Planning of Territorial Location of Fire-Rescue Formations in Administrative Territory Development Projects

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Abstract. The proposed systematic approach to the implementation of the process of determining the territorial location of fire-rescue units in the projects of development of administrative territories eliminates the shortcomings of the existing ones and is the basis of their quality planning. The grounded approach involves the use of a complex criterion for determining the location of the territorial location of fire-rescue units in the administrative district. They also take into account the characteristics of the project environment, which include the number of inhabitants of settlements, the time of arrival of the formations to the emergency response sites. The developed software in Python 3.6 provides quality planning of the territorial location of fire-rescue units in the development projects of the administrative territories. In addition, the developed software is fundamental to planning an effective scenario for the implementation of these projects. The adequacy of the developed software was tested according to the paired t-criterion. The results obtained indicate that the quantitative values of the duration of arrival of fire- rescue units to the emergency response site were determined on the basis of calculations using the developed software and their experimental values do not exceed 5 %.

Keywords: Planning; Process; Project; Fire-Rescue Units; Territorial Location.

1 Introduction

Nowadays, the reform of the administrative-territorial system is taking place in Ukraine. The basic levels of the new administrative and territorial structure are the administrative districts and communities. At the same time project management is used in all spheres of life and human activity. It remains an important and rather effective way of developing administrative territories. In each of the newly created ad-

ministrative districts there are a number of administrative tasks related to the implementation of projects for the development of these territories. One of the most urgent projects for the development of administrative districts is the development of population security systems and territories. Their products are the creation of new rescue units.

The implementation of any projects, including those of the development of population security systems and territories, requires the implementation of a number of administrative processes. To do this, you need to have quality tools for executing management processes. One if such processes in the development of population and territorial security systems is the planning of the territorial location of fire-rescue units in a given administrative territory. For the qualitative implementation of this process, a method and software, that will take into account the specific features of the administrative area and the components of the project environment, should be available.

2 Analysis of Literary Data and Problem Statement

Known methods and models of project planning that relate to the development of administrative territories are aimed at solving a number of specific management tasks [1-3]. They are considered both in relation to individual planning processes and in the system for managing individual types of projects. Existing project planning tools are based on different methods and approaches. However, for the successful implementation of projects for the development of population security systems and territories, a toolkit should be provided to ensure the quality implementation of the planning process for the territorial location of fire-rescue units in a given administrative territory [4-6].

The development of project planning tools, based on various criteria, has received much attention from both domestic and foreign scientists [7-9]. Based on their analysis, it can be concluded that the systematic approach is the most effective tool for managing the development of population security systems and territories. It makes it possible to describe a separate territory as a system that functions as a unit. In addition, the systematic approach allows to improve the quality of planning of projects for the development of population security systems and territories by taking into account the interconnections between individual management processes [10-12].

Based on the analysis of existing methods and models of project management of the development of population and territorial security systems [13-15], it can be argued that there is no qualitative toolkit to perform the process of planning the territorial location of fire-rescue units in a given administrative territory. In particular, they do not systematically take into account a number of features of projects for the development of population security systems and territories. Regarding the process of planning the territorial location of fire-rescue units in a given administrative territory, the existing tools do not take into account the following:

1. The settlements of the given administrative territory are not evenly distributed;
2. Settlements have unequal population;

3. The presence of different types of roads (with and without solid surface, etc.) connecting the settlements of the administrative territory with each other.

In addition, the existing method [16] is designed to determine the territorial location of fire-rescue units in the administrative area and does not take into account the specific features of the design environment. In particular, this method involves taking into account the type of roads connecting individual settlements, but does not take into account their existing condition. The above points to the need to use a comprehensive criterion for determining the location of the territorial location of fire-rescue units in the administrative district, which takes into account both the number of residents of settlements and the time of arrival of units to emergency response sites.

The purpose of the work is to develop a systematic approach and software for planning the territorial location of fire-rescue units in projects of the development of administrative territories.

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

- to substantiate a systematic approach to the process of determining the territorial location of fire-rescue units in projects for the development of administrative territories;
- to develop software for planning of territorial location of fire-rescue units in projects of development of administrative territories and to check it for adequacy.

