DESCRIPTION DEVELOPMENT OF FIRES IN RURAL SETTLEMENTS ADJOINING ON FORESTS

Farid ABDULALIEV [1], Alexey IVANOV [2]

SUMMARY:

In thesis consider the new approach of forecasting and spreading of fires in rural settlements with use percolation models and of the neural networks. It also gives recommendations for planning of fire prevention, firefighting strategy. The percolation process represents the spreading of the process through the grid where there is at least one continuous way through adjacent nodes from the one side to the opposite one. The neural network is description of process fire development on difficult building objects with weather conditions.

Key words: *methods of forecasting of fires, percolation process, fire extension, Markov process, the neural networks*

INTRODUCTION

Forecasting occurrence and extension of burning is one of the pressing questions in the sphere of people's safety at fires and protection of material resources. One specific thing about researching fires is that that when calculating the likelihood estimation, especially for a large and complex object, the quantity of the information needed, number of settlement methods and modeling of particular situations required are enormous. At that point the insufficiency of the information necessary to estimate the danger of fire extension, including methods of settlement substantiation of the causes of fires is quite common.

Any approach to modeling, whether it is physical or mathematical, represents a complex challenge for researchers. The concept of fire modeling covers physical and mathematical representation of all the processes anyhow associated with the occurrence and extension of a fire, including influence of dangerous factors of a fire (DFF) on person, people's behavior in extreme situations, strategy and tactics of firefighting, an estimation of a potential and real damage from a fire.

1. FIRES ON OPEN AREAS

Fires on open areas especially in rural settlements (gardening communities, country sites) are notable for their big scales, necessity to take into account the weather conditions, remoteness of fire brigades, specific location of water sources etc [1–12].

Today modeling of the processes of burning is associated with the mathematical deterministic and stochastic (probabilistic) models describing the extension of a fire on compartment [13, 14]. In each of the methods of fire forecasting there is a specific evaluation of decision-making. Fire spreading on open areas which can lead to the occurrence of the ardent burning, decaying burning or termination of burning are studied not enough. In many cases doing an analysis of the processes occurring during the fire it is impossible to consider a random factor of occurrence and development of a fire. In connection to that the necessity of perfection of fire forecasting methods arises. In some resent works a special attention is given to the probability approach of forecasting burning process, with use of the percolation theory [15–18].
Percolation represents the spreading of the process in the environment where there is at least one continuous way through the adjacent

[1] Farid Abdulaliev, Ing., The Saint-Petersburg University of State Fire Service of EMERCOM of Russia, Faculty of preparation and retraining of scientific and scientific and pedagogical staff, 149, Moskovsky pr., 196105, Saint-Petersburg, Russia. Tel.: +7-921-889 90 15, e-mail: hasfarid@inbox.ru

[2] Alexey Ivanov, Ing., PhD., The Saint-Petersburg University of State Fire Service of EMERCOM of Russia, Faculty of scientific and pedagogical staff training, 149, Moskovsky pr., 196105, Saint-Petersburg, Russia. Tel.: +7-812-388 73 18, e-mail: aspirantura_ugps@mail.ru

nodes from one side to the opposite. A percolation process of burning exists if there is at least one continuous way of fire spreading in space from one side of object to another. This model can be presented on a two-dimensional lattice (Fig. 1).

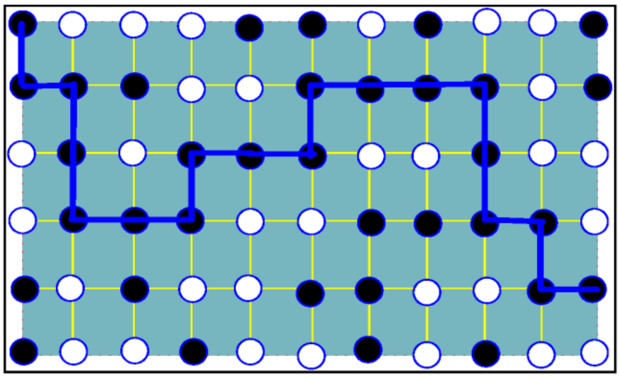


Figure 1. **An example of a percolation process**

The way represented by the line shows the system is above the threshold of the environment. The phenomena described by the theory of percolation are related to the so-called critical phenomena. The most important feature of physics of all the critical phenomena lies in the fact that close to the critical condition the system breaks up into some blocks with different properties, and the size of separate blocks unlimitedly grows when approaching to the critical (threshold) point. Thus the configuration of blocks is casual. In some physical phenomena the whole configuration changes chaotically, in others it changes at the transition from one sample to another. Blocks are located randomly and in the course of their formation it is difficult to see any geometrical laws. However these laws exist and possess quite certain properties. Physical and chemical properties of the system are intrinsically linked to its geometry (for a square lattice the percolation threshold X_c, namely 0.59 was defined) [16]. Process of percolation is described by a stochastic area in space and a vector area of transitive numbers.

