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SYSTEM APPROACH TO FORECASTING AND PREPAREDNESS OF RESPONSE TO EMERGENCY SITUATIONS

Purpose. Development of system approach and formation of complex methods for joint forecasting of emergency situations (ES) and ensuring the preparedness of the response of civil protection units in real conditions.

Methodology. When developing methods for predicting ES and possible damage as result of them, polynomial-regression method with varied order, weighted least square method, probabilistic-statistical method, methods of time series and mathematical statistics were used. When developing models of resource provision of preparedness for emergency response, methods of regression analysis, time series and mathematical statistics were used. The principle of forecasting the costs of funds for the elimination of the consequences of ES is based on the fact that they are determined by the costs of eliminating man-made and natural emergencies. When choosing models for predicting technical support and the number of personnel required for emergency response, we proceeded from the fact that they should be determined not only by the predicted number of ES, but also by their nature. The model for optimization of territorial structures of civil protection (CP) is based on the principle of compliance of the number of regional structures with the level of threats in these territories. Methods of mathematical statistics and mathematical modeling were used in the study on the effectiveness of the application of system approach to joint forecasting and provision of preparedness for emergency response.

Findings. Methods for forecasting the processes of emergencies and damage as a result of them, models for optimizing territorial structures of civil protection, taking into account the state of man-made natural hazards in the regions of the state, forecasting technical support and the number of personnel to eliminate possible emergencies.

Originality. A system approach to solving the problem of joint forecasting of ES and maintaining the preparedness of response of civil protection units in order to minimize the consequences of these situations is proposed.

Practical value. The proposed set of methods and models is the foundation for substantiating organizational and technical measures to prevent and adequately respond to emergencies both on national scale and in the country's regions.

Keywords: *emergency, civil protection, preparedness of response, resource support, model*

Introduction. Consequences from emergency situations have a strong negative impact on the environment [1, 2] and the country's economy [3, 4]. Decreasing the number of emergency situations (ES), reducing the number of the fallen and injured, as well as reducing damages is a difficult scientific and practical problem, the solution of which can be obtained only through the use of the system approach.

Without the system approach use, solving this problem will be one-sided and not effective enough. The world experience shows that it is better to prevent ES than to deal with their consequences. Wherein, emergency preparedness should be considered as a priority step in ensuring the national security of the country. Ensuring the national security is an integral function of the state, which guarantees the necessary conditions for the life and activity of its citizens, the preparedness for and elimination of man-made and natural emergencies [5, 6].

At the present stage, ES prevention should be considered as a complex systemic process based on joint forecasting of ES occurrence and early response to threats of their occurrence or mitigation of possible consequences. At the same time, emergency prediction should be aimed at regulating technogenic, natural and social security, assessing the threat of occurrence and early ES response. The process of mitigating the consequences of emergencies should be aimed primarily at ensuring the preparedness of the response of civil protection (CP) units. Alongside this, the preparedness for response must be adequate to the levels and nature of the threats from ES otherwise the possibilities of ensuring the readiness of the CP units response to different levels of emergencies in different state regions are significantly limited.

Thus, today, emergency prevention should be considered as a complex systemic process based on joint forecasting of threats of their occurrence and ensuring the readiness of the CP unit response.

However, the known methods have limited capabilities regarding joint forecasting of threats of emergencies and ensuring readiness to respond to them. This creates a contradiction – on the one hand, the need to consider emergency prevention as a complex systemic process associated with joint forecasting of threats of their occurrence and early response to them, and on the other hand, the possibilities of available methods and models for this are limited.

Proceeding from this, the relevance of research aimed at developing the system approach to joint forecasting and preparedness to respond to emergencies is beyond doubt.

Literature review. ES prevention is a set of measures taken in advance and aimed at the maximum possible reduction of the risks of ES occurrence, as well as preserving human health, decreasing the size of damage to the environment and material damages in case of their occurrence [6]. Known methods for preventing emergencies have limited capabilities regarding the joint identification of threats to their occurrence and assessing the preparedness of response units. This gives rise to the contradiction mentioned above.

Important significance for preventing and responding to emergencies is acquired by information that contains data on forecasted and occurred emergencies and their consequences,

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as well as statements on the potential capabilities of the state CP units to eliminate the possible ES consequences.

