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# DEVELOPMENT OF THE METHOD FOR TERRITORIAL COMMUNITY FORMATION BASED ON MULTI-CRITERIA SWARM ALGORITHM APPROACH

*Запропоновано метод формування територіальних громад за допомогою алгоритмів кажанів та сірих вовків. Розроблено математичну модель методу формування громад. Досліджено ефективність виконання методу на прикладі формування територіальних громад у Чернівецькій області (Україна). Тестування запропонованого методу виконується на базі ГІС технологій і статистичних даних.*

**Ключові слова:** *алгоритм кажанів, алгоритм сірих вовків, формування територіальних громад, критерії оцінювання.*

## 1. Introduction

The task of structuring administrative-territorial communities on a hierarchical level is now topical. The solution of this problem leads to the solution of one of the most important complex problems of the heterogeneity of administrative units (demographic, economic, social, etc.). An important aspect of the work is the choice of criteria, such as the availability of hospitals, fire departments, police departments, social institutions, etc., through which potential administrative centers and administrative units close to them will be identified, and territorial communities will be formed.

Studies on the structuring of administrative-territorial units form the task of strengthening administrative units by combining them. Larger formations of administrative units make it possible to combine the budgets of existing territorial entities, and to increase financing for solving economic, public, transport issues. In addition, the optimization of the structure through the strengthening of administrative units suggests a method of solving the problem of financial heterogeneity by reducing adjacent administrative units through partial integration with administrative centers.

To regulate the process of creating new territorial communities of Article 11 of the Law of Ukraine «On the Voluntary Association of Territorial Communities», the Cabinet of Ministers of Ukraine decided in 2015 to approve the Methodology for the formation of capable territorial communities.

The article proposes a formalized structural approach to the formulation and solution of the problem of strengthening administrative units by solving the optimization problem and combining it according to selected criteria.

## 2. The object of research and its technological audit

*The object of research* is the process of formation of territorial communities through the use of swarm algorithms and the method of multi-criteria optimization. One of the most problematic places in this process is the choice of the administrative center of the territorial community. It is necessary that the selected center has a full set of evaluation criteria, such as: the availability of fire units, hospitals, police departments, kindergartens and social institutions. To identify the specifics of this process, it is necessary to conduct a technological audit to identify the main aspects of such process.

The transition from the centralized planning economy to market relations is accompanied by a number of changes in the regional development model. Its main problems are: deepening the network of administrative centers, districts, large and medium-sized cities, as well as an increase in unemployment and other social problems caused by the inability to work. As a result, the economic potential of isolated administrative districts and centers is being destroyed, which leads to social degradation and an increase in spending on social needs. Therefore, new methods are necessary to optimize the structure of the location of territorial communities in order to achieve the same level of social living in all regions that will not depend on the number of people, the size of the territory, etc.

The article proposes to use the gray wolf algorithm to obtain the most effective result of optimizing the location of administrative centers when building new territorial communities.

The gray wolf algorithm is a metaheuristic search algorithm. This article will describe the main components of the process, determine the approach of elected administrative units (gray wolf) to the administrative center (prey). It is necessary to optimally distribute the administrative units in such way that their location is closest to the administrative center.

The essence of the algorithm is based on the hunting model of a group of wolves. It is believed that other wolves are rebuilt to the wolf that is closer to mining, forming a ring. In the future, other wolves are reconverted to the wolf, which is even closer to the goal. The process

 

of shifting takes place until the wolves get together in the group. When this goal is achieved, this will be the optimal distance before the attack on the prey.

The gray wolf algorithm includes the main advantages over other metaheuristic algorithms for its simplicity and flexibility. There are not many actions in it that work on a cyclic basis, which makes it simple in the implementation of solving the problems of process optimization.

The next stage in the work is the definition of criteria for evaluating administrative units for the administrative center and the possibility of their association in a territorial community. For this, it is proposed to use the multi-criteria optimization method and the bats algorithm. In multi-criteria optimization, the most often is not the verbal description of a problem, but its model. That is, the mathematical model of decision making by several criteria. These criteria may reflect an assessment of the various qualities of the object or process for which a decision is made. To obtain a solution, it is necessary to determine which criteria will be given greater preference. To solve such problem it is necessary to formulate a special optimality principle, to determine additional subjective information about objects, and to determine procedures for obtaining the advantage of one object over another. This task includes one criterion, and restrictions are added to the initial procedure, and it will be the main determinant of the evaluation criterion of the administrative center, which contains additional information that is necessary for the association. To obtain a sustainable solution to determine subjective information, the bats algorithm is used.