Broadbent and Hammersley considered the process of wandering on the graph consisting of a certain number of knots connected to each other with directed links. Transition is possible only on such links. If such graph submits to certain laws it is named a percolation cluster. Fire distribution in the environment can occur only through the directed links [17].

As an example it is possible to consider the real fire which occurred in gardening settlement in which houses are located in the certain area (Fig. 2).

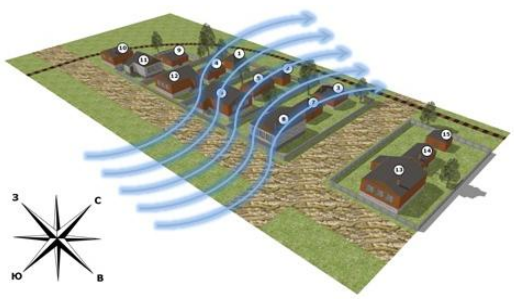


Figure 2. **A fire in Gatchina area, Leningrad region.**

As a rule the basic consequence of fire distribution is transmission of energy as a result of radiant heat exchange in active burning. The quantity of the heat radiation allocated in a unit of time depends on capacity of a source of ignition. Another factor of fire distribution are sparks. The quantity of sparks depends on a set of casual parameters, such as a territorial arrangement of combustible objects, natural and weather conditions.

At occurrence of a fire the houses will be connected by the directed links characterizing the fire distribution. Each link has an independent probability of blocking or prevention of distribution of the fire, depending on design features of a building, wind and distance between buildings (Fig. 3). Houses 11, 8 are built of bricks, i.e. they are blocking knots therefore fire does not pass over to these houses, while the other houses are made of timber and thus threat of transition of fire remains.

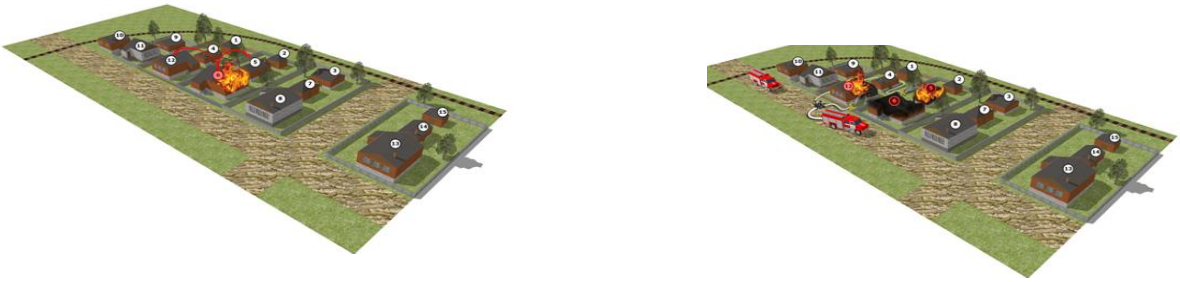


Figure 3. **Free extension of a fire in time with the account fire brigade**

The entire time interval from the moment of a fire occurrence up to the beginning of its suppression is defined as the time of free extension of a fire. If we consider the worst scenario of free extension of a fire when the process will get through the whole environment (without considering the arrival of fire brigade or something, or preventive measures undertaken) there can be defined the area the fire to extend according to the theory of percolation (Fig. 4).

The countryside is modeling in the form of a square site. Nodes on a site are fire loading which corresponds to the houses. Nodes are connected with each other by links. These links can be of the two classes. One of them connects sites between which there is a probability that fire will be transferred as a result of radiant heat exchange. Links of the other class connects pair of sites between which fire will spread by means of sparks.

Figure 4. **Free fire spreading in time without taking into account fire brigade (according to the percolation process)**

2. MATHEMATICAL MODELS

For the analysis the statistical data about the fires which occurred in Leningrad region in 2009–2011 were used. Settlement fire area S_{calc} on percolation on 50 fires (table 1) was defined. As a result of the analysis the indicator of reliability of the model which shows the area above the percolation threshold on which the fire spreads was received, confirming the development of process in space.