Forecasting is the basis of ES prevention. Analysis of methods for forecasting the processes of ES occurrence was carried out in [7–9] and it was shown that they are united in the following main groups: extrapolational and interpolational methods; extrapolation by envelope curves; regression and correlation methods; statistical and probabilistic methods; expert methods; methods of logical modeling; construction of development scenarios methods.

The most important ES property is their random nature due to the influence of a large number of factors affecting the process of their occurrence. Therefore, the probabilistic approach to forecasting the process of ES occurrence [10, 11] is one of the most common methods for analyzing emergencies. The main disadvantage of the probabilistic approach is the difficulty in developing models of ES occurrence, which greatly complicates the analysis of the development of these processes in dynamics. An option to overcome these difficulties may be to use regression methods and forecasting models.

The purpose of the regression analysis is to determine the relationship between the output variable and many external factors. There are many variations of regression: linear, nonlinear, logistic, degree, autoregression and so on [12, 13]. The advantages of these models include simplicity, flexibility, unambiguity of their analysis, transparency of modeling. When using linear regression models, the forecast result can be obtained much faster than when using other models. The disadvantages of linear regression models are low adaptability and the lack of the ability to simulate nonlinear processes. The main disadvantages of nonlinear regression models are the difficulty in determining the type of functional dependence, the difficulty in determining the model parameters.

An important advantage of autoregressive models is the simplicity and transparency of modeling, the unambiguity of analysis and design. The disadvantages of this class of models are a large number of parameters, the identification of which is ambiguous and very complex, low adaptability and linearity, and as a result, the lack of the ability to simulate nonlinear processes, which is typical for emergencies of various kinds [7].

With insufficient information on the process of ES occurrence, models based on Markov chains are used [13]. However, in this case, when forecasting the future state of the process, only its current state is taken into account and information from the previous development of the process is neglected. This does not allow tracing the dynamics of the process and identifying trends in its development.

In article [8], the perspectiveness of developing combined methods for forecasting the ES occurrence processes, which are a combination of different methods to compensate for the disadvantages of some with the help of others, are shown.

The results of the forecast of ES threats are the foundation for solving the problem of readiness of maintaining the forces and means of CP for responding to them. The readiness of forces and means of CP for ES response is the state of forces and means of CP that determines their ability to fulfill the tasks assigned to them. The analysis of the literature shows that the content of the notions of readiness comes down to the concept about the state of governing bodies and CP forces. This concept is characterized by the ability of civil defense units to carry out tasks, taking into account the relationship "readiness level – risk level" [5], "readiness level – acceptable damage level" [14], "readiness level – danger level" [5, 14]. Thus, readiness is considered as a category reflecting the need to ensure the safety of the population in case of emergency.

The components of readiness are the providing of weapons and equipment, material resources, the optimal distribution of CP units in the state regions, the quality of personnel training, and so on. ES readiness is achieved by planning, training, equipping, and responding to emergencies.

The authors [15] conducted a comparative analysis of prevention and counteraction systems to large-scale emergencies in China, the USA, and the EU. The disadvantages and advantages of three- and four-criteria prevention and counteraction systems to large-scale emergencies, respectively, are considered. The advantages are given to an algorithm that takes into account the following processes: analysis, preliminary risk calculation, improvement and coordination.

In article [16], a combined method was proposed for minimizing the consequences of a state level emergency, which is based on well-known approaches for modeling stochastic processes by discrete Markov chains.

To ensure the readiness of ES response units in many countries of the world, the organizational structure, number and staffing of rescue units is determined by the administration of the community or city [17]. The disadvantage of this approach is that in determining the staffing of units, their technical support, and resources, the real potential threats of ES in this territory are not fully taken into account. At that, the territory area, the density of the living population and the severity of the ES consequences are not taken into account.

This leads to the fact that the organizational and staffing structure, technical support are not adequate to the risks of threats in these territories, which means that they reduce the readiness of units for ES response.

Thus, the analysis of the state of forecasting, prevention and response to ES shows that existing methods do not solve the problem of preventing and responding to emergencies from a systemic point of view, given the threats of emergencies in the state regions and the possibility of CP units. Existing methods are not complex and have the following disadvantages:

- forecasting the processes of ES occurrence in an integrated manner, by kind, types and levels, is not possible;
- the complete set and the organizational and staffing structure of the regional divisions of civil protection do not fully comply with the threats of ES in these territories.

