Analysis of the cognitive model «Safety of people in emergency situations»

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Abstract. The stages for cognitive modeling designed by the authors to build and analyze a cognitive model are presented in the article. The theory of graphs and evaluation methods are used to formalize a simplistic cognitive model visualized as a cognitive map. Alignment of evaluations is provided using mathematical statistics.

The simulation experiment to support the model is developed with both Microsoft Excel and the original software program worked out by the authors using the algorithm based on a mathematical model represented by finite and differential equations. Auctorial original software to analyze the cognitive model is necessary in order to substitute the imported computer programs. Comparing both outcomes reveals that the developed software performs calculations correctly. The results obtained with both software are given to support the experiment.

1. Introduction
At present, great attention is paid to people safety in connection with considerable growth of different emergencies resulting from natural and technological disasters and their pressures. Therefore, research to simulate and predict emergencies of various kind and their consequences is of urgent necessity. In accordance with GOST R 22.0.02-94 emergency is defined as a situation in a particular territory or area, resulted from an accident, natural disaster, catastrophe, or any other dangers and threats, which may be accompanied with human sacrifices, health hazards or damages to natural environment, significant loss of resources and life disorder.

The system should be rather instrumental for quick and adequate respond to changing conditions, facilitate to make decisions at the state of uncertainty, etc. K.P. Das and A.K. Dey approach the retrospective analysis to evaluate the risk of air crashes. They predict the risk of death accidents in the air crashes against the value of the investigated factor based on Pareto method [1]. S. Gil et al. examine associations between general family relations, family climate and young males’ driving styles using the completed several self-report questionnaires. The results reveal the direct effect between the cost of thrill and the safe driving style. The outcomes of the research may be useful to develop recommendations to prevent youngster’s risky driving and car crashes as well as to encourage safe and considerable driving [2]. Usón T.J. et al. focus on the analysis of information management to reduce risk of natural hazards such as floods. Based on in-depth interviews and document analysis, the study indicates lack of communication between local and regional authorities and the community; therefore, local actors’ views to discuss possible solutions and risk-management strategies to avert damages are not considered when making decisions [3]. G.C.Jr. Carim and his colleagues, statistically define how a cockpit manages emergencies and other non-normal situations. The initial data is collected through participant observations, interviews and analysis of technical documents. The results indicate that some situations uncounted by pilots are far more complicated to eliminate than the procedure
anticipates. In order to cope with these situations, these findings suggest the pilots should be provided with the choice of actions rather than mandatory instructions [4]. P. Pecha and V. Šmídl propose a stepwise sequential assimilation algorithm within optimization approach to inverse modeling and tracking of radioactive plume propagation for real-time estimation of radiological consequences in the early stage of an accidental radioactivity release. It predicts the dissemination of radioactive substances at every moment taking into account the weather forecast. The proposed method is designated as a stepwise re-estimation of release dynamics. The method developed results in a more precise determination of the adversely affected areas in the terrain where the negative effects of the accident can be manifested. To build a model of experimental data deviations from theoretical assumptions, nonlinear methodology, regression analysis and the least squares method are applied [5].

R.S. Murthy researches psychosocial and behavioral aspects of populations affected by humanitarian emergencies. Data analysis reveals that the most important thing for people in emergency situations is to recover mental health. For population living in situations of potential emergency, the urgent need is to work toward adequate preparedness for possible natural disasters and rehabilitation after them [6].

2. Prediction methods

*Extrapolation method.* The aim of the research of emergencies is to monitor their natural and technological reasons as well as to predict their parameters and consequences. The research is based on mathematical and heuristic approach. Mathematical approach suggests using the data available on the basic characteristics of an object, which can cause emergencies; then subsequent mathematical data processing, and identifying different dependencies linking the above-mentioned characteristics. Heuristic approach presupposes the analysis of expert opinions on the past situations using approximate reasoning based on knowledge, intuition and experience.

Extrapolation method is widespread in prediction practice now. It envisages study on retrospective characteristics of the object to be predicted and subsequent transfer of its development patterns from past to future (Table, Fig.1)

| Emergency/year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|----------------|------|------|------|------|------|------|------|------|
| technogenic    | 178  | 185  | 229  | 166  | 186  | 179  | 129  | 117  |
| natural        | 118  | 65   | 150  | 116  | 44   | 45   | 53   | 44   |
| biosocial      | 43   | 42   | 56   | 46   | 31   | 33   | 54   | 26   |