Table 1

Leningrad region

№	On moment localization	$S_{calc.}$ time of free development of a fire * arrival and/or operations fire brigade ! localization					Coefficient application models $F_a = S_{calc.} / S_{fact.}$				
	$S_{fact.}$	0-20 min	20-40 min	40-60 min	60-90 min	90-120 min	0-20 min	20-40 min	40-60 min	60-90 min	90-120 min
1	108m^2	-	*! 168m^2	216m^2	270m^2	-	-	1,55	-	-	-
2	170m^2	-	-	*! 260m^2	357m^2	477m^2	-	-	1,52	-	-
3	102m^2	*!	226m^2	388m^2	-	-	1	-	-	-	-
4	250m^2	*	* 116m^2	* 460m^2	! 600m^2	751m^2	-	-	-	2,4	-
5	314m^2	-	* 64m^2	* 236m^2	! 520m^2	-	-	-	-	1,65	-
6	100m^2	*	! 170m^2	268m^2	268m^2 the fire transition on forest area	-	-	1,7	-	-	-

Source: The Author

In percolation models the territory on which rural settlements are located is presented as system of combustible (flammable at external thermal influence) sites (knots) distributed in space. Possible conditions of various (separate) sites (knots) and transitions between these conditions can be put into the matrix, according to Markov *process* [19].

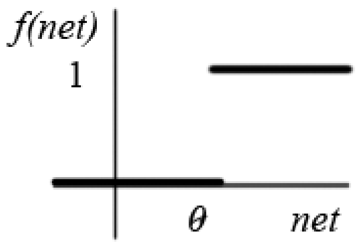
Evaluation fire danger in constructions of rural type two problems was considered. Firstly the factors influencing development distribution of a fire were taken into consideration. Secondly the problem was connected to the accuracy of data processing. The way to resolve the problems was to use *the neural networks* [20, 21].

The neural network is a set of the elements connected so that between them the interaction was provided. These elements named *neurons* or knots represent the simple processors and their computing possibilities are usually limited to a rule of a combination of entrance signals and a rule of activization allowing calculating final emitted signal as a response to a set of entrance signals. The final signal of an element can be sent to other elements on the weighed links each of which has a weight factor. Depending on value of weight factor the transmitted signal either amplifies or chokes. One of the most attractive aspects of using neural networks consists in the fact that the network as a whole uniting a great number of such elements appears capable to carry out quite difficult tasks [20].

An advantage of neural networks consists in the ability of weight factors to be trained in performance of a problem on the basis of the data which the network receives and accumulates in the course of real work. The structure of the links reflects how elements of a network are connected. The structure of links usually is represented in the form of a weight matrix W, in which each element w_{ij} represents the weight factor for the link going from the element *i* to the element *j*. For the description of the structure of links not only one but some weight matrixes can be used if elements of a network appear grouped in layers. The matrix of scales is memory of the network, storing the information about how the task should be carried out. Quite often entering signals are supposed to be combined by summation of their weighed values.

For all the elements there is a rule of calculation of target value, which it is supposed to transfer to other elements or the environment (if it is a question of the target element representing the end result of calculations). This rule is named activity function, and corresponding target value is named activity of a corresponding element. Activity can be represented either by some valid value of any kind or by a valid value from some limited interval of values (for example, from an interval [0,1]), or some value from a certain discrete set of values (for example, {0,1} or {+1,-1}). On an input of function of activity value of the combined input of the given element arrives.

In the majority of models of neural networks nonlinear functions of activity are used. Threshold function are limited to the values 1 or 0 depending on value of the combined input in comparison with some threshold size θ (Fig. 5).



$$f(net) = \begin{cases} 1, if\ net_j \geq \theta \\ 0, if\ net_j < \theta. \end{cases}$$

Figure 5. **Threshold function**

Most often used function of activity is logarithmic function. Target values of such function continuously fill the range from 0 to 1 (Fig. 6).

$$f(net) = \frac{1}{1 + \exp(-net)}$$

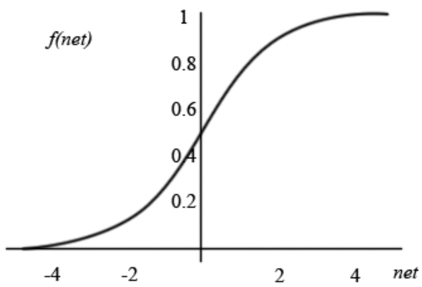


Figure 6. **Logarithmic function**

The inclination and area of target values of logarithmic function can be different [21].