Purpose. The aim of the work is to develop the system approach and form a set of methods for joint forecasting of the number of emergencies and ensuring the readiness of the response of CP units in real conditions.

To achieve this, it is necessary to solve the following tasks:
- to offer a combined method for forecasting emergencies of different kinds by state and its regions;
- to develop a method for assessing damage due to emergencies;
- to develop resource support models of the civil defense units' readiness at emergency response.

Results. ***Combined Emergency Forecasting Method for the State and its Regions.*** The combined method for ES forecasting allows predicting the total number of ES, the ES number by origin and levels both in the state as a whole and in its regions.

Wherein, the forecast of the total number of ES n_{Emg}^{frc} is carried out in accordance with the regression model in the form of a k-degree polynomial

$$n_{Emg}^{frc} = r_0 + r_1 t + r_2 t^2 + r_3 t^3 + \ldots + r_k t^k, \quad (1)$$

where $n_{Emg}^{frc} = n_{Emg}(t)$ is forecasted value of the number of emergencies in the state at the time of the forecast $t = t_{frc}$; (r_0, r_1, r_2, ..., r_k) are polynomial coefficients.

The degree of the polynomial k is chosen so that the number of given points is five times higher than the degree of the polynomial. The polynomial coefficients r_i, $i = \overline{0, k(t)}$, based on the ES information for a certain monitoring period, are found by the weighted least squares method [18].

The forecasted number of ES in the i^{th} region is calculated based on the forecasted number of ES in the state n_{Emg}^{frc} and the emergency probability in the i^{th} region of the state P_{Emg}^{i} as follows

$$n_{frcEmg}^{i}=n_{Emg}^{frc}\cdot P_{Emg}^{i},$$

where $n_{frcEmg}^{i}=n_{Emg_i}\left(t\right)$ is the forecasted number of ES in the i^{th} region of the state at the time of the forecast $t=t_{frc}$; P_{Emg}^{i} is emergency probability in the i^{th} region in case of emergencies in the state.

The forecasted number of ES in the state according to the origin and levels is calculated based on the forecasted number of ES in the state n_{Emg}^{frc} and the emergency probabilities

$$P_{TK},\ P_{NK},\ P_{SK},\ P_{StL},\ P_{RgL},\ P_{LcL},\ P_{ObL}:$$

$$n_{frcTK}=n_{Emg}^{frc}\cdot P_{TK};\quad n_{frcNK}=n_{Emg}^{frc}\cdot P_{NK};$$
$$n_{frcSK}=n_{Emg}^{frc}\cdot P_{SK};\qquad (2)$$

$$n_{frcStL}=n_{Emg}^{frc}\cdot P_{StL};\quad n_{frcRgL}=n_{Emg}^{frc}\cdot P_{RgL};$$
$$n_{frcLcL}=n_{Emg}^{frc}\cdot P_{LcL};\quad n_{frcObL}=n_{Emg}^{frc}\cdot P_{ObL},\qquad (3)$$

where $n_{frcTK}=n_{TK}(t_{frc})$, $n_{frcNK}=n_{NK}(t_{frc})$, $n_{frcSK}=n_{SK}(t_{frc})$ are the forecasted numbers of ES, respectively, of technogenic, natural and social kinds in the state; $n_{frcStL}=n_{StL}(t_{frc})$, $n_{frcRgL}=n_{RgL}(t_{frc})$, $n_{frcLcL}=n_{LcL}(t_{frc})$, $Dmg_{frcTK}^{avg}-\sigma<Dmg_{TK}\left(t_{frc}\right)<Dmg_{frcTK}^{avg}+\sigma$ are the forecasted numbers of ES, respectively, at the state, regional, local and object levels in the state; P_{TK}, P_{NK}, P_{SK} are emergency probabilities, respectively, of technogenic, natural and social kinds in case of emergency in the state; P_{StL}, P_{RgL}, P_{LcL}, P_{ObL} are emergency probabilities, respectively, at the state, regional, local and object levels in case of emergency situations in the state.