The bats algorithm is an optimization algorithm. The main advantage of this method is the speed of its execution. Such algorithm is potentially more powerful than the particle swarm algorithms, as well as the genetic algorithm, which are also used to solve similar problems. The genetic algorithm and the swarm algorithm are simplified versions of the bats algorithm, because the genetic algorithm uses descendants, and in the swarm of particles, an optimal solution is sought by minimizing local points. Meanwhile, the bats algorithm contains the search for points and regions based on the local minimum and maximum, and also carries out the search and optimization process by means of the «distribution» of echolocation, which contain information about the initial position of a particular point.

## 3. The aim and objectives of research

*The aim of research* is development of a method for the optimal allocation of territorial communities by using the gray wolf algorithm, the bats algorithm, and the multi-criteria optimization method. The above methods and algorithms are used to form administrative communities taking into account the selected criteria in order to improve economic and social ties between administrative units and centers.

To achieve this aim it is necessary:

1. To construct a mathematical model of the process of formation of a territorial community and to optimize the parameters of territorial units using the multi-criteria optimization method.

2. To identify information and a set of evaluation criteria for regulating the accession process to the territorial community using the bats algorithm.

3. To establish the position of the administrative center in the territorial community, using the gray wolf algorithm.

4. To test the work of the developed method on the example of the formation of territorial communities in Zastavnivskyi district of the Chernivtsi region (Ukraine).

## 4. Research of existing solutions of the problem

Optimization of the structure of administrative communities requires addressing the problem of financial heterogeneity by reducing adjacent administrative units through partial integration with administrative centers. To create new territorial communities, it is necessary to be guided by the current laws of Ukraine, which regulate this process [1].

The gray wolf algorithm is used to find the catch, in this case the administrative center. The peculiarity of this algorithm is the presence of cycles. The more cycles of the administrative center being located, the more accurate the final result will be. Such a process is noted in [2, 3].

Among the main algorithms used to form territorial communities, one can single out the genetic algorithm and the classical bats algorithm [4].

Using the genetic algorithm, the main elements of the formation of territorial communities are taken into account, namely: the number of participants in the formation process, the definition of the initial population, in this case the administrative centers, the population as a whole. This algorithm is widely used to solve the problems of forming territorial communities due to its function of crossing. That is, by forming a population, among which the administrative center of the community will be selected, the genetic algorithm remembers the information necessary for such process and passes it on to the next generation (descendants). Thus, each next population has a tendency to elect a more appropriate administrative center. The disadvantage of using this algorithm is that with a large number of iterations there are many potential solutions, and there is a possibility of a dual link. When such relationship arises, the genetic algorithm does not provide for a check on the subject of the administrative center of two or more candidates.

An alternative solution to this problem is the use of the classical bats algorithm [5]. The authors of [6–8] show that the bats algorithm, using its peculiarity, namely echolocation, allows choosing among potential candidates the one with the highest concentration of election criteria in a given area. Among them may be: the saturation of transport links, the number of people and the number of social and state institutions.

Works [9, 10] are devoted to the global optimization of the parameters of the region using the bats algorithm. The process of formation of territorial communities occurs in a given area (cluster). This restriction is set in order to avoid a recursive procedure, leading to an increase in the number of participants in the process of forming a territorial community. Such participants may be adjacent councils or settlements of another territorial community.

Thus, the results of the analysis allow to conclude that using one algorithm the most effective result can't be achieved. It is necessary to use functions of several algorithms in order to improve the method of forming territorial communities.

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## 5. Methods of research

Studying the gray wolf algorithm and the method of multi-criteria optimization, it is determined that to solve the task it is necessary to determine all the participants of the territorial community. Next, it is necessary to build a mathematical model of the algorithm, in particular, the model for determining evaluation criteria. The next step will be to simulate the process of optimal location of administrative centers and administrative units in territorial communities.

