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A New Approach to Assessing the Accuracy of Forecasting of Emergencies with Environmental Consequences Based on the Theory of Fuzzy Logic

Eduard Tshovrebov[1], Vladimir Moshkov[1], Irina Oltyan[1] and Filyuz Niyazgulov[2†]
[1]All-Russian Scientific Research Institute for Civil Defence and Emergencies of the EMERCOM of Russia (Federal Science and High Technology Center), Moscow, 121352, Russia
[2]Russian University of Transport (RUT MIIT), Moscow, 127994, Russia
†Corresponding author: Filyuz Niyazgulov; flyuz1989@yandex.ru

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ABSTRACT

Prevention of the occurrence and development of emergencies of a natural and man-made nature is one of the basic fundamental foundations of ensuring the national security of any state. The most important mechanism for preventing emergencies is an effective system of monitoring and forecasting emergencies established at the state level. In the process of functioning such a system, one of the main urgent problems requiring constant attention, continuous research, system analysis, and the search for solutions by scientific methods and methods is to increase the reliability of emergency forecasts. In this format, special attention is currently being paid worldwide to a comprehensive assessment of the adverse consequences of emergency situations, primarily related to the safety of the population, environmental conservation, and environmental safety. From the standpoint of solving this significant scientific and practical problem, the purpose of this work was to develop and justify a more advanced method for calculating the feasibility of forecasts of emergencies with environmental consequences as a tool for a reasonable detailed assessment of the quality, optimality of emergency forecasting processes and the reliability of the forecasts themselves.

INTRODUCTION

Forecasting of possible emergencies and related risks is aimed at ensuring the safety of life and protecting the population, the environment, and territories from natural and man-made emergencies, and their wide range of adverse consequences. In this regard, it seems to be the most important and relevant to ensure the effectiveness, quality, accuracy, and validity of emergency forecasting, the results of which are currently evaluated by the analytical indicator "justifiability of emergency forecasts".

The calculation of the feasibility of emergency forecasts is carried out following the Methodology for calculating the indicator "The proportion of justified emergency forecasts prepared by the emergency monitoring and forecasting system in the total number of emergency forecasts". In this Methodology, the proportion of justifiability of emergency forecasts (Pi) prepared by the emergency monitoring and forecasting system (reliability of the forecast) is calculated using the formula:

$$P_i = \frac{n\,(T)}{N\,(t)} * 100\,\%\,, \quad \ldots(1)$$

n (*T*) - the number of emergencies and incidents during the time period *T* provided for by the forecast;

N (*t*) - the actual number of emergencies and incidents over a period of time *T*;

T - the forecast time period (year, season, month, decade, day).

The share of justified emergency forecasts in their total number ($К_o$, %) is determined by dependence:

$$К_o = \frac{\sum_1^i Pi}{i} \quad \ldots(2)$$

P_i – the indicator of the justifiability of the *i*-th forecast, *i* - the number of forecasts.

A high expected result for this indicator can be achieved provided that effective information support is provided, and a high degree of intersubjective, interdepartmental interaction of participants in the unified state emergency prevention and response system is achieved.

However, the practice of predicting emergencies of a mixed natural and man-made nature shows that this approach reduces the accuracy and validity of forecasting due to the underestimation of some factors:

1. The full range of possible upcoming adverse events;
2. A reasonable assessment of the final results of forecasting;
3. The mutual influence of the resulting dangerous events among themselves.

A decrease in the degree of accuracy and validity of emergency forecasting occurs in the absence or incompleteness of objective reliable data for monitoring dangerous events, sources of negative impact on the environment and public health, accounting for such information in state information systems (registers, cadastres, etc.). In addition, when predicting a large number of emergencies, or consistently transforming among themselves, it appears the use of statistical, heuristic methods is ineffective.