3 Systemic Approach to the Rationale of the Territorial Location of Fire-Rescue Formations in the Development Projects of the Administrative Territories

The proposed systematic approach to justification of the territorial location of fire-rescue units in the projects of development of administrative territories involves the use of such criterion as the level of emergency protection ($R_{нij}^{m}$) of its *j*-settlements, which is determined by the expression:

$$R_{нij}^{m} = n_{nj}^{m} \cdot t_{i,j}^{m}, \quad (1)$$

where $R_{нij}^{m}$ – the level of emergency protection from the *j*-th settlement, which is the part of *m*-th administrative territory, min; n_{nj}^{m} – number of emergencies in the *j*-th settlement, units; $t_{i,j}^{m}$ – duration of arrival of units from the location of the fire depot in the *i*-th settlement of the *t*-th administrative territory to the emergency with the *j*-th settlement, h.

Let's consider a separate administrative territory, which is represented as a graph (see Fig. 1).

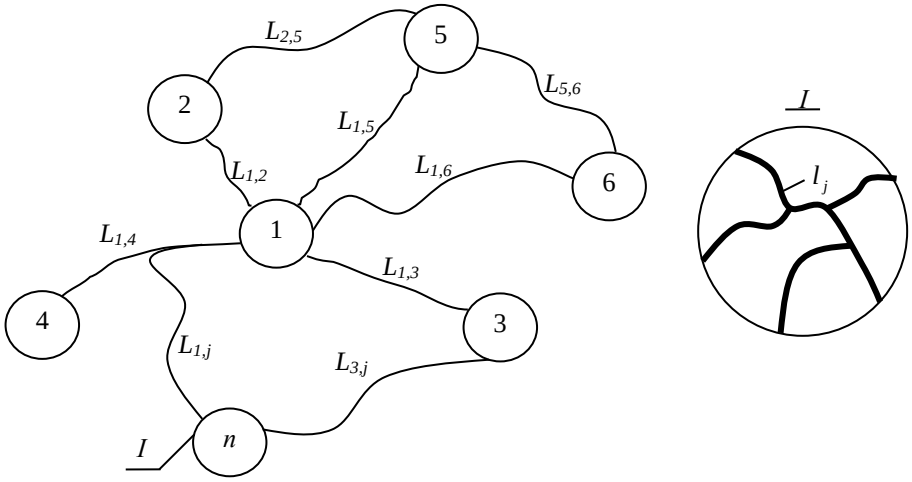

Fig. 1. – Graph of location of settlements in a separate administrative territory: 1, 2, ….*n* – the number of settlement; $L_{1,j}$ – distance between *1*-th та *j*-th settlements; l_j^m – the longest branch of the internal road network of the *j*-th settlement

There is a limited population ($N_{нс}^m$) in the *t*-th administrative territory, which is dispersed in the territory of its *j*-settlements:

$$N_{нс}^m = \left\{ n_{нс_j} \right\}, \; j = 1, n, \tag{2}$$

where $N_{нс}^m$ – the size of the population living in the t-th administrative territory, persons; $n_{нс_j}$ – population, living in the territory of the *j*-th settlement of the *t*-th administrative territory, person; *n* – number of settlements in the territory of the *t*-th administrative territory, units.

In this case, a fire-rescue unit should be located in one of these settlements, which will provide the minimum possible level of protection from emergencies of all settlements of the administrative territory ($R_н^m \to \min$).The following restrictions and assumptions are adopted in solving this problem:

1. The technical support of fire-rescue units and their personnel depend on the organizational variant of the development of the administrative territory;
2. Fire-rescue units are located in the territory of one of the settlements of the administrative territory;
3. No more than one fire-rescue unit is located in one administrative territory.

First of all, to determine the territorial location of fire-rescue formation in the administrative territory, perform research of the configuration of the project environment. The objects of this configuration are settlements (n_i), their population ($n_{нс}$) and high risk objects (n_0) in each of them, as well as the network of roads between and

within settlements. To accomplish this task, you must identify the specified configuration objects using a known method [17-20].

Given the quantitative values of the characteristics of the objects of the configuration of the project environment, we forecast the annual number of emergencies (n_{nj}^{m}) in the *j*-th locality, which depends on the population ($n_{нс_j}$) in it:

$$n_{nj}^{m} = f(n_{нс_j}), \tag{3}$$

where n_{nj}^{m} – annual number of emergencies in the *j*-th settlement of the *t*-th administrative territory, units; $n_{нс_j}$ – population in the *j*-th settlement of the *t*-th administrative territory, person.

