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Information Technologies

Development and Usage of a Computer Model of Evaluating the Scenarios of Projects for the Creation of Fire Fighting Systems of Rural Communities

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***Abstract*—The analysis of the state of the theory and practice of project management for the development of fire fighting systems of communities of Ukraine and the world is carried out. The expediency of designing and using a computer model for evaluating scenarios of projects for the creation of fire fighting systems of rural communities is substantiated. There is an algorithm developed and the computer model of estimation of projects' scenarios of creation of fire extinguishing systems in rural communities take into account peculiarities of changing project environment of the mentioned projects. They are based on simulation modeling of projects, and also provide a quick assessment of each of the development scenarios for the development of firefighting communities. The proposed computer model provides an iterative overview of the possible variants of the project configuration objects for the creation of fire fighting systems of rural communities for each of the five substantiated scenarios and provides an identification of the effective scenario among them according to the criterion of maximum value.**

On the basis of the developed and tested computer model, a quantitative assessment of the scenarios of the creation of fire extinguishing systems for the conditions of the Zhovtanets community was performed. It is established that the value of projects depends both on the type of objects of configuration, and on the location of fire and rescue units on its territory. It is substantiated that the smallest consolidated expenses (UAH 2155,725 thousand) are observed for the desired condition of the fire extinguishing system of the Zhovtanets community in the scenario, which involves the creation of a fire brigade of the III category in the Kolodentsi village. Such a scenario of the development of a fire extinguishing system, compared with its current state, provides a reduction of annual damage from fires by 158.58 thousand UAH, or 7.9 %.

Keywords—computer model, project, extinguishing system, community, value

I. INTRODUCTION

Currently, the problem of ensuring the safety of the population is very relevant in the world. Especially it concerns the rural areas of Ukraine, which are characterized by the least fireproofness. At the same time, the state is implementing a number of measures to reform the existing fire-fighting system of rural areas. However, most rural areas in Ukraine are unprotected from fires, as the duration of the arrival of fire brigades to the places of fires significantly exceeds its regulated value (20 minutes) [1]. This is due to the ineffective territorial location of fire brigades in rural areas. The average distance from settlements to fire brigades ranges from 30 to 40 km. At the same time, the network of roads in rural areas is characterized by unsatisfactory status [2].

The strategy for reforming the SES (The State Emergency Service) of Ukraine, which is directly related to the systems of fire fighting in rural areas, provides the implementation of regional programs and projects [3]. However, this strategy does not ensure the creation of the maximum value for the inhabitants of rural areas because it does not foresee the assessment of possible scenarios of fire fighting projects (FFP) in communities.

The development of conceptual plans for FFP should be based on the project management methodology. Reformation of the existing fire fighting systems of rural communities is possible only with the systematic implementation of the FFP and their qualitative management [2]. In order to implement the FFP, it is necessary to develop the set of tools for their planning. This will ensure an adequate determination of the predicted value, which underlies the development of effective conceptual plans of the FFP.

II. PROBLEM STATEMENT

The analysis of scientific works [4-6] concerning the operation of fire extinguishing systems in different countries of the world, shows that they include voluntary fire brigades, which are formed and financed from local budgets. They include voluntary and partly employed firefighters-rescuers.

The creation of voluntary fire brigades in European countries takes place on the basis of approved regulations. They prescribe the procedure for stimulation of firefighters and the conditions of their social protection.

Also, the attention of scientists is paid to the task of substantiating the effective configuration of fire extinguishing systems in different natural and climatic conditions [7-9]. The analysis of the mentioned scientific works testifies that the presented methods and models of the justification of the configuration of fire extinguishing

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systems have their disadvantages. They do not foresee the possibility of implementing projects of the creation of fire fighting systems in rural communities under different scenarios. Also, they do not take into account the peculiarities of a changing project environment, which has its own specifics for certain administrative territories of the state and communities.

