A mathematical formulation of the problem in preventing emergencies in the area of the Joint Forces Operation

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Abstract

The article considers Donbass as a transformed military natural-technogenic geosystem, formed as a result of an armed conflict in a largely urbanized industrial-urban agglomeration.

The Joint Forces operation has seen a significant increase in natural and man-made threats associated with potentially dangerous objects in the area affected by artillery systems. Emergencies at such facilities can result in significant human casualties and significant environmental and economic damage.

This raises the question of increasing the efficiency of the organizational and technical system of rescue operations in the civil defense system.

Key words: emergency, civil defense, striking impact, potentially dangerous object, high-risk object, Joint Forces Operation.

Introduction

In the context of the Joint Forces operation (JFO), there is a significant increase in natural and man-made threats associated with potentially dangerous objects in the area affected by artillery systems. Emergencies at such facilities can result in significant human casualties and significant environmental and economic damage. Analysis of the state of management theory of the organizational and technical system of liquidation of natural and man-made disasters in areas of hostilities showed the lack of scientific and methodological apparatus for assessing the effectiveness of its operation in Ukraine during hostilities and adjacent territories. Analysis of man-made state safety associated with the existence of radiation and chemically dangerous objects, the need to improve the methods for assessing the effectiveness of man-made safety management systems, that function JFO in the area. The task of man-made safety management requires the application of a macro-level criterion, as the consequences of accidents and destruction of potentially dangerous objects may be regional in nature and will require the use of regional resources designed to ensure man-made safety. Existing approaches that do not take into account this provision is not fully suitable for decision-making at the regional (state) level.

That is why improving the efficiency of the organizational and technical system of rescue operations in the civil defense system, especially during hostilities, is an urgent scientific task.

Material and methods

Aspects of regional security management in emergency situations have been very thoroughly analyzed by Bychenko M.M. and Dovhyy S.O. [1]. Their monograph provides a detailed overview of all informatization issues of the main tasks for the prevention and emergency state (ES) elimination. The monograph [2] is devoted to the issues of risk analysis for the safety of life in the EE, in which the authors clearly set out the methodological basis of risk assessment, application of geographic

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information technologies in performing this scientific task and the main aspects of developing databases for the Government emergency information system. The monograph [3] considers the management of military-man-made risks during the application of the Armed Forces of Ukraine in peacetime and wartime. However, the realities of today indicate the peculiarities of the use of scientific and methodological apparatus to manage the organizational and technical system of emergency rescue operations during emergencies of natural and man-made origin in the area of the JFO.

The purpose of the article is to form a problem mathematical statement of preventing emergency states in the area of JFO.

Results and discussion

For a mathematical formulation, we introduce a number of refined terminological definitions, which were partially proposed in the monograph [1]. Emergencies of military-technogenic nature are such unacceptable conditions for life, which are characterized by regional manifestations in the form of possible or real striking effects of military-technogenic nature of weapons and military equipment (WME) on potentially dangerous objects (PDO) and objects of increased dangers (OID) that generate secondary damage from these facilities and cause the cost of resources for protective measures. The area of JFO will be considered as a military natural and man-made geosystem (MNMMG), which manifests striking effects, which is a set of socio-economic, industrial and natural components, interconnected and interacting in certain administrative-territorial, climatic or economic-geographical boundaries of the area of JFO. Among the regional components of the nature of behavior in emergency situations different: sources of military-man-made threat, objects of defeat and resources of civil defence. Sources of military-man-made threat are components of WME that allow such difficult to predict changes in their conditions, which are either a clear threat of destruction, or direct damage to people or livelihoods (industrial and natural facilities). Sources of military-man-made threat can be located not only within the JFO, but also outside the region. Populations and livelihoods that need civilian protection from military-man-made threats are possible or real objects of damage.

The resources of civil protection are the forces and means of civil protection, which carry out protective measures against people and objects of life support in the conditions of possible or real devastating impacts in the JFO.

Not only the resources of the region and the Armed Forces of Ukraine, the Ministry of Internal Affairs (The State Emergency Service of Ukraine, the Border Guard Service, the National Guard, the National Police), but also neighboring regions (Kharkiv, Dnipropetrovsk, Zaporizhia, Kherson region may be involved in the implementation of civil protection measures). The set conditions of the regional components on the JFO at any time create situations consist of ordinary and extraordinary. These situations are characterized by a clear military-man-made threat, or a direct manifestation of the impact. The functioning of the region of the JFO in emergency situations is considered as a consistent and interdependent change (continuous or discrete) of the states of its components. The process of interaction these components is the emergence, manifestation and extinction of the emergency. Accordingly, there are three characteristic periods of emergency development: threatening, crisis and post-crisis.

The threatening period is characterized by the appearance of risk zones in the region, where the military-man-made threat of striking influences is growing.

In the crisis period there is a direct (primary) manifestation of the striking effects, which leads to the appearance of affected areas.

The post-crisis period is final and is characterized by a residual (secondary) manifestation of striking effects in the areas of aftereffect.

Depending on the period of emergency development, protective measures of civil protection are carried out: preventive, rescue and remedial.