Separate administrative territories are described by the model of territorial location of settlements with a network of roads, which is presented as a matrix of shortest distances on general-purpose roads between individual settlements of this territory:

$$M_{L}^{m} = \left\{ L_{i,j}^{m} \right\},\ i = 1, n,\ \ j = 1, n, \tag{4}$$

where M_{L}^{m} – matrix of the shortest distances on general-purpose roads between individual settlements of the *t*-th administrative territory; $L_{i,j}^{m}$ – distance along the road of general purpose between the *i*-th and the *j*-th settlements of the *t*-th administrative territory; *n* – the number of settlements in the *t*-th administrative territory.

The condition is accepted that fire-rescue units may be located in each of them. To determine the distance on the road of general purpose between the *i*-th settlement in which the fire-rescue unit is located and the *j*-th settlement of the *t*-th administrative territory, which needs protection from emergency situations, use the expression:

$$L_{i,j}^{m} = l_{i_0,j_0}^{m} + \frac{l_{i}^{m} + l_{j}^{m}}{2}, \tag{5}$$

where l_{i_0,j_0}^{m} – distance along the road of general purpose between the beginnings of the *i*-th and *j*-th settlements of the *t*-th administrative territory; l_{i}^{m}, l_{j}^{m} – the distance of the longest branch of the internal road network, respectively, of the *i*-th and *j*-th settlements of the *t*-th administrative territory.

For each branch of the network of roads, the administrative territory is evaluated for its condition. In particular, it is envisaged to determine the type of road (with and without solid pavement, field, etc.) and its condition. The type and condition of roads is determined on the basis of production experiments. On the basis of these experiments, for general purpose roads between the beginnings of settlements and roads of the internal network of settlements, their type and coefficients ($k_{i,j}^{m}$) are determined by formula:

$$k_{i,j}^{m} = \frac{\sum_{b=1}^{n} l_{i_b,j_b}^{m}}{l_{i,j}^{m}}, \quad (6)$$

where $k_{i,j}^{m}$ – coefficient of condition of the road between the *i*-th settlement and the fire-rescue unit and the ith settlement of the *t*-th administrative territory; $l_{i,j}^{m}$ – distance between the *i*-th settlement in which the fire-rescue unit is located and the *j*-th settlement of the *t*-th administrative territory; $\sum_{b=1}^{n} l_{i_b,j_b}^{m}$ – total distance of the damaged road between the *i*-th settlement in which the fire-rescue unit is located and the *j*-th settlement of the *t*-th administrative territory; *b* – the number of damaged sections on the road between the *i*-th settlement in which the fire-rescue unit is located and the *j*-th settlement of the *t*-th administrative territory.

The state of the roads of a separate administrative territory is described by a model, which is presented as a matrix of road condition coefficients:

$$M_{k}^{m} = \left\{k_{i,j}^{m}\right\}, i = \overline{1,n}, j = \overline{1,n}, \quad (7)$$

where M_{k}^{m} – matrix of road condition coefficients between individual settlements of *t*-th administrative territory; $k_{i,j}^{m}$ – coefficient of the state of roads between the *i*-th and *j*-th settlements of the *t*-th administrative territory; *n*– the number of settlements in the *t*-th administrative territory.

Having models of territorial location of settlements with the network of roads of a separate administrative territory (4) and the state of roads in its territory (7) form a matrix of the duration of arrival of fire-rescue units to emergency situations:

$$M_{t}^{m} = \left\{t_{i,j}^{m}\right\}, \; i = \overline{1,n}, \quad j = \overline{1,n}, \quad (8)$$

where M_{t}^{m} – matrix of duration of arrival of fire-rescue units to the emergency situations of the *t*-th administrative territory; $t_{i,j}^{m}$ – the duration of arrival of fire-rescue units from the location in the *i*-th settlement to the emergency facilities of the *j*-th settlement of the *t*-th administrative territory; *n*-the number of settlements in the *t*-th administrative territory.

Duration ($t_{i,j}^{m}$) of the movement of formations from the location of their location in the *i*-th settlement to the objects of emergency situations of the *j*-th settlement of the *t*-th administrative territory is determined by the formula:

$$t_{i,j}^{m} = t_{ін} + t_{з} + t_{о} + t_{об} + t_{н} + t_{нб} + t_{р}, \quad (9)$$

where $t_{ін}$ – duration from the moment of occurrence of an emergency situation to the receipt of information on its appearance in the fire-rescue formation, h; $t_{з}$ – duration

of emergency rescuers' collection, h; $t_д$, $t_н$ – accordingly, the duration of traffic formation on the sections of the road with the road without damaging the road surface between settlements and on the territory of settlements, h; $t_{дb}$, $t_{нb}$ – accordingly, the duration of movement of formations on sections of the road with a damaged road between settlements and on the territory of settlements, h; t_p – duration of deployment of combat calculations, h.