Works [10, 11] indicate that an adequate assessment of the value of projects with a changing design environment is possible based on their simulation modeling. In this case, there should be computer models that will provide specific research. Given the lack of consideration of a specific project environment, as well as the prognosis of FFP values in different scenarios, it is impossible to adequately substantiate the desired configuration of these projects.

There are scientific papers [12-14], in which models of changing components of the design environment are developed. However, it is not possible to use them to assess the scenarios of the FFP, since they relate to urban fire extinguishing systems. This does not fully reflect the FFP design environment. Also a significant disadvantage of the existing toolkit for project management of fire extinguishing systems is that it does not provide the possibility of evaluating different scenarios for FFP.

A well-known method for identifying effective scenarios for the implementation of FFP and tools for their implementation (Fig. 1) [15] deserves attention. It enables to take into account the variable configuration of the FFP environment, to form a plurality of possible scenarios and to substantiate between them an effective one that will provide the maximum value for the stakeholders.

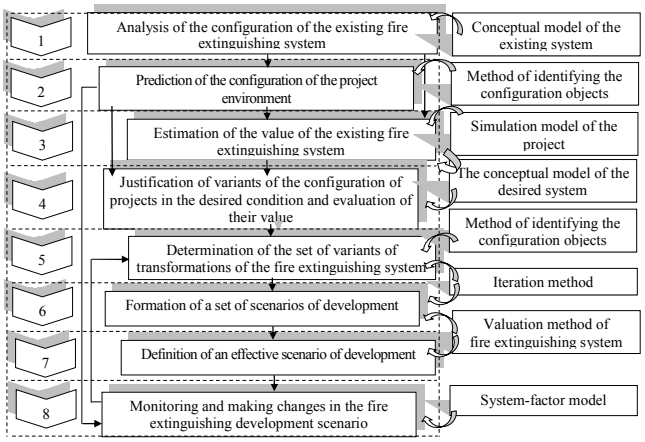

Fig. 1. Stages of the method of determining the effective scenarios for the implementation of FFP and tools for their realization [15].

To implement each of the steps of the proposed method, a specific toolkit based on the development of conceptual models of community fire suppression systems in the present and desired states, the simulation model of the project, as well as the use of iteration, identification of the object of configuration and valuation should be used.

The number of variations (N_ρ) of the transformation of firefighting communities depends on the number of configuration of existing (N_{O_b}) and effective desired (N_{O_d}) system, and also on relationships (β_O) between them:

$$N_\rho = \left(N_{O_b}, N_{O_d}, \beta_0\right). \quad (1)$$

Based on the known effective configuration K_{Sd}^e of firefighting system in communities in desired condition and variations of transformation N_ρ, and also predicted configuration of project environment K_{pe} we will conduct an adjustment of set of transformation $\{\rho\}$ and actions $\{d\}$. Each variant of transformation (ρ) has its own variations of actions (d), that enable mentioned transformations. The number of possible conversion options and actions ($N_{\rho\text{-}d}$) is determined by:

$$N_{\rho-d} = \sum_{\rho=1}^{n}\sum_{d=1}^{m} N_{\rho d}\ . \quad (2)$$

Transformation set coordination $\{\rho\}$ and actions $\{d\}$ is performed on the basis of modeling of projects of emergency response systems in the communities according to the known, K_{Sd}^e , that enable determination its organizational and technological indicators of value.

To determine an effective scenario C_S^e of FFP implementation we use iteration selection of possible variations of systematic coordination of transformations and actions $\{\rho—d\}$ for transferring these systems from its current condition in a desired one. Each of them is evaluated by the criteria $B_{\rho-d}^i$ of project's effectiveness under the i-scenario of its implementation, that is determined by such formula:

$$B_{\rho-d}^i = \frac{C_i}{V_i}, \quad (3)$$

where $B_{\rho-d}^i$ – FFP effectiveness under i-scenario of its implementation; C_i – FFP value under i-scenario of its implementation ; V_i – expenses on FFP realization under i-scenario of its implementation.

