108–118.
3. Kholshchevnikov V.V. Human flows in buildings, structures and ontheir adjoining territories. Doctor of science thesis. - Moscow Civil Engineering Institute, 1983.

4. Kholshchevnikov V.V. Statistics of relations between parameters of human flow // Research in accordance with bases of architecture engineering. (Functional, physical technical and esthetical architectural problems) – Tomsk: Tomsk university, 1983.- p.155-175.
5. K. Marks. The Capital. Chapter XLVIII, part 7.
6. Pustilnik E.I. Statistical methods of the analysis and the processing of observations. –M.: Science, 1968.
7. Druzhinin N.K. The mathematical statistics in economics. – M.: Statistics, 1971.
8. Olshanskii D.V. Mass psychology. – Moscow, Saint-Petersburg, Voronezh, Kiev, Kharkov, Minsk, etc., 2002.
9. Fechner G. Elemente der Psychophysik. - Leipzig, 1860; 2-te Auflagen, Leipzig, 1889.
10. Stevens S.S. Psychophysics. – N.Y., 1975.
11. Zabrodin Yu.M., Lebedev A.N.. Psychophysiology and psychophysics. – Moscow, 1977.
12. Volkov P.P., Oksen V.H. Informational modeling of emotional states. Minsk, 1978.
13. Gumbel E.I. Statistical Theory of Extreme Values and Some Practical Applications. - Washington, 1954.
14. Volgin N.L. Coordinated optimum principle. Moscow, Soviet Radio Publisher, 1977.
15. Building regulations. Fire safety of buildings and structures. SNiP II-2-80. Moscow: Stroizdat; 1981.
16. State Standard 12.1.0004-91 (GOST). ‘‘Fire Safety. General requirements’’. Moscow, 1992.
17. The methodic of fire risk calculationin buildings, constructions and structures of various functional usage. – Ministry of Justice of the Russian Federation: reference number №14886 (6.07.2009).
18. Kholshchevikov V.V. Research of human flow and methodology of standardization of people fire evacuation from buildings. – Moscow, 1999.
19. Develop and implement new space planning and constructions decisions for underground stations taking into account the high-speed train running. Report/ MISI; research supervisor Kholshchevnikov V.V., responsible agent Dmitriev A.S. - № 01860005733 – M., 1989.
20. Isaevich I.I. A development of multi-variative analysis of design solution for subway stations and transfer knots based on foot traffic flow modeling. : Thesis … candidate of techn. science (Supervisor V.V. Kholshchevnikov). - Moscow Civil Engineering Institute, 1990
21. Kholshchevnikov V.V., Kiruchantcev E.E., Shurin E.T. First experimental research on disabled persons in a crowded flow. Human safety in fire. Moscow: Higher Fire Safety Engineering School; 1999.
22. Shurin E.T., Apakov A.V. The classification of mobile groups and individual movement in pedestrian flow as a background for ‘‘mixed’’ pedestrian flow modeling. Problems of Fire Safety in Construction. In: Proceedings of Scientific–Practical Conference. Moscow: Academy of State Fire Service; 2001. p. 36–42.
23. Research and calculation of movement relations for pupils. Report/ MISI; research supervisor Predtechenskii V.M., responsible agent Kholshchevnikov V.V. - № GR 75006136; Inv. № B 378487 – M.: 1975
24. Eremchenko M.A. Human flow movement in schools.: Thesis … candidate of techn. science (research supervisor Predtechenskii V.M.) – Moscow Civil Engineering Institute, 1979.
25. Kopylov V.A. The study of people’ motion parameters under forced egress situations.: Thesis … candidate of techn. science (research supervisors Predtechenskii V.M.. Roytman M.Y.) - Moscow Civil Engineering Institute, 1974.
26. Zailin S.V., Bushmanov S.A., Parfenenko A.P., Belosokhov I.R. Providing safety of people in fire in buildings by self-rescuers. Fire and explosion safety 2011, №3,4.
27. Kholshchevnikov V.V., Parfenenko A.P. Children evacuation from educational institutions. Fire safety in constructions. 2011, №4.
28. Kholshchevnikov V.V., Samoshin D.A., Parfenenko A.P., Belosokhov I.R. Study of Children Evacuation from Preschool Education Institutions. Fire and Materials Journal. Accepted for publication.
29. Kholshchevnikov V.V., Samoshin D.A., Istratov R.N. An evacuation of people with physical disabilities. Online journal “Technology of Technosphere Safety” № 3 (43) 2012, pp. 1-9.