Duration (t_i) from the moment of the onset of an emergency prior to the receipt of information on its occurrence depends on the location of the facility with an emergency situation in the specified administrative territory, the period of the year and day, as well as the availability of telecommunications facilities, etc. Duration ($t_з$) of the gathering of the emergency rescuers depends on both the organizational variant of the development of the administrative territory and the efficiency of the dispatching service, the level of discipline, the training of rescuers and the technical condition of the fire trucks.

As regards the duration of movement of fire-rescue units, both between individual settlements in a given administrative territory and on their internal roads, it has several components:

$$t_д = \frac{l^m_{i,j} \cdot \left(1 - k^m_{i,j}\right)}{V_n}, \tag{10}$$

$$t_{дb} = \frac{l^m_{i,j} \cdot k^m_{i,j}}{V_{nb}}, \tag{11}$$

$$t_н = \frac{l^m_i \cdot \left(1 - k^m_i\right) + l^m_j \cdot \left(1 - k^m_j\right)}{V_н}, \tag{12}$$

$$t_{нb} = \frac{l^m_i \cdot k^m_i + l^m_j \cdot k^m_j}{2V_{нb}}, \tag{13}$$

where $t_д$, $t_н$ – accordingly, the duration of the formation movement between settlements and the territory of settlements of separate administrative territories, h; $t_{дb}$, $t_{нb}$ – accordingly, the duration of the formation on the sections of the road with a damaged road between the settlements and their territory, h; $l^m_{i,j}$ – distance between the *i*-th settlement in which the formation is located and the *j*-th settlement of the *t*-th territory, km; l^m_i ,l^m_j – respectively, from the longest branch of the internal road network of the *i*-th settlement in which the formation is located and the *j*-th settlement in which an emergency occurred in the territory of the *t*-th territory, km; $k^m_{i,j}$ – coefficient of the state of roads between the *i*-th and the *j*-th settlements in the *t*-th territory; k^m_i ,k^m_j – respectively, the coefficients of the state of roads in the *i*-th settlement where the formation is located and the *j*-th settlement where an emergency occurred; $V_д$, $V_н$ – accordingly the speed of movement of formations between settlements and on their

territory, km/h; $V_{\partial b}$, $V_{нb}$ – accordingly the speed of movement of formations on sections of the road with a damaged road between settlements and on their territory, km/h.

Having the quantitative value of the estimated number of emergencies in *j*-settlements (n_{nj}^{m}) (3) and the model of the duration of arrival of formations to emergencies in the *t*-th territory of the united territorial communities (8) form a matrix of levels of emergency protection against emergencies ($R_{нij}^{m}$) *j*-th of its settlements under different variants of arrangement of formations in *i*-th settlements:

$$M_R^m = \left\{ R_{нij}^m \right\}, i = \overline{1,n}, j = \overline{1,n}, \tag{14}$$

where M_R^m – matrix of levels of emergency protection from emergency situations of *j*-th settlements for the location of formations in *i*-th settlements in *t*-th territory, min; $R_{нij}^{m}$ – the level of emergency protection from the *j*-th settlement for the location of formation in the *i*-th settlement in the *t*-th territory, min.

Using the quantitative data of the matrix (14) determine the total level of protection from emergency situations of settlements ($R_{нi}^{mk}$) for the location of formations in each of the *i*-settlements in the *t*-th administrative territory:

$$R_{нi}^{mk} = \sum_{j=1}^{n} R_{нij}^{mk}, \tag{15}$$

where $R_{нi}^{mk}$ – the total level of protection from emergencies of settlements by the location of *k*-th types of formations in the *i*-th settlement of the *m*-th territory, min; $R_{нij}^{mk}$ – the level of protection from emergency situations of the *j*-th settlement due to the location of the *k*-th formations in the *i*-th settlement of the *m*-th territory, min; *n* – the number of settlements in the *m*-th territory.