Based on the comparison of the quantitative criteria of the criterion $B_{\rho-d}^i$ under i-scenarios of their implementation, FFP choose such scenario C_S^e of implementation, that has the maximum value of $B_{\rho-d}^i$:

$$C_S^e = f\left(B_{\rho-d}^i\right) \to \max\ . \quad (4)$$

However, this method for determining the scenarios for the implementation of FFP is labor-intensive and requires the development of a computer model, which is a practical tool for making managerial decisions when developing their conceptual plans for the relevant projects.

The purpose of the work is to develop and use a computer model for evaluating the scenarios of projects for the creation of fire fighting systems in rural communities.

To achieve this goal, the following tasks should be solved:

- to develop a computer model for assessing the scenarios of projects for the creation of fire fighting systems in rural communities, providing an iterative overview of their possible variants and identifying

between them an effective criterion of maximum value;

- carry out a quantitative assessment of the scenarios of projects for the creation of fire extinguishing systems for the project environment of a given rural community.

III. Computer Model Of Estimating The Scenarios Of Projects Of Creation Of Fire Fighting Systems In Rural Communities

For the purpose of expedited and qualitative substantiation of the configuration of the FFP we have developed a computer model for evaluating the scenarios of these projects. The given model provides prediction of the values of FFP values in different scenarios for their implementation, taking into account the changing design environment. The computer model is based on a well-known method for determining the effective scenarios for the implementation of FFP [15], which involves the systematic execution of eight interrelated steps (Fig. 1). In this case, simulation of FFP is envisaged.

The algorithm of the computer model of estimation of scenarios of the FFP is realized in the following sequence:

1. Specify the characteristics of the project environment FFP: the number of settlements (n_i) in the community; population (n_p) and objects of high fire hazard (n_o) in eac of them.

2. To substantiate and insert in computer memory the model of the content and time of execution of works in the FFP.

3. Select the required number of variables, create their arrays and reset them for correct model operation.

4. Generate rows of arrival time of information of fire appearence (t_i), duration of team gathering (brigade) for departure on fire (t_t) and duration of deployment of fighting calculations (t_p):

$$M_{t_i} = \left\{ t_{i\,k} \right\}, k = \overline{1,n}, \tag{5}$$

$$M_{t_t} = \left\{ t_{t\,k} \right\}, k = \overline{1,n_k}, \tag{6}$$

$$M_{t_p} = \left\{ t_{p\,k} \right\}, k = \overline{1,n_k}, \tag{7}$$

where n_k – number of scenarios for the development of fire fighting systems of communities (types of fire depots), units.

5. Generate arrays of speed (V) of fire-fighting formations on ε – roads in settlements and beyond them, destinations ($L_{i,j}$) and type ($\varepsilon_{i,j}$) of roads between particular settlements:

$$M_{V_{ij}} = \left\{ V_{ij} \right\},\ i = \overline{1,\varepsilon},\ j = \overline{1,\nu}, \tag{8}$$

$$M_{L_{ij}} = \left\{ L_{ij} \right\},\ i = \overline{1,n},\ j = \overline{1,n}, \tag{9}$$

$$M_{\varepsilon_{ij}} = \left\{ \varepsilon_{ij} \right\},\ i = \overline{1,n},\ j = \overline{1,n}, \tag{10}$$

where ε – type of road surface; v – limitation of the speed of fire rescue units; n – number of settlements in the community.

6. Determine the coefficients ($k_{i,j}$) of roads condition between між i-and j-settlements of communities and to form an array:

$$M_k = \left\{ k_{ij} \right\},\ i = \overline{1,n},\ j = \overline{1,n}, \tag{11}$$

where n – number of settlements in the community.

7. Forecasting the annual number of fires (n_{nj}) in j-settlements, that are located in the territory of community.

8. Set an option (C_K) of fire fighting system configuration in desired condition. It is chosen from a set $\left\{ C_{n_k n_i} \right\}$ of types (k = 1, 2, …, n_k) and territorial location of fire fighting depot in i-settlement of community (ψ = 1, 2, …, n_k):

$$C_k \in \left\{ C_{n_k n_i} \right\}, k = \overline{1,n_k}, \psi = \overline{1,n_i}, \tag{12}$$

where n_k – the number of options for the development of the fire extinguishing system of the community (k – types of fire fighting depots), units; n_i – number of settlements in community where fire fighting depot is located, units.