To determine the criteria for estimating the region in the created algorithm, let's use the multi-criteria optimization method, namely, let's optimize the parameters of the domain (cluster) in which the administrative units are searched.

Thus, the $i$-th cluster is defined as follows:

$$R_{ij}: \text{If } X_1 = A_{1i} \left| X_2 = A_{2i} \right| X_3 = A_{3i} \ldots \left| X_n = A_{ni} \right|,$$
$$\text{then } class = c_j, \quad (1)$$

where $x = (x_1, x_2, x_3 \ldots x_n)$ – the number of administrative units; $A_{ki}$ – a set of properties that characterize the $k$-th criterion in the $i$-th cluster $(i \in [1,R])$, $R$ – the number of admissible administrative centers, $c_j$ – the identifier of the $j$-st level, $j \in [1,m]$.

The task of clustering can be described by a function:

$$f: R^n \{0,1\}^m, \quad (2)$$

where $f(x) = (c_1, c_2, c_3 \ldots c_m)$, and $j \in [1,m]$, $i \neq j$ when the criterion given by the number $x$ refers to the class $c_i$.

A ready solution is a class, defined as follows:

$$class = c_j \arg = \max_{1 \lhd j \lhd m} B_j. \quad (3)$$

Thus, the given process of optimizing the parameters of the domain for determining the criterion for evaluating administrative units for the administrative center is carried out using the multi-criteria optimization method shown in Fig. 1. This allows to effectively solve the task.

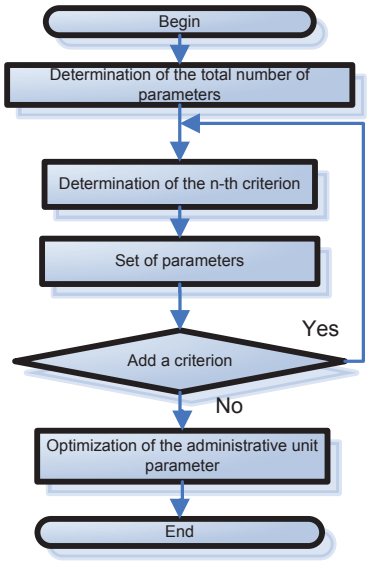


**Fig. 1.** Multi-criteria optimization of the administrative unit parameters

A step-by-step method is proposed for the formation of territorial communities using the gray wolf algorithm:

*Step 1.* Finding the nearest administrative units. Each administrative center corresponds to administrative units $x_i = (x_i, x_2, \ldots, x_n)$, and their position is generated by the area $\theta = (\theta_1, \theta_2 \ldots, \theta_n)$ where $\theta$ is the index of the position of administrative centers.

*Step 2.* Finding the next three administrative units. The final position of the administrative center is generated by the function:

$$f_x^n = \min\left\{(\theta_1 - x_{11})^2 + (\theta_2 - x_{12})^2 + \ldots + (\theta_n - x_{1n})^2\right\}. \quad (4)$$

At this stage, a list of three administrative centers is formed, closest to administrative units.

*Step 3.* Calculation of the coordinates of the position of the administrative center in relation to administrative units. Further, the positions of the following administrative centers are calculated $D_{\theta_1}$, $D_{\theta_2}$, $D_{\theta_3}$ and $Y_{\theta_4}$, $Y_{\theta_5}$, $Y_{\theta_6}$.

$$\vec{D}_a = \left|\vec{C}_1\vec{X}_a - \vec{X}\right|, \ \vec{D}_b = \left|\vec{C}_2\vec{X}_b - \vec{X}\right|, \ \vec{D}_d = \left|\vec{C}_3\vec{X}_d - \vec{X}\right|, \quad (5)$$

$$\vec{Y}_1 = \vec{X}_a - \vec{A}_1\vec{D}_a, \ \vec{Y}_2 = \vec{X}_a - \vec{A}_2\vec{D}_a, \ \vec{Y}_3 = \vec{X}_a - \vec{A}_3\vec{D}_a. \quad (6)$$

The position of administrative centers is calculated by the formula:

$$\vec{A} = 2\vec{a}\vec{r}_1 - \vec{a}, \quad (7)$$

$$\vec{C} = 2\vec{r}_2, \quad (8)$$

where $r_1$ and $r_2$ is the maximum number of administrative units located in the region where $a$ is a future territorial community:

$$\vec{a} = 2 - 2\left(\frac{itr}{\max itr}\right), \quad (9)$$

where $itr$ is the number of repetitions of the search, and $\max itr$ – how many repetitions will be all.