To train a neural network applied in research of process of fire spreading in rural settlements, mathematical package MATLAB® was used, as entrance characteristics were the statistical data of fires in Leningrad region during the period 2009 to 2011 were taken (table 2).

Table 2

The situation characteristic on fires in rural settlements of the Leningrad region

№ n/n	Main characteristics							
1	Fire date		27.03.11	02.04.11	24.04.11	04.05.2011	02.06.11	8.07.2011
2	Speed of a wind and temperature	m/s	↑3 Clear	→5 Cloudy	→2 Clear	↙6 Cloudy	↘6 Cloudy	↖2 Cloudy
		C°	12	+6	+6	+4	+20	+22
3	Distance to a fire from Fire Station, km		8	40	17	15	10	16
4	Time of following, min $t_{arrival} - t_{messages}$		14	37	19	15	18	20
5	Time of giving of the first fire trunks, min $t_{giving} - t_{messages}$		15	38	20	16	19	21
6	Time of localization, min $T_{loc} - t_{arrival}$		26	36	20	77	102	16
7	Quantity of staff of a fire brigade, $N_{fire\ auto} \cdot 3$ units.		6	6	6	6	6	6
8	Consumption of water, Q, m/s $Q_{dw} = N_{tr} \cdot q_{tr} + N_{tr} \cdot q_{trt}$		14,8	14,8	14,8	14,8	14,8	14,8
10	Distance to a water source, min		FG, 1000	FR, 400	FR, 150	FG, 700	FR, 1000	FG, 800
11	Fire resistance degree		V	V	V	V	V	V

Source: The Author

As the entrance data of model are: speed of a wind, temperature, distance from FS to a fire, following time, time of giving of the first trunks, localization time, distance to a water source (Fig.. 7).

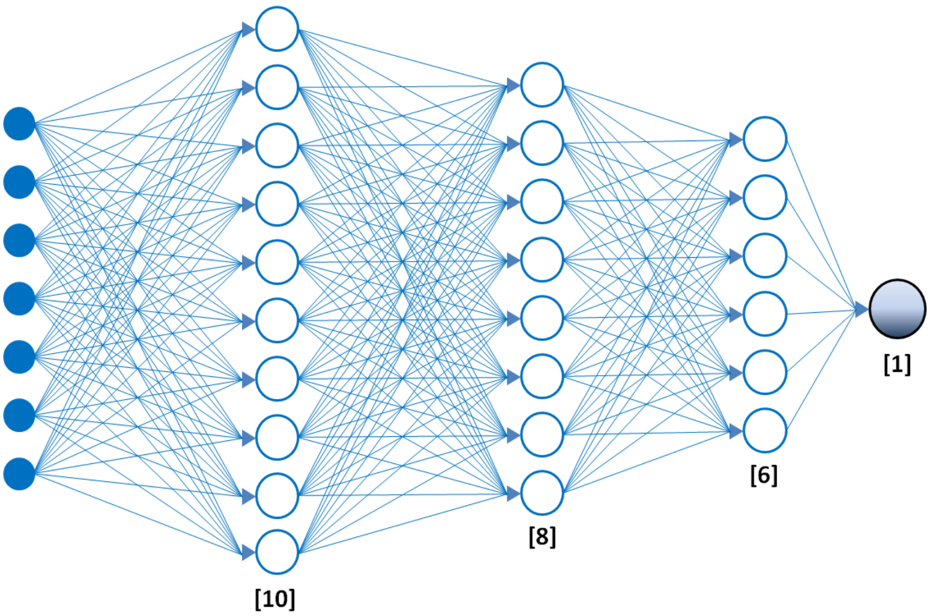


Figure 7. **The scheme of application of a neural network for an estimation of fire danger in rural settlements**

During research the 4h-layer neural network is constructed:

– 10 neurons in the first layer,
– 8 neurons in the second layer,
– 6 neurons in the third layer,
– 1 neuron in the last.

Layers get out by means of an expert estimation. The maximum deviation in the trained neural network makes 5.1970e-005. The Maximum quantity of cycles of training made 1200.

Links of the elements are shown by arrows. Entrance elements receive the information directly from the statistical data on fires. The target element is factor of definition of a fire area.

When the approbation of the results of the research was carried out the estimation of fire danger proceeding from the statistical data received in 2011 was completed. Reliability of the received results makes 100 %. A divergence was no more than 10 % that allows estimating adequately the given model (table 3).