The forecasted number of ES of the respective kind and level in the regions of the state is equal to

$$n_{frcTK}^{i}=P_{TK}^{i}\cdot n_{frcTK};\quad n_{frcNK}^{i}=P_{NK}^{i}\cdot n_{frcNK};\quad n_{frcSK}^{i}=P_{SK}^{i}\cdot n_{frcSK};$$
$$n_{frcStL}^{i}=P_{StL}^{i}\cdot n_{frcStL};\quad n_{frcRgL}^{i}=P_{RgL}^{i}\cdot n_{frcRgL};$$
$$n_{frcLcL}^{i}=P_{LcL}^{i}\cdot n_{frcLcL};\quad n_{frcObL}^{i}=P_{ObL}^{i}\cdot n_{frcObL},$$

where $n_{frcTK}^{i}=n_{TK_i}\left(t_{frc}\right)$, $n_{frcNK}^{i}=n_{NK_i}\left(t_{frc}\right)$, $n_{frcSK}^{i}=n_{SK_i}\left(t_{frc}\right)$ are the forecasted numbers of ES, respectively, of technogenic, natural and social kinds in the i^{th} region of the state; $n_{frcStL}^{i}=n_{StL_i}\left(t_{frc}\right)$, $n_{frcRgL}^{i}=n_{RgL_i}\left(t_{frc}\right)$, $n_{frcLcL}^{i}=n_{LcL_i}\left(t_{frc}\right)$, $n_{frcObL}^{i}=n_{ObL_i}\left(t_{frc}\right)$ are the forecasted numbers of ES, respectively, at the state, regional, local and object levels in the regions of the state; P_{TK}^{i}, P_{NK}^{i}, P_{SK}^{i} are emergency probabilities, respectively, of technogenic, natural and social kinds in the i^{th} region in the case of an emergency of this kind in the state; P_{StL}^{i}, P_{RgL}^{i}, P_{LcL}^{i}, P_{ObL}^{i} are emergency probabilities, respectively, at the state, regional, local and object levels in the i^{th} region in case of emergencies of the corresponding level in the state.

Damage Assessing Method from Emergencies. Damage caused to the state due to emergencies is determined by natural and technogenic ES. Forecasted data on the number of ES of a natural and technogenic kind, respectively, by types and levels, are the basis for assessing the potential damage caused. The total forecasted damage due to an emergency in the state is the sum of the damages due to an ES of technogenic and natural kinds

$$Dmg(t_{frc})=Dmg_{TK}(t_{frc})+Dmg_{NK}(t_{frc}),\qquad (4)$$

where $Dmg(t_{frc})$ is the total forecasted damage due to ES; $Dmg_{TK}(t_{frc})$ is damage due to a technogenic kind of ES; $Dmg_{NK}(t_{frc})$ is damage due to a natural kind of ES.

Forecasting of possible damage due to an ES of a natural kind is based on the fact that the total damage is calculated as the sum of damage due to an ES of various types

$$Dmg_{NK}(t_{frc})=\sum_{j=1}^{n}Dmg_{j}(t_{frc}),\qquad (5)$$

where $Dmg_{NK}(t_{frc})$ is the total forecasted damage due to natural kind of ES; $Dmg_j(t_{frc})$ is damage due to a natural kind of ES of the j^{th} type.

The forecasted damage due to an ES of the j^{th} type is estimated taking into account their quantity by levels and specific gravity in the damage caused per ES

$$Dmg_j(t_{frc})=\nu_{jStL}(t_{frc})\cdot SG_{jStL}+\nu_{jRgL}(t_{frc})\cdot SG_{jRgL}+$$
$$+\nu_{jLcL}(t_{frc})\cdot SG_{jLcL}+\nu_{jObL}(t_{frc})\cdot SG_{jObL},\qquad (6)$$

where SG_{jStL}, SG_{jRgL}, SG_{jLcL}, SG_{jObL} are specific gravity in damage from the j-type emergency (UAH million for 1 ES), respectively, by ES of state, regional, local and object levels; $\nu_{jStL}(t_{frc})$, $\nu_{jRgL}(t_{frc})$, $\nu_{jLcL}(t_{frc})$, $\nu_{jObL}(t_{frc})$ are forecasted numbers of ES of the j^{th} type, respectively, of the state, regional, local and object levels.