*Step 4.* Calculation of the new coordinates for administrative units.

To calculate new coordinates of administrative units, it is necessary to find the arithmetic mean of the previous coordinates $A_1$, $A_2$, $A_3$.

$$\vec{x}(i,1) = \frac{y_1 + y_2 + y_3}{3}. \quad (10)$$

*Step 5.* Comparison of the number of iterations. If they do not match, then everything returns to the second step.

*Step 6.* In this step is the nearest administrative center in relation to the existing administrative centers. It will be checked in the future on the subject of the administrative center by the method of multi-criteria optimization.

The proposed algorithm makes it possible to effectively find the ready-made solution for building territorial communities with the help of the gray wolf algorithm, as well as creating the possibility of checking administrative units for the administrative center using the multi-criteria optimization method.

The purpose of using the bats algorithm, shown in Fig. 2, is the optimization of the parameters of the fuzzy cluster.

The main idea is to describe the area in which the participants of the territorial community are involved.

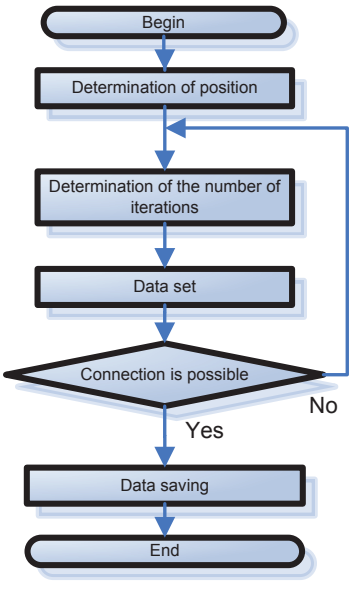


**Fig. 2.** Functions of the bats algorithm

For the formation of territorial communities in the Zastavnivsky district of the Chernivtsi region (Ukraine), a method is developed that includes the functions of the gray wolf algorithm. The principle of the algorithm is shown in Fig. 3.

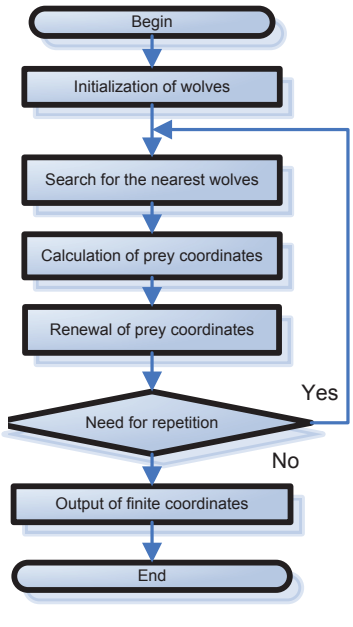


**Fig. 3.** The gray wolf algorithm

In the bats algorithm, echolocation is used to analyze the information given in Table 1, as well as the position between the administrative centers and administrative units shown in Table 2.

Given the feature of the gray wolf algorithm, namely the search for the position of the closest potential members of the territorial community, the concept of distance between settlements in any case will be satisfactory.

**Table 1**

Set of evaluation criteria

| Names of settlement | Number of schools, $k_1$ | Number of kindergartens, $k_2$ | Number of police departments, $k_3$ | Number of fire units, $k_4$ | Number of hospitals, $k_5$ | Number of social institutions, $k_6$ |
|---|---|---|---|---|---|---|
| Zastavna | 2 | 3 | 1 | 1 | 2 | 30 |
| Verenchanka | 1 | 2 | 0 | 1 | 2 | 1 |
| Kadubivtsi | 1 | 1 | 0 | 0 | 1 | 2 |
| Rzhavintsi | 1 | 1 | 1 | 1 | 1 | 1 |
| Yurkivtsi | 2 | 1 | 1 | 1 | 1 | 2 |