Problems and contradictions in the field of emergency forecasting, analyzed based on the results of evaluating the application of methods for calculating the reliability of forecasts, are classified from the positions:

1. Unclear identification of emergencies themselves and their adverse consequences; incompleteness, unreliability of initial forecast data.
2. Incompleteness, unreliability of the initial forecasting data.
3. Underestimation of all conditions, external and internal factors in the process of emergency forecasting, cause-and-effect relationships between dangerous events and phenomena, and their resulting consequences.
4. The unreasonableness or inaccuracy of choosing a predictive method for a specific event, situation, phenomenon, or incident.
5. Imperfections of one or another predictive method that does not provide the necessary level of forecast accuracy.

There is an insufficient number of scientifically based emergency forecasting methods for all types of emerging emergencies, both single and sequentially occurring with a domino effect, assessing their adverse environmental and other consequences within the framework of an integrated approach.

In this regard, there is a need to find new methods and ways to evaluate the results of forecasting in conditions of incomplete data. The present work of the team of authors presented to readers is devoted to the methods of solving the raised scientific and practical problem.

MATERIALS AND METHODS

The materials for this study were the results of research by domestic and foreign authors in the field of application of modern technologies for forecasting natural emergencies (Akimov et al. 2023, Arefyeva et al. 2022), safety in construction (Lomakin et al. 2021, Arefeva et al. 2019, Telichenko et al. 2016, Slesarev et al. 2020, Zelinskaya et al. 2019), environmental and economic risks in waste management (Hart et al. 2019, Hertwich et al. 2020, Kirchherr et al. 2017, Murray 2002, Domenech et al. 2019), environmental safety of life support facilities and forecasting man-made hazards of sources of negative impact on the environment (Tskhovrebov et al. 2018, Tshovrebov et al. 2021, Tskhovrebov et al. 2018, Zelinskaya et al. 2021), forecasting emergency risks (Anisimov et al. 2016, Oltyan et al. 2020, Plyuschikov et al/ 2021, Prus et al. 2022), mathematical methods for analyzing various systems (Buryi et al. 2020, Vahdani et al. 2013), modeling of safety processes in natural and man-made systems (Sereda et al. 2019, Sereda et al. 2021, Sereda et al. 2022).

Research methods include collection, generalization, systematization, grouping, composition of initial information and research results, classification, comparative and comparative analysis, and numerical methods of processing the data obtained. The method proposed by the authors for assessing the feasibility of emergency forecasts and their environmental consequences is based on the application of fuzzy logic theory and soft computing methods.

RESULTS AND DISCUSSION

As part of the implementation of the task, the use of the apparatus of mathematical logic in proving the truth of the statements of the hypothesis put forward was chosen from the position that the analysis carried out using records in the language of predicate logic essentially implements the function of transition from the "organizational and technical" formulation of the problem to its mathematical formalization. In this process, the possibilities of effective use of the method are revealed in conditions of incompleteness, insufficient accuracy, and reliability of the initial data for predicting emergencies.

A similar approach has already been used by Perm scientists S.N. Kostarev and T.G. Sereda in assessing the safety of technical means and has received an effective practical application in the adaptation process in predicting the safety of technical and technological systems.

Let's formulate a logical statement in the language of predicates.

Statement: An unjustified forecast is either a statement about a future event that did not come true (did not actually occur) or the absence of a statement about an event that subsequently actually occurred (within the forecasting period).

Proof: Let's say: F – forecast (a statement about the occurrence of a possible dangerous event in a certain period of time); E – event forecast; J – justifiability of the event forecast.

Let's form a logical formula for expressing the justifiability of the forecast:

$$J = (\forall F \rightarrow \exists \neg E) \vee (\forall E \rightarrow \exists \neg F)$$

Let's build truth tables of a given formula using definitions of logical operations:

Since the last column consists only of units, the formula presented above is logically consistent.