The values SG_{jStL}, SG_{jRgL}, SG_{jLcL}, SG_{jObL} are determined on the basis of statistical data on damage due to emergencies for a certain previous monitoring period.

Forecasting of damage due to a technogenic kind of ES is carried out in accordance with the regression-probabilistic forecast method, which takes into account the average damage and its root-mean-square deviation from real values. Estimates of the forecasted damage values will be within

$$Dmg_{frcTK}^{avg}-\sigma<Dmg_{TK}\left(t_{frc}\right)<Dmg_{frcTK}^{avg}+\sigma,$$

where Dmg_{frcTK}^{avg} is assessment of the forecasted average damage due to a technogenic kind ES; $Dmg_{TK}(t_{frc})$ is assessment of the forecasted damage due to a technogenic kind ES; σ is root-mean-square deviation of calculated damage estimates due to technogenic kind ES.

Forecasted data on the number of emergencies and possible damage caused are the basis for the development of methods and models for assessing the resource support of the readiness of CP units to prevent ES or liquidate their consequences.

Response Readiness Resource Support Models of Civil Protection Units at Emergency. The total forecasted costs of ES consequences mitigation are the sum of the costs of managing ES of technogenic and natural kinds

$$Cst(t_{frc})=Cst_{TK}(t_{frc})+Cst_{NK}(t_{frc}),$$

where $Cst(t_{frc})$ is total forecasted costs; $Cst_{TK}(t_{frc})$ is forecasted costs of mitigation of man-caused emergency; $Cst_{NK}(t_{frc})$ is forecasted costs of managing natural emergency.

Studies have shown that it is advisable to choose a selective regression model for forecasting the costs for the mitigation of natural ES in the form of a power function

$$Cst_{NK}\left(t_{frc}\right)=a\cdot\left[n_{NK}\left(t_{frc}\right)\right]^{a_1},$$

where a and a_1 are model parameters.

The regression model of forecasting the cost of funds for the mitigation of technogenic ES has the form

$$Cst_{\grave{O}K}(t_{frc})=\beta_0\beta_1^{\frac{1}{n_{TK}(t_{frc})}}\beta_2^{Q_1}\beta_3^{Q_2}\beta_4^{Q_3},$$

where Q_1, Q_2, Q_3 are dummy variables (equal to 0 or 1 and are determined based on the analysis of statistical data); β_0, β_1, β_2, β_3, β_4, are model parameters.

As a regression model for the forecast of the required number of pieces of equipment for managing an emergency used an exponential model can be which has the form

$$T\left(t_{frc}\right)=\gamma_0\cdot\left[n\left(t_{frc}\right)\right]^{\gamma_1}\cdot\left[n_{TK}\left(t_{frc}\right)\right]^{\gamma_2}\cdot\left[n_{NK}\left(t_{frc}\right)\right]^{\gamma_3}\cdot\left[n_{SK}\left(t_{frc}\right)\right]^{\gamma_4},$$

where $T(t_{frc})$ is the forecasted number of pieces of equipment for the mitigation of ES; γ_0, γ_1, γ_2, γ_3, γ_4 are model parameters.

According to the results of the study, we can conclude that as a regression model for forecasting the required number of personnel for the mitigation of an emergency it is advisable to use a model of the form

$$Prs\left(t_{frc}\right)=\lambda_0\cdot\left[n\left(t_{frc}\right)\right]^{\lambda_1}\cdot\left[n_{TK}\left(t_{frc}\right)\right]^{\lambda_2}\cdot\left[n_{NK}\left(t_{frc}\right)\right]^{\lambda_3}\cdot\left[n_{SK}\left(t_{frc}\right)\right]^{\lambda_4},$$

where $Prs(t_{frc})$ is the forecasted number of necessary personnel managing ES; λ_0, λ_1, λ_2, λ_3, λ_4 are model parameters

Method of Optimization of Territorial Structures of Civil Protection. As an optimization criterion, we select the requirement that the numerical strength of certified CP structures in the i-th region of the state should correspond to the level of threats in this territory, i. e. the following condition must be fulfilled

$$S_i^{CP}=k_{Z_i}\cdot S_{typ}^{CP},$$

where S_i^{CP} is numerical strength of certified CP structures in the i^{th} region; S_{typ}^{CP} is numerical strength of the typical territorial CP structure; k_{Z_i} is the rate of the annual intensity of emergency of a state region.