Table 3

Approbation of results of research

№	Fire area		Coefficient of applicability F_A	Coefficient of applicability trained by neural networks	$\Delta = [F_A^{HC} - F_A]$	$\delta = \frac{\Delta}{F_A^{HC}} x100\%$
	S_{fact} (m^2)	S_{calcul} (m^2)				
1	106	186	1,75	1,79	0,04	2,23
2	120	370	3,08	3,16	0,08	2,53
3	105	320	3,04	3,13	0,09	2,87
4	90	182	2,02	2,05	0,03	1,46
5	115	200	1,73	1,81	0,08	4,41
6	112	170	1,51	1,67	0,16	9,58
7	156	275	1,76	1,83	0,07	3,82
8	100	148	1,48	1,55	0,07	4,51
9	108	208	1,92	2,08	0,16	7,69
10	106	172	1,62	1,65	0,03	1,81

Source: The Author

CONCLUSION

Thus, research has shown that fire spreading in rural settlements on the basis of the percolation process with application of function of a neural network, considering the certain data, will allow estimating fire danger of complex objects. These recommendations can be used to plan fire-prevention actions and firefighting tactics.

Literature

[1] Volf M, *Fire tactics. Rules of fires suppression in questions and answers.* SPb: Type. T-va., 1907.
[2] Povzik J.S. *Fire tactics: The textbook*. M: HEFTS the Ministry of Internal Affairs of the USSR, 1984.
[3] Terebnev V.V. *Century of Century Fire tactics. Concept about fire extinguishing.* Yekaterinburg: Publishing house «Kalan», 2010.
[4] Artamonov V.S. *Fire tactics: The manual*. SPb: the St.-Petersburg university GPS of the Ministry of Emergency Measures of the Russian Federation, 2011.
[5] Methodical recommendations about actions of divisions of a federal fire service at suppression of fires and carrying out of a wrecking: Letter CRC the Ministry of Emergency Measures of Russia from 22.06.10 № 5427-5-1-2*. M, 2011. 112 with.
[6] FRS 01-03. *Fire prevention rules in the Russian Federation*: The order of the Ministry of Emergency Measures of the Russian Federation from 6/18/2003 № 313; зaper. In Ministry of Justice of the Russian Federation of 6/27/2003, per. № 4838//the Russian newspaper. 2003. № 129.
[7] Recommendations about the firefighting organization in countryside: 12/26/2000 the Ministry of Internal Affairs of Russia: 12/26/2000. M: FGU VNIIPO the Ministry of Internal Affairs of Russia, 2001.
[8] The joint venture 53. 13330.2011. A lay-out and building of territory of gardening (country) associations of citizens, buildings and constructions: approved. The order of Ministry of Regional Development of the Russian Federation from 30.12.11 № 849; 20.05.11. M: Open Society «CPP», 2011.
[9] Technical regulations about requirements of fire safety: Federal. The law from 7/22/2008 № 123-FZ.
[10] The joint venture 11.13130.2009. Places of a disposition of divisions of fire protection. An order and a definition technique: approved. The order of the Ministry of Emergency Measures of the Russian Federation from 3/25/2009 № 181; 5/1/2009. M: FGU VNIIPO the Ministry of Emergency Measures of Russia, 2009.

[11] An order of attraction of forces and means of divisions of fire protection, garrisons of fire protection for suppression of fires and carrying out of a wrecking: The order of the Minister of the Ministry of Emergency Measures from 5/5/2008. № 240.
[12] Brushlinskij N.N., Sokolov C.B. *About rationing of an arrival time of fire divisions to a fire place* // Fire and explosion safety. 2011. T. 20. № 9. P. 42–48.
[13] Koshmarov J.A. *Forecasting's nightmares of dangerous factors indoors: the manual*. M: Academy of State Fire Service of the Ministry of Internal Affairs of Russia, 2000.
[14] Ramachandran G. *Non-Deterministic Modeling of Fire Spread*//Journal of Fire Protection Engineering. 3 (2). 1991. P. 37–48.
[15] Abdulaliev F.A. *Description of fire development by percolation models*: Proceedings international scientific conference: Safety engineering (Fire, Environment, Work environment, Integrated risk). Novi Sad, Republic Serbia, 2010. P. 563–567.
[16] Efros A.L. *Physics and disorder geometry*. M: publ. «Nauka», 1982. 265 p.
[17] Kemeny J., *Snell of J. Final chains of Markova*. The Lane with English. M: publ. A science, 1970. 272 p.
[18] Kallan R. *The River the Basic concepts of neural networks*. The lane with English. M.: publ. «Williams», 2001. 290 p.