Precautionary measures of civil protection are implemented in the threatening period to prevent the emergence of sources of threat and increase the resistance of regional components of the JFO in risk areas.

During the crisis period, rescue measures of civil protection are carried out, aimed at localizing the consequences of the threat and increasing the survivability of the regional components of the JFO in the affected areas.

For the prevention problem, we assume that ES *i*-th type (*i=1…m*) at a potentially dangerous object of the regional system W_j (*j=1…n*) is associated with the level of damage from the emergency, calculated at the level of the JFO, which is expressed by the matrix:

$$\|W_{ij}\|_{m\cdot n}. \quad (1)$$

Probability of occurrence ES *i*-th type on each *j*-th the object is denoted as

$$Q = \|q_{ij}\|_{m\cdot n}, \quad (2)$$

and the corresponding regulatory costs for prevention ES –

$$C = \|c_{ij}\|_{m\cdot n}, c_{ij} > 0. \quad (3)$$

If the budget funds for the prevention of ES are distributed according to plan

$$X = \|x_{ij}\|_{m\cdot n}, \quad (4)$$

then the probabilities *Q* are functions of the ratio *H* and *C*, ie

$$Q = \left\|q_{ij}\left(\frac{x_{ij}}{c_{ij}}\right)\right\|_{m\cdot n} \quad (5)$$

and the total probable averted damage (effect) in the prevention plan *X* is

$$WS(X) = \sum_{i=1}^{m}\sum_{j=1}^{n} w_{ij}\cdot\left(1 - q_{ij}(x_{ij})\right), \quad (6)$$

and the cost of the plan –

$$CS(x) = \sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij}, \quad (7)$$

It is easy to see that the effectiveness of a prevention plan is determined by the ratio of the probable averted damage and the cost of the plan by which this effect is achieved:

$$e_{pz}(X) = \frac{WS}{CS} \quad (8)$$

Optimal economic damage prevention planning from the ES always maximizes the efficiency to use of civil protection resources and has two interpretations of the problem.

Direct problem – on a set of plans {*X*}, each plan of which satisfies a system of budget constraints, –

$$CS(x) = \sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} \le CS^{\text{budget}},$$

$$(x_{ij} \le c_{ij},\ i = 1\ldots m,\ j = 1\ldots n), - \quad (9)$$

find such an (optimal) plan

$$XO = \|xo_{ij}\|_{m\cdot n}, \quad (10)$$

which maximizes the probable averted damage from ES

$$WS(XO) = \max_{\{x\}} WS(X) = \sum_{i=1}^{m}\sum_{j=1}^{n} w_{ij}\cdot\left(1 - q_{ij}(xo_{ij})\right) \quad (11)$$

Inverse problem – on a set of plans {*X*}, each plan of which satisfies the system of restrictions on the required level of probable averted damage, –

$$(x_{ij} \le c_{ij},\ i = 1\ldots m,\ j = 1\ldots n),$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} w_{ij}\cdot\left(1 - q_{ij}(x_{ij})\right) \ge WS^{potr}, \quad (12)$$

find such an (optimal) plan

$$XO = \|xo_{ij}\|_{m\cdot n}, \quad (13)$$

minimizing its cost (budget)

$$CS(XO) = \min_{\{X\}} CS(X) = \sum_{i=1}^{m}\sum_{j=1}^{n} xo_{ij}. \quad (14)$$

Efficiency plan for the direct problem –

$$e_{pz}(XO) = \frac{\max_{\{X\}} WS(X)}{CS^{\text{budget}}} = max\ e, \quad (15)$$

and for the inverse problem –

$$e_{zv}(XO) = \frac{WS^{potr}}{\min_{\{X\}} CS(X)} = max\ e. \quad (16)$$

Search a problem of optimum management decision at prevention of ES on military-technogenic objects, PDO and OID with reception of quantitative indicators it is expedient to carry out, using methods of computer modeling. First of all, this is due to the use in the proposed method of simulation macroeconomic model. Visual geospatial distribution of chemical and radiation contamination zones can also be obtained only with the help of a geographic information system. Therefore, in the course of research, the author used the appropriate software "Slavutych". A computer model was developed to determine the zones of chemical pollution on the basis of a mathematical apparatus for modeling the spread of hazardous chemicals and radionuclides. Algorithms for solving resource optimization problems were implemented using MS Visual Studio programming tools.

The efficiency was checked by comparative analysis of the proposed method and the method of suboptimal distribution. The experiments were performed on a PC using the developed algorithms.

The method of "specific efficiency" (SE) is by nature a heuristic. The heuristics of the SE method in resource allocation planning are contained in the following.