The rate of the annual intensity of emergency of a region is equal to

$$k_{Z_i}=\frac{Z_i}{Z_{St}},$$

where $Z_i=PD_{ppl}^{Rg}\cdot\overline{n}_{iRg}$ is a comprehensive indicator that characterizes the state of threats to the territory and population of a state region; $Z_{St}=PD_{ppl}^{St}\cdot\overline{n}_{St}$ is a comprehensive indicator that characterizes the state of threats to the territory and population per state region; PD_{ppl}^{Rg} is population density in the region; PD_{ppl}^{St} is population density in the state; $\overline{n}_{iRg}$ is the average annual number of ES in the i^{th} state region; $\overline{n}_{St}$ is the average annual number of ES per state region.

Results of Studies on the Effectiveness of Applying a System Approach to Joint Forecasting and Preparedness to Emergency Response. The application of a system approach to joint forecasting and preparedness of ES response is promising for any country in the world. Features of the application will be determined by the availability of reliable statistic data on ES in the state, the organizational structure of the CP forces and the potential resource capabilities of the state on ES recovery. Based on the available reliable data [19, 20], the authors conducted a study on the effectiveness of the application of the system approach to emergency prevention on the example of Ukraine.

As an effectiveness criterion, we choose the module of relative forecast error, which is calculated on the basis of previous statistic data

$$|\Delta|=\frac{\sum_{i=1}^{n}|\Delta_i|}{n},$$

where $|\Delta|$ is the module of the average relative forecast error; $|\Delta_i|$ is the relative error module of the i^{th} forecast step; n is the number of statistic data.

The results of the actual number of ES in the whole state n_{Emg}^{act} (the total number of ES of technogenic, natural and social kinds at all levels – state, regional, local and object ones) and their forecasts (optimistic $n_{Emg}^{frc_o}=n_{Emg}^{frc}\left(1-|\Delta|\right)$ and pessimistic $n_{Emg}^{frc_p}=n_{Emg}^{frc}\left(1+|\Delta|\right)$) are shown in Figure.

Based on the forecasted values of the total number of ES, a forecast is made at the types and levels (2, 3).

Forecasting emergencies for 2018 and 2019 will be incorrect and have significant errors due to the lack of reliable data on emergencies in some part of the territory of Ukraine (the Autonomous Republic of Crimea, Donetsk and Luhansk regions).

Table 1 shows the value of damage due to ES, which are given in official sources [19] (actual values in million UAH – column 4). The predicted values of damage due to ES (columns 2, 3) are calculated using expressions (4–6). In accordance with these expressions and statistical data, the main contribution to the amount of damage is made by state emergency situations and then at the regional level.

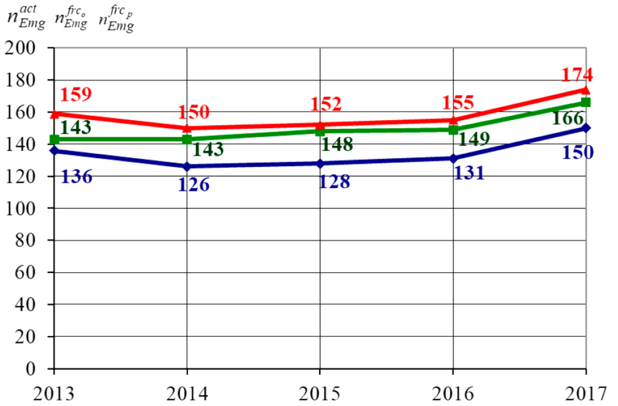

Fig. Actual n_{Emg}^{act} and forecast $n_{Emg}^{frc_o}$, $n_{Emg}^{frc_p}$ number of emergencies in Ukraine as a whole for 2013–2017:

—— – actual number of ES; —— – optimistic forecast of the number of ES; —— – pessimistic forecast of the number of ES

Table 1

The results of calculations of the effectiveness of forecasting damage due to emergency

Year	Optimistic forecast (mln. UAH)	Pessimistic forecast (mln. UAH)	Actual value (mln. UAH)	The module of the relative forecast error (%)
1	2	3	4	5.0
2013	390	450	396.33	6.0
2014	150	210	198.65	9.4
2015	450	536	532.72	7.5
2016	220	270	265.31	8.0
2017	800	900	896.8	5.2
The module of the average relative forecast error for the period				7.22

The calculation results show that when forecasting at least a year ahead, the modulus of the average relative error in forecasting the total damage from ES for the period from 2013 to 2017 is 7.22 % (Table 1).