9. Calculate the duration ($t_{i,j}$) of fire fighting formations arrival from the place of fire fighting depots dislocation in i-settlement in community to the object of fire of j-settlement and to form an array:

$$M_t = \left\{ t_{ij} \right\}, i = \overline{1,n},\ j = \overline{1,n}, \tag{13}$$

where n – number of settlements in community, units.

10. Determine the levels of fire insecurity (R_{ij}) of j-settlement in community under the conditions of given variant of fire fighting depot's location in i-settlement and for an array:

$$M_R = \left\{ R_{ij} \right\}, i = \overline{1,n},\ j = \overline{1,n}. \tag{14}$$

11. Determine the total level of fire insecurity of settlements (R_i^k) under the conditions of given variant of fire fighting configuration system of community in desired condition (location of k-type of fire fighting depot in i-settlement of community):

$$R_i^k = \sum_{j=1}^{n} R_{ij}^k, \tag{15}$$

where R_{ij}^k – the level of fire insecurity of j-settlement in case of location of k-type of fire fighting depot in i-settlement, min of fire; n – number of settlements in community.

12. Check for unsettled options for configuring the fire extinguishing system in the desired state. If such variants are available, return to step 8. If not, proceed to step 13.

13. To form an array of values of total levels of fire insecurity of settlements (R_i^k) for various configuration of the fire extinguishing system in the desired state:

$$M_{R_i^k} = \left\{ R_i^k \right\}, i = \overline{1,n},\ j = \overline{1,n_k}. \tag{16}$$

14. Perform a ranking of the values of the total levels of fire insecurity of community settlements (R_i^k), that are presented in array ($M_{R_i^k}$), in the order of their growth:

$$M_{R_i^k} = \left\{ R_4^{m3} < R_2^{m2} < ... < R_i^{mk} \right\}, \qquad (17)$$

where R_i^{mk} – the total level of fire insecurity of settlements of the community for the location of *k*-type of fire depot in the *i*-settlement, fire min.

15. Determine the effective configuration (K_{Sd}^e) of the community fire extinguishing system in the desired state on the criterion $R_i^{mk} \to \min$ of the minimum total fire insecurity level of its settlements (14).

16. Specify the parameters of the configuration objects (O_k) community fire extinguishing systems in desirable condition: type and quantity of technical equipment; number of performers of the fire brigade.

17. Perform a simulation of the work in the project for the predicted type and number of fires in *j*-settlements of community, specified parameters of the configuration objects (O_k) community fire extinguishing systems in the desired state and configuration of the project environment.

18. Conduct calculation of value indicators in FFP.

19. Perform valuation of FFP O_c.

20. Check for unmanaged options for configuration objects (O_k) community fire extinguishing systems in the desired state and configuration of the project environment. If such variants are available, return to step 16. If not, move to step 20.

21. Choose the effective firefighting configuration of the community in the desired state.

22. Include the results obtained in an array of results. Print results and shut down.

Based on the above algorithm, a computer program in Python 3.6 was developed (Fig. 2).

In order to verify the adequacy of the computer model for estimating the scenarios of the FFP, a preliminary modeling of the FFP was performed. Prediction of the values of the FFP values was carried out for the conditions of the Zhovtanets community in the Kamianka-Buzky District of Lviv Region. The developed computer model of estimation of FFP scenarios was tested for the adequacy of the *t*-criterion paired. During the check, its adequacy was compared with the experimental and simulated values of the level of fire insecurity (R_{ij})of individual settlements of the community.

It was discovered that the deviation of the quantitative values of the level of fire insecurity (R_{ij}) of individual settlements of the community on the basis of computer simulation and the obtained experimental values does not exceed 2.1 %. This testifies to the adequacy of the developed computer model of estimation of scenarios of the FFP.