For all objects and types of ES, the specific efficiency of the required costs is defined as the ratio of the partial loss w_{ij} and the cost c_{ij} to exclude this loss – the matrix of "specific efficiencies"

$$B = \left\| b_{ij} \frac{w_{ij}}{c_{ij}} \right\|_{m \cdot n}. \quad (17)$$

At each *k* step of the distribution of financial resources we will look for the array *b* "maximum element"

$$b_{rs} = \max_{ij} b_{ij} \quad (18)$$

as a sign of expediency of allocation of financial resources $x_{rs} = c_{rs}$, which will give the largest increase (w_{rs}) of the total effect of WS at this step. We accumulate the amount of averted damage –

$$WS := WS + w_{rs} \quad (19)$$

and the cost of its exclusion –

$$CS := CS + c_{rs} \quad (20)$$

Check the conditions for stopping the distribution: for a direct problem – budget depletion ($CS > CS^{budget}$), for the inverse problem – to achieve the desired effect ($WS > WS^{potr}$). If the conditions are not met, continue the distribution: "exclude" the element b_{rs} from the array B ($b_{rs} = 0$) and make the next (k + 1) -*th* step, returning to the search in the array *B* of the new maximum element.

If the conditions for stopping the distribution are met, a suboptimal (rational at the level of "common sense" (CS)) cost allocation plan will be obtained $X = \|x_{ij}\|_{m \cdot n}$. The method is discrete because $\|x_{rs} = c_{rs}\|$.

The experiment consists in repeatedly solving planning problems by both methods on the same initial data in each case with comparison of data-results.

The difference of target effects is determined by the results of solving a direct problem by each of the methods with the same restriction on the budget. The economic effect, as the difference in costs, is determined by the results of solving the inverse problem by each of the methods with the same restriction on the desired target effect. Comparative data (averaged) for the evaluation of methods are given in table. 1.

Table 1 – Comparative performance evaluation data

Limitation	method	method
direct problem CS^{budget} =2523,588 thousand UAH	method CS WS^O=36749,640 thousand UAH	method SE WS^E=28474,120 thousand UAH
inverse problem WS^{potr}=30054,49 thousand UAH	method CS CS^O=1528,135 thousand UAH	method SE CS^E=2726,267 thousand UAH

The table contains data for the most probable values of constraints

$$CS^{\text{budget}} = (0.33\ldots0.67) \cdot \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij,}$$

$$WS^{\text{potr}} = (0.33\ldots0.67) \cdot \sum_{i=1}^{m} \sum_{j=1}^{n} w_{ij,} \quad (21)$$

existing in the optimization problems of resource allocation when the plan $X = \|x_{ij} \leq c_{ij}\|$. Trivial problems at $X = \|x_{ij} \leq c_{ij}\|$ are not optimizing. The increase in the functional (target) effect in solving the direct problem of optimal planning by the analytical method CS in relation to the heuristic method is:

ΔWS^{O}=36749,640 – 28474, 120 =

= 8275, 520 thousand UAH (29,7%) (22)

Relative growth rate of the target effect (gain in the target efficiency of the analytical method CS versus heuristic) –

π= 36749,640 / 28474,120 = 1,297 times. (23)

The economic effect in solving the inverse problem of optimal planning by the CS method in relation to the heuristic method is:

ΔCS^{O}= 2726,267 – 1528,135 =

= 1198,132 thousand UAH (78,4%). (24)

Relative level of economic effect (gain in economic efficiency of analytical method CS against heuristic –

ε=2726,267 / 1528,145 = 1,784 times. (25)

Thus, the experimental data confirm the high efficiency of the proposed analytical method CS and the feasibility of its use in solving the problem of "ES Prevention". This corresponds to the main purpose of the research – to increase the efficiency of the military-man-made security system of the region.

The SE method allows to obtain an exact discrete solution of direct and inverse problems of optimal resource allocation, if “concessions” on costs or system effect within their discreteness in the final solution of the problem are permissible. The SE method should be used when solving discrete ES prevention planning tasks when it is required to provide $\|x_{rs} \leq c_{rs}\|$.

Conclusions

Using computer simulations for each military-man-made facility, PDO and OID, the predicted chemical contamination zones in the ES cases at these facilities were obtained.

Based on the spatial distribution of chemical contamination zones, the projected natural losses are calculated and with the help of a simulated macroeconomic model – the reduction of gross domestic product caused by the accident and destruction of each object. The expected economic damage, expressed in GDP decline, is from 200 to 600 million UAH in case of destruction of the object and from 100 to 300 million UAH – in case of an accident.

Based on the developed methodology, quantitative results were obtained for the first time, which represent the optimal allocation of resources in the protection of military-man-made objects, PDO and OID during hostilities and in preventing ES from actions of sabotage and reconnaissance groups in peacetime. The calculations show that the expected effect (averted economic damage) is from a few (in the prevention of accidents) to hundreds (in the prevention of destruction by percussion) of millions of hryvnias. This, given the limited resources, corresponds to an average reduction in the probability of man-made risk from 10^{-3} to $3\cdot10^{-4}$ in peacetime and from 0.6 to 0.4 – during hostilities.

The results of the computational experiment show that when applying the developed methodology, the expected efficiency of the military-technogenic security management system at the regional level in the JFO area increases by an average of 30% (compared to suboptimal management methods), which gives rise to recommendations for practical use of results. obtained during research.

The results of the practical solution of the problem of ES prevention for military-man-made objects, PDO and OID prove the efficiency of the developed methodology and its high efficiency, which fully corresponds to the main purpose of the research.

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