The results of calculations of the effectiveness of the application of resource support models for response readiness on emergency are shown in Table 2.

The results obtained (Table 2) confirm the prospects of applying the system approach to solving the problem of joint forecasting and ensuring readiness to ES respond. This is due to the fact that the proposed approach provides for a comprehensive solution of interrelated tasks, taking into account the threat of emergencies in the regions of the state and the capabilities of the CP units.

Difficulties and limitations of studying the effectiveness of applying the system approach to joint forecasting and ensuring preparedness of ES response may be associated with a lack of reliable statistical data on emergencies in the state. In addition, the availability of information on the organizational structure of the CP forces and the potential resource capabilities of the state to liquidate of emergencies has no small importance.

Conclusions. The system approach to solving the problem of joint forecasting and ensuring preparedness of ES response should be based on combination of methods that take into account both the threats of emergencies in the regions of the state and the capabilities of CP units, resource support, organizational structure and staffing.

Table 2

The results of calculations of the effectiveness of the application of resource support models for response readiness on emergency

Year	Relative error module of forecasting the costs of mitigation of emergencies (%)	Relative error module of forecasting the technical support for mitigation of emergencies (%)	Relative error module of forecasting the number of personnel for mitigation of emergencies (%)
2013	3.0	3.2	3.0
2014	3.5	4.3	3.0
2015	3.2	4.1	3.1
2016	4.0	5.0	3.3
2017	2.5	4.2	3.0
for the period	**3.25**	**4.2**	**3.1**

1. A combined method for forecasting emergencies of different kinds regarding the state and its regions is proposed. In developing the combined method, a polynomial regression method with a varying order, a weighted least squares method, and a probabilistic-statistical method were used.

2. When developing models of resource support for the readiness of CP units for ES response, methods of regression analysis, time series methods and mathematical statistics methods were used.

The principle of forecasting the costs of emergency mitigation is based on the fact that they are determined by the costs of response to technogenic and natural ES. Wherein, it is advisable to use regression models in the form of a power function to forecast costs on managing natural ES, and it is advisable to use the time series analysis method to forecast costs on managing technogenic ES, which allows you to take into account some periodic patterns in the dynamics of changes in the emergency mitigation costs.

When choosing models for forecasting the technical support and the number of necessary personnel for emergency mitigation, we proceeded from the fact that they should be determined not only by the forecasted number of ES, but also by their nature. Therefore, exponential models that most adequately simulate these processes are selected as models.

The optimization model of the territorial structures of civil protection is based on the principle that the numerical strength of regional structures corresponds to the level of technogenic and natural threats in these territories.

3. The developed set of mathematical methods and models allows substantiating organizational and technical measures to prevent emergencies both at the state level and on the scale of each region, taking into account potential threats. This will increase the effectiveness of actions to minimize the consequences of an emergency.

Further improvement of the system approach to joint forecasting and ensuring readiness of ES response should be aimed at studying the influence of the tactical and technical characteristics of weapons and equipment on the readiness of the CP units to ES respond, the mobility of modern forces and assets of the CP, taking into account their presence in the territories of neighboring regions, optimal allocation of financial resources to maintain preparedness to ES respond.

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Системний підхід до прогнозування та забезпечення готовності реагування на надзвичайні ситуації

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Мета. Розробка системного підходу та формування комплексу методів сумісного прогнозування надзвичайних ситуацій і забезпечення готовності реагування підрозділів цивільного захисту в реальних умовах.