Ranking scenarios for the development of security systems of the *t*-th territory in the desired state, given their configuration in the order of increasing the level $R_{нi}^{mk}$ of vulnerability to emergency situations of their settlements makes it possible to build an appropriate series

$$R_{н4}^{m3} < R_{н2}^{m2} < ... < R_{нi}^{mk}, \tag{16}$$

where $R_{нi}^{mk}$ – the total level of protection from emergencies of settlements of the *m*-th territory for the location of the *k*-th form of formation in the *i*-th settlement, min.

Such a configuration is considered effective ($K_{Sб}^{e}$)(type and territorial location) of the formations in the desired state of the *t*-th administrative territory, which provides a minimum level of protection from the emergency situations of its settlements:

$$K_{Sб}^{ef} = f\left(R_{нi}^{mk} \right) \to min. \tag{17}$$

Thus, the use of the proposed system approach allows to substantiate the effective type and optimal location of the territorial location of fire-rescue units in the projects of development of administrative territories, taking into account the changing configuration of the project environment (population in settlements, the presence of potentially dangerous objects and network characteristics of roads administrative area).

4 Software for Planning the Territorial Location of Fire-Rescue Formations in the Administrative Territorial Development Projects

Python 3.6 software was developed to accelerate decision-making regarding the location of fire-rescue units for elementary systems with the most insecurity from emergency situations (Fig. 2).

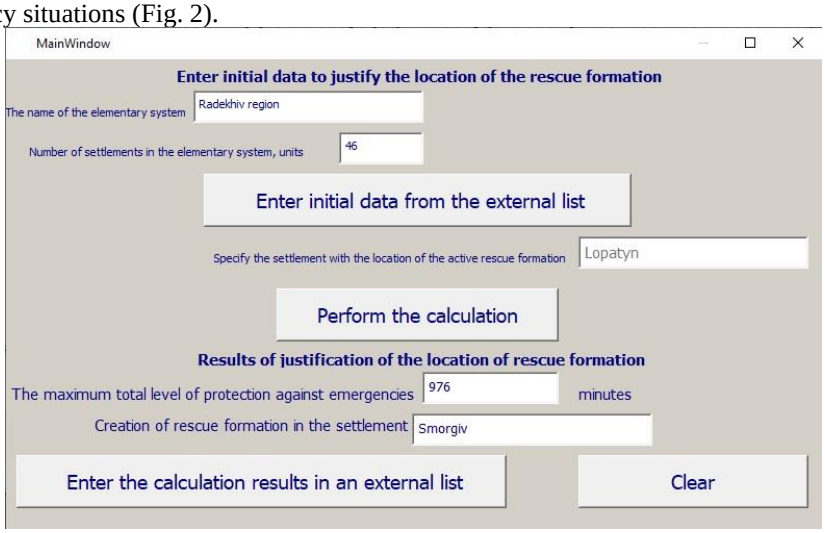

Fig. 2. Software window to justify the location of fire-rescue units in the specified administrative area with the greatest protection against emergencies

The proposed software is based on a well-grounded algorithm that incorporates all components of the above systematic approach to planning the territorial location of fire-rescue units in administrative development projects. In particular, it envisages the selection of settlements for the implementation of the priority project of the development of fire-rescue structures of the elementary system of a given administrative territory by the criterion of the minimum total level of protection from the emergency situations of their points. An algorithm block diagram and software for substantiating the location of fire-rescue units for elementary systems with the most emergency protection provides 16 steps.

The proposed software for justifying the location of fire-rescue units for elementary systems with the most emergency protection provides consideration of different

scenarios of their territorial location in the administrative area. Their number depends on the number of settlements in the administrative district.

The result of calculations is a list of ranked in descending order ($M_{R_{ni}^k}$) quantitative values of the total levels of emergency protection items (R_{ni}^k) in different scenarios of the territorial location of fire-rescue units in the *i*-th settlements of the elementary system of a given administrative territory. This list can be output to an external file. The software window displays the name of the locality where the fire-rescue formation for elementary systems should be located, as well as the quantitative value of the greatest emergency protection.

The software of grounding of location of fire-rescue formations for elementary systems with the most emergency protection against emergency situations is tested for adequacy by the paired *t*-criterion. In particular, the adequacy check was performed for the conditions of the Radekhiv district of Lviv region. There are 21 state rescue units (Radekhiv city) and 51st state emergency rescue headquarters of Ukraine in the Lviv region (Fig. 3).