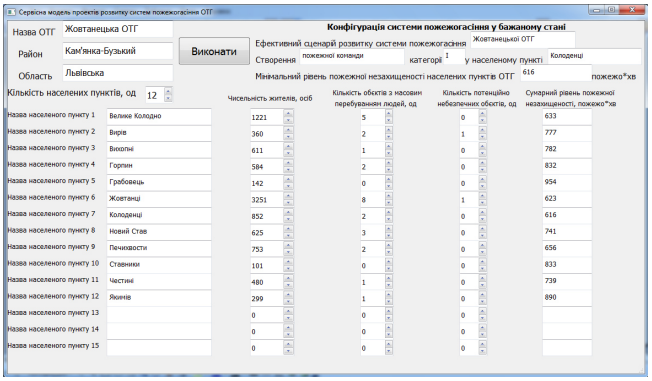

Fig. 2. Computer model of estimation of FFP scenarios.

IV. QUANTITATIVE ASSESSMENT OF PROJECT SCENARIOS FOR THE CREATION OF FIRE EXTINGUISHING SYSTEMS FOR THE PROJECT ENVIRONMENT OF A GIVEN RURAL COMMUNITY

In order to quantify the scenarios of the in the conditions of the project environment of the Zhovtanets community of Kamianka-Buzky district of Lviv region, simulation modeling of the corresponding projects was carried out. For this purpose, a developed computer model for assessing the scenarios of the FFP (Fig. 3) was used. In particular, the computer model provides modeling of five variants of scenarios for the creation of fire and rescue groups on the territory of Zhovtanets community, twelve variants of their territorial location (in each of the settlements of the community). Based on the results of the research, quantitative values of the total level of fire insecurity (*R*) of settlements of Zhovtanets community for establishing different types of fire and rescue units were established (Fig. 3).

The obtained diagram (Fig. 3) shows that the difference between the average and the minimum, as well as between the maximum and average values of the total level of fire insecurity (*R*) of settlements of Zhovtanets community is almost identical for the creation of all types of fire and rescue units. In this case, the mean square deviation, accordingly, varies within the limits – 100,8 ... 104,6 fires min.

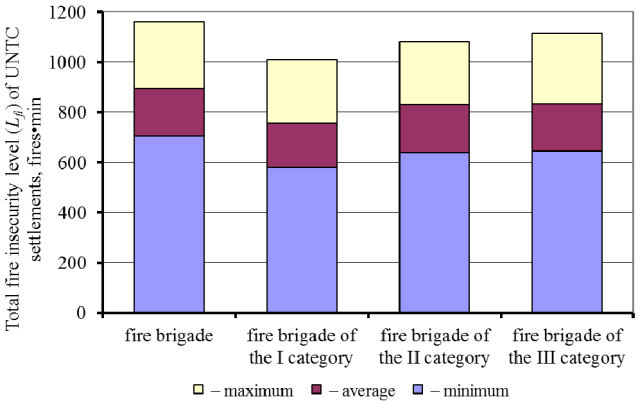

Fig. 3. Histogram of changes in the quantitative values of the total level of fire insecurity (Rн) of settlements of Zhovtanets community for the creation of various types of fire and rescue units.

In order to assess the value of the implementation of the FFP, the Zhovtanets community compared the existing and desired fire extinguishing systems. The existing fire extinguishing system is formed from the local fire brigade, located in the Velyke Kolodno village. The system consists

of 1 professional firefighter and 6 volunteers who use the fire truck АЦ-40 (131) 137 to extinguish fires. The preferred fire extinguishing system of the same community was estimated for four types of fire and rescue units under the condition of a new building. For the option of creating a fire brigade, they will be equipped with pickup Mitsubishi New L200 2.4 with the mobile complex Geyser MP-20/100P, and fire teams – a fire truck Tata LPT 613 + АЦ-18.