Методика. При розробці методів прогнозування надзвичайних ситуацій і можливих завданих збитків унаслідок них використано поліноміально-регресійний метод із варійованим порядком, зважений метод найменших квадратів, імовірнісно-статистичний метод, методи часових рядів і математичної статистики. При розробці моделей ресурсного забезпечення готовності реагування на надзвичайні ситуації використані методи регресійного аналізу, часових рядів і математичної статистики. Принцип прогнозу витрат коштів на ліквідацію наслідків надзвичайних ситуацій ґрунтується на тому, що вони визначаються витратами на ліквідацію техногенних і природних надзвичайних ситуацій. При виборі моделей прогнозування технічного забезпечення й кількості необхідного особового складу для ліквідації надзвичайних ситуацій виходили з того, що вони повинні визначатися не тільки прогнозною кількістю надзвичайних ситуацій, але й їх характером. В основу моделі оптимізації територіальних структур цивільного захисту покладено принцип відповідності чисельності регіональних структур рівню техногенних і природних загроз на цих територіях. При дослідженні ефективності застосування системного підходу щодо сумісного прогнозування й забезпечення готовності реагування на надзвичайні ситуацій використані методи математичної статистики й математичного моделювання.

Результати. Запропоновані методи прогнозування процесів виникнення надзвичайних ситуацій і збитків унаслідок них, моделі оптимізації територіальних структур цивільного захисту з урахуванням стану техногенно-природної небезпеки регіонів держави, прогнозу технічного забезпечення й кількості особового складу для ліквідації можливих надзвичайних ситуацій.

Наукова новизна. Запропоновано системний підхід до вирішення задачі сумісного прогнозування надзвичайних ситуацій і підтримання готовності реагування підрозділів цивільного захисту з метою мінімізації наслідків цих ситуацій.

Практична значимість. Запропонований комплекс методів і моделей є фундаментом для обґрунтування організаційно-технічних заходів з адекватного реагування на надзвичайні ситуації як у масштабах держави, так і її регіонів.

Ключові слова: *надзвичайна ситуація, цивільний захист, готовність реагування, ресурсне забезпечення, модель*

Системный подход к прогнозированию и обеспечению готовности реагирования на чрезвычайные ситуации

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Цель. Разработка системного подхода и формирование комплекса методов совместного прогнозирования чрезвычайных ситуаций и обеспечения готовности реагирования подразделений гражданской защиты в реальных условиях.

Методика. При разработке методов прогнозирования чрезвычайных ситуаций и возможного ущерба вследствие их использован полиноминально-регрессионный метод с варьированным порядком, взвешенный метод наименьших квадратов, вероятностно-статистический метод, методы временных рядов и математической статистики. При разработке моделей ресурсного обеспечения готовности реагирования на чрезвычайные ситуации использованы методы регрессионного анализа, временных рядов и математической статистики. Принцип прогноза затрат средств на ликвидацию последствий чрезвычайных ситуаций основывается на том, что они определяются затратами на ликвидацию техногенных и природных чрезвычайных ситуаций. При выборе моделей прогнозирования технического обеспечения и количества необходимого личного состава для ликвидации чрезвычайных ситуаций исходили из того, что они должны определяться не только прогнозным количеством чрезвычайных ситуаций, но и их характером. В основу модели оптимизации территориальных структур гражданской защиты положен принцип соответствия численности региональных структур уровню техногенных и природных угроз на этих территориях. При исследовании эффективности применения системного подхода относительно совместного прогнозирования и обеспечения готовности реагирования на чрезвычайные ситуации использованы методы математической статистики и математического моделирования.

Результаты. Предложены методы прогнозирования процессов возникновения чрезвычайных ситуаций и ущерба вследствие их, модели оптимизации территориальных структур гражданской защиты с учетом состояния техногенно-природной опасности регионов государства, прогноза технического обеспечения и количества личного состава для ликвидации возможных чрезвычайных ситуаций.

Научная новизна. Предложен системный подход к решению задачи совместного прогнозирования чрезвычайных ситуаций и поддержания готовности реагирования подразделений гражданской защиты с целью минимизации последствий этих ситуаций.

Практическая значимость. Предложенный комплекс методов и моделей является фундаментом для обоснования организационно-технических мероприятий по адекватному реагированию на чрезвычайные ситуации как в масштабах государства, так и его регионов.

Ключевые слова: *чрезвычайная ситуация, гражданская защита, готовность реагирования, ресурсное обеспечение, модель*

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