Based on the results of the logical and mathematical justification, it is proposed to improve the calculation of the indicator of the validity of emergency forecasts and to assess the accuracy of predicted man-made emergencies according to the formula:

$$D = (1 - P_J) * 100, \quad \ldots(3)$$

D – accuracy of the forecast;

P_J – the probability of an incorrect (erroneous) forecast.

F	E	F®E
0	0	1
0	1	1
1	0	0
1	1	1

E	F	E ®F
0	0	1
1	0	0
0	1	1
1	1	1

F®E	E ®F	∨ (J)
1	1	1
1	0	1
0	1	1
1	1	1

$$P_J = P_I + P_2, \quad \ldots(4)$$

P_I – the proportion of unjustified forecasts equal to the ratio of the number of predicted but not occurred events to the total number of predicted events within the framework of this forecast;

Table 1: Threshold impact of technospheric emergencies on natural components.

Technosphere emergencies	Threshold effect on natural components		
	Water	Soil quality	Atmospheric air
Accidents of freight and passenger trains with the release, spillage, scattering, and dumping of hazardous chemicals	1	1	1
Accidents of cargo and passenger ships	1	1	0
Aviation disasters	1	1	1
Major car accidents	0	1	0
Accidents on oil pipelines	1	1	1
Accidents on main gas pipelines	0	0	1
Accidents on electric power systems	0	1	0
Accidents on utility systems	1	1	1
Accidentsonheating networks	0	0	1
Hydrodynamic accidents	1	1	0
Accidents with the release (threat of release) of chemically hazardous substances	1	1	1
Accidents at agricultural facilities	1	1	0
Explosions in buildings in populated areas	0	1	1
Explosions at industrial facilities	0	1	1
Explosions on communications	1	1	1
Sudden collapse of buildings	0	1	1
Sudden collapse of rocks, dumps, embankments	0	1	1
Poisoning and pollution of water bodies	1	0	0
Forest fires and forest arson	0	0	1
Fires in landfills	0	0	1
Infiltration, the translocation of toxicants from the body of landfills and landfills into the environment	1	1	1

P_2 – the proportion of unfounded forecasts equal to the ratio of the number of events that actually occurred, but were not predicted, to the total number of predicted events within the framework of this forecast.

We note the limitations, scope, and conditions of application of the proposed method for assessing the feasibility of forecasts. According to experts and specialists, the derived formula will be most applicable in calculating short-term forecasts as part of the implementation of the forecasting process at the federal, interregional, and regional levels.

It is proposed to assess the environmental consequences of an emergency using the soft computing method in conditions of incomplete data in a matrix way: according to the types of emergency situations classified according to established criteria in the format of effects on the components of the natural environment: atmospheric air, water, soil (Table 1).

The presented method, according to the authors, will contribute to increasing the degree of validity and accuracy of predicted emergencies due to the systematic analysis of both justified events and predicted factors and forecasting conditions.

CONCLUSIONS

The conducted research has a high level of practical significance in solving the issues of system analysis of the processes of forecasting man-made emergencies. The approbation and implementation of the method proposed by the authors for calculating the feasibility of emergency forecasts, on the one hand, will contribute to increasing the degree of responsibility of bodies and officials involved in the preparation of such forecasts, and, on the other, will give impetus to the development of a scientific and methodological basis for forecasting, the search for optimal, effective methods, tools and algorithms that provide a complex increase in the level of reliability, the validity, accuracy and quality of the emergency forecasting process.

Taking into account the fact that science has no state borders, the authors of the work invite readers to discuss the urgent scientific problem of emergency prevention and their dangerous environmental consequences, concerning the safety of the entire world community, the life and health of future generations in order to develop optimal, effective ways and measures to resolve it.

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ORCID DETAILS OF THE AUTHORS

Eduard S. Tshovrebov: https://orcid.org/0000-0002-9481-3832
Irina Yu. Oltyan: https://orcid.org/0000-0002-2178-5033
Filyuz Kh. Niyazgulov: https://orcid.org/0000-0001-6901-3318