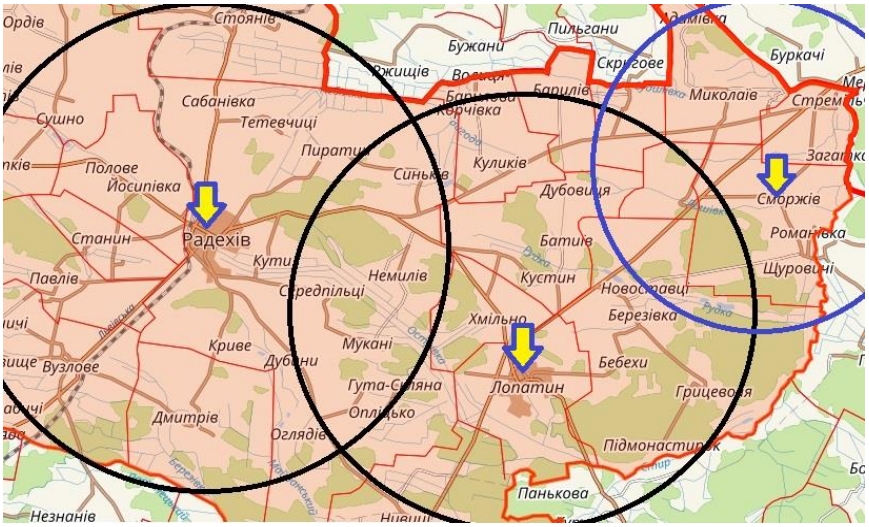

Fig. 3. Scheme of location of objects of protection against emergency situations of Radekhiv district of Lviv region

Based on the calculations made using the developed software, it is established that in the territory of the Radekhiv district of Lviv region it is necessary to place fire-rescue formation in the village Smorgiv, which will reduce the maximum total level of emergency protection from human settlements (R_{ni}^k) from 976 minutes up to 328 minutes.

To test the adequacy of the software for justifying the location of fire-rescue units for elementary systems with the most emergency protection, we compared the quantitative values of the arrival of special units to the emergency response site

obtained from manufacturing and computer experiments. They are obtained as a result of using the developed software. At the same time, production experiments were conducted in the current 51st State Fire-Rescue Post of the Emergency Management of Ukraine in Lviv region. The initial data for the validation of the software of justification of the location of fire-rescue units for elementary systems with the greatest protection against emergency situations for adequacy are given in Table 1.

Table 1. Initial data to verify the adequacy of the software for the location of fire-rescue units.

Option of arrival of special units to the place of emergency elimination	Duration of arrival of formations to the place of emergency elimination, min		Difference ($x_{2n} - x_{1n}$)
	Production experiment, x_{1n}	Computer experiment, x_{1n}	
1	16.4	17.2	0.8
2	20.3	19.9	– 0.4
3	26.1	25.2	– 0.9
4	12.5	13	0.5
5	12.9	13.5	0.6
6	7.2	6.9	– 0.3
7	15.4	16.1	0.7
8	8.6	8.2	– 0.4

As a result of the verification of the aforementioned software for adequacy, it is established that the experimental and simulated values of the arrival time of the special units to the emergency elimination site are within acceptable limits. In particular, the duration of arrival of special units to the emergency response site is determined on the basis of a calculation using the developed software and their experimental values do not exceed 5 %. This testifies to the adequacy of the calculations received based on the use of the developed software to justify the location of fire-rescue units.

5 Conclusions

The proposed systematic approach to the implementation of the process of determining the territorial location of fire-rescue units during the implementation of projects for the development of administrative territories eliminates the shortcomings of the existing and underlies the quality of their planning. This approach involves the use of a complex criterion for determining the location of the territorial location of fire-rescue units in the administrative district, takes into account both the number of residents of settlements and the time of arrival of formations to emergency response sites, as well as provides for the determination of a rational variant of the territorial location of fire-rescue units, that provides the minimum total level of protection from emergencies of settlements of the given administrative of the territory.

Developed software in Python 3.6 for planning the territorial location of fire-rescue units in administrative development projects provides rapid management decisions to determine the location of these units in the areas most vulnerable to emergencies. The performed check for the adequacy of the developed software by the paired t-criterion indicates that the quantitative values of the duration of arrival of fire-rescue units to the emergency response place determined on the basis of calculations using the developed software and their experimental values do not exceed 5%. This indicates that the software adequately reflects the real processes and can be used by project managers when planning projects for the security of administrative territories.

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