Figure 1 shows a retrospective analysis of the certain number of technogenic (1), natural (2) and biosocial (3) catastrophes according to the Russian Ministry for Emergency Situations. Curved line 4 is data approximation based on technogenic indicators in the form of a polynomial trend line. Dotted line 5 is extrapolation of data based on biological and social indicators in the form of a linear trend line. Extrapolation is based on alignment of time series. The alignment is performed by relevant mathematical calculations, which allow building a trend graph. It is a straight line falling for the minimum sum of squares of distances behind the points representing the actual values registered over the years of observation for a specific phenomenon. The line should fall as close as possible to all points of the time series. The trend line falling beyond the real observations transfers tendencies specific for the past state of the studied phenomenon to its future state. Taking into account standard deviations of the actual data from the calculated trend values on the phenomenon in question, its probability characteristics can be defined. With our example, we can predict decrease in socio-biological emergences in 2019.
Cognitive modeling is one of the effective methods of prediction. The method represents cognitive structured knowledge about the object studied as well as about the external environment. The technique of cognitive modeling was designed by foreign scientists and then adapted to the Russian conditions by the scientists from the Institute of Control Sciences Academician VA Trapeznikov of Russian Academy of Sciences. The aim of cognitive modeling is to identify the most significant factors for the situation and to determine qualitative causal relations between them. Selection of the main factors is carried out using two instruments: PEST and SWOT analyses. PEST analysis is a four-element strategic analysis of environment aimed at such aspects as politics, economy, social factors and technology. SWOT analysis examines strengths and weaknesses, opportunities, and pressures for the object of research. Further, a cognitive model is developed and a simulation experiment started to identify alternatives for the developing situation. The model is presented in the form of a cognitive map as a directed graph (F, W), where F is set of factors of the situation, W is set of causalities. Situational factors are divided into control and target factors. Curves connecting the factors represent the values and directions of impact.

The authors analyze the situation for people safety in emergency when such factors as «destructions», «fire», «pollution», «panic» as well as ‘time of arrival of rescuers’ have a significant impact. All factors are closely interconnected, uncontrollable and contribute to uncertainty of the situation analyzed. Figure 2 represents a simplistic cognitive map «People safety in emergencies» with expert evaluations of control and target factors influencing each other.

Formalization of the cognitive model is realized in the form of tuple $F = (G, X, F)$, where $G = <V, E>$ is directed graph; $X$ is set of nodes $V$; $X: V → R$; $R$ is set of real numbers; $F = F (X, E) = F (x_i, x_j, e_{ij})$ is arc-transformation functional, which assigns appropriate weighting coefficient $w_{ij}$ to each arc.

The simulation experiment reconstructs the possible development of the investigated situation in a virtual reality by means of software. The point of computational experiment is that an impulse directed to one of the nodes of the graph actualizes the whole system of indicators on the graph to a greater or lesser extent. If there is dependence between two control factors, of 0.5 in the conventional units for example, and the value of a single control factor increases by 10% (perturbation effects), then the value of another controlling factor in this case increases by 5%. The parameters of the cognitive model $x_i (t), t = 1, ..., n$ are dependent on time. If at the time $t$ the impulse $p_j ∈ P$ is directed to the node, then transfer of the system status $t$ into $t+1$ is performed according to the rule: $x_i(t+1) = x_i(t) + \sum_{j=1}^{k-1} f(x_i, x_j, e_{ij}) p_j(t)$, under all initial values.
Figure 2. Simplified cognitive map "People safety in emergency".

The curves in Fig. 3 (a, b) visualize the changes in the directed graph while directing impulses to different nodes of the graph. Decreasing controlling factor "panic" to zero causes increase in the values of the target factor "People safety in emergency".

Figure 3 a, b. Visualization of changes in the situation with several steps of calculations a) «panic» 5 conventional units, «time of arrival of rescuers» 10 conventional units, b) decrease of indicators

The simulation experiment uses both the Microsoft Excel and the original software program developed by the scientists of Omsk and Baikal universities. The original software to analyze the cognitive model contributes to the Russian policy to substitute the imported computer programs. Diagrams in Fig. 3a and 3b are developed with Microsoft Excel. In Fig. 3a and b, the target factor 'people safety in emergencies' (red dotted line) under changes in controlling factors 'panic' and 'time of arrival of rescuers' is presented. The original software developed by the authors is designated for laboratory research on sustainability of a cognitive model designed as a weighted directed graph with nodes (factors of a cognitive model) and arcs linking them. Based on the formed graph the table (adjacent matrix) is filled in with the size $n \times n$, where $n$ is an integer. The elements of the matrix are expert
evaluations of the relations between the factors. The algorithm of developing the simulation model is based on difference equations. The impulse directed to one of the digraph nodes

\[ P_i(t) = v_i(t) - v_i(t - 1) \]

is defined by the relation

\[ v_i(t) = v_i(t - 1) + \sum_{j=1,j\neq i}^N F(v_i, v_j, e_{ij}) P_j(t - 1) + P_i^0(t), \]

where \( P_i(t) \) – external impulse directing to node \( e_i \) in time interval \( t \). Of two final difference equations, we come to the equation for the impulse in the process investigated:

\[ P_i(t) = \sum_{j=1,j\neq i}^N F(v_i, v_j, e_{ij}) P_j(t - 1) + P_i^0(t). \]

Verifying the sustainability of the cognitive model envisages several steps of calculations alongside with their subsequent visualization [8]. Figure 4 shows the result of the simulation experiment, developed with the original software. The results of the computations obtained with both programs coincide. That means we can use the auctorial original program instead of the Microsoft Excel-based tool to analyze the cognitive models. The original program starts using cross-platform method. The method provides running the original software without foreign operational systems.

![Figure 4](image_url)

**Figure 4.** The result of the simulation experiment, developed with the original software.

Figure 5 shows the fragment of the original software algorithm.
Figure 5. The fragment of the original software algorithm
Conclusion
The simulation modeling reveals efficiency of cognitive methods to analyze structural characteristics and controlling functions as a theoretical means to train specialists. The simulation experiment in this case is regarded as a training and assessment tool illustrating the development of a situation, independent of any particular sphere when changing corresponding influential factors. The software developed will be further used to analyze cognitive models in different fields of human activities.

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