On the basis of conducting the corresponding calculations, a histogram of the consolidated expenses for the existing and desired variants of the fire-fighting system configuration of the Zhovtanets community was constructed (Fig. 4).

The obtained research results (Fig. 4) indicate that in the structure of consolidated costs of funds for the existing and desirable states of the fire extinguishing system of the Zhovtanets community, most of them are occupied by losses from fires. Their share for the creation of various types of fire and rescue units varies from 72 to 91.5 %, and the lowest is in fire teams of the I category - UAH 1685 thousand, or 72 %. It should be noted that the cost of maintaining the fire brigade for various options for the creation of fire and rescue formations fluctuate in considerable limits - 4.1 ... 22 %. The smallest expenses on maintenance of firemen are observed for the creation of fire brigades - 90 thousand UAH, and the largest – 513.6 thousand UAH. for the creation of firefighting teams of category I, which is explained by the growth of the staff of firefighters, who must round-the-clock alternate in fire fighting depots.

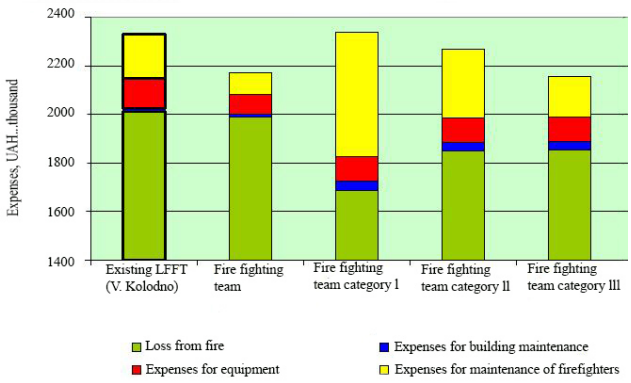

Fig. 4. Histogram of consolidated expenses for the existing and desired condition of the fire extinguishing system of the Zhovtanets community.

The small share is taken by the costs of maintaining buildings and technical equipment, which varies between 0.6 ... 1.7% and 3.7-2.5 % respectively. At the same time, the lowest consolidated cost of funds for the desired condition of the fire extinguishing system of the Zhovtanets community is observed in the scenario, which involves the creation of a fire brigade of the III category in the Kolodentsi village and they make up 2155,725 thousand UAH. At the same time, in this scenario, the development of the fire extinguishing system of the Zhovtanets community, compared with the existing state, can reduce the damage from fires in this system by 158.58 thousand UAH, or 7.9 %.

Consequently, the developed computer model provides research and determination of the quantitative values of the cost of funds for the functioning of the fire extinguishing system of communities in different scenarios of their development.

V. Conclusion

The developed computer model of estimation of scenarios for projects of creation of fire fighting systems of rural communities is based on an algorithm that involves the implementation of 23 steps that provide simulation of these projects, as well as a quick assessment of each of the scenarios for the development of fire fighting systems communities. The given model provides an iterative overview of possible variants of objects of configuration of projects for the creation of fire fighting systems of rural communities for each of the five substantiated scenarios, takes into account the changing components of the project environment and provides an identification of the effective scenario among them according to the criterion of maximum value.

Based on the developed and tested on the adequacy of the computer model, a quantitative assessment of the scenarios of projects for the creation of fire extinguishing systems for the project environment of the given rural community was performed. It has been established that the main indicators of the value of the project for the development of fire extinguishing systems in the Zhovtanets community depend on both the type of configuration objects and the location of the fire and rescue units on its territory. The total level of fire insecurity of settlements of Zhovtanets community is variable for certain scenarios of fire extinguishing systems development. The smallest combined costs for the desired condition of the fire extinguishing system of Zhovtanets community are observed in the scenario, which involves the creation of a fire brigade of the III category in the Kolodentsi village and they make up 2155,725 thousand UAH. In this scenario, the development of the fire extinguishing system of the Zhovtanets community, in comparison with the existing state, can reduce the damage from the fires in this system by UAH 158.58 thousand, or by 7.9%.

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