**Table 2**

Composition of Zastavnivsky district of Chernivtsi region (Ukraine)

| $A_n$ | Administrative status | Population | Distance to administrative center, km |
|---|---|---|---|
| 1 | Zastavna City Council<br>Zastavna city | 8068 | 0 |
| 2 | Tovtriv village council<br>Tovtry village | 1573 | 6.4 |
| 3 | Doroshovetka village council<br>Doroshivtsi village | 1372 | 10.4 |
| 4 | Verenchatska village council<br>Verenchanka village<br>Jablunivka village | 3602 | 8.4 |
| 5 | Gorishnosherovetskaya village council G. Sherivtsi village | 2498 | 22 |
| 6 | Zadubrivska village council<br>Zadubrivka village | 862 | 18 |
| 7 | Vaslovs'ka village council<br>Vaslovivtsi village | 1229 | 14 |
| 8 | Kadubivska village council<br>Kadubivtsi village | 2838 | 10 |
| 9 | Yurkovetska village council<br>Yurkivtsi village | 1652 | 10 |
| 10 | Goroshovetska village council<br>Goroshivtsi village | 981 | 15 |
| 11 | Boianchutska village council<br>Boianchuk village | 922 | 13 |
| 12 | Dobrinovetska village council<br>Dobrinovtsi village | 1366 | 18 |
| 13 | Verbovetska village council<br>Verbivtsi village | 472 | 12 |
| 14 | Malokuchurivska village council<br>Malyi Kuchuriv village | 1141 | 9 |
| 15 | Rzhavinetska village council<br>Rzhavintsi village | 2752 | 23 |
| 16 | Viknianska village council<br>Vikno village | 1416 | 17 |
| 17 | Bridotska village council<br>Bridok village | 423 | 24 |
| 18 | Mytkivska village council<br>Mytkiv village | 312 | 24 |
| 19 | Onutska village council<br>Onut village | 557 | 24 |
| 20 | Chornopotitsa village council<br>Potik village | 498 | 22 |
| 21 | Pogorelivska village council<br>Pogorelivka village | 1436 | 15 |
| 22 | Mosorivska village council<br>Mosorivka village | 278 | 26 |
| 23 | Samushinska village council<br>Samushino village | 342 | 26 |
| 24 | Balamutivska village council<br>Balamutivka village | 1595 | 24 |

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Once all participants in the process of forming a territorial community are determined using the bats algorithm, it is possible to check administrative units for the administrative center in the following steps:

*Step 1.* Definition of objective function $f(x)$, $x=(x_1 x_d)^T$.

*Step 2. Initialization* of the initial number of bats $x_i$ $(i=1\ldots n)$ necessary for the verification, the speed of the criteria choice $v_i$, the definition of the administrative unit $A_i$, the number of criteria $r_i$ are given in Table 2. At this stage, the initial position of the bats in the area is set. Also, the number of iterations is set, that is, the number of test cycles.

*Step 3.* Determination of the processing frequency $f_i$ in $x_i$.

*Step 4.* Generation of a decision regarding the position of the potential administrative center.

At this step it is important to fix the position of bats in potential administrative centers, using the feature of the algorithm, namely the ability of bats to «sit down» at a local point. This feature is used to further regulate the possibility of joining administrative units from another territorial community to the current one. Thus, the bats contain the position information and the distance required for the joining process:

$$f_t = f_{\min} + (f_{\max} - f_{\min})\beta,\ \beta \in [0,1], \tag{11}$$

$$v_1^t - 1 + (x_1^t - \bar{x}) f_t, \tag{12}$$

where $\bar{x}$ – the current location.

$$x_1^t = x^{t-1} + v_1^t. \tag{13}$$

*Step 5.* Generation of a local solution, provided that the specified number in the range from 0 to 1 is more than the number of criteria $(rand \triangleright r_i)$:

$$x_{new} = x_{old} + EA^t,\ E[-1,1], \tag{14}$$

where $A^t$ – the number of potential administrative units.

*Step 6.* If the local solution is less than the current solution and a random number *rand* and in the interval (0,1) is less than the number of criteria $(rand \triangleright A_i)$, then a new solution is applied. In addition, the speed of processing also decreases and the number of participants in the formation of the territorial community increases:

$$A^{t+1} = a_1^t,\ a \in [0,1], \tag{15}$$

$$r^{t+1} = r_0^t [1 - \exp(-yt)],\ y \triangleright 0. \tag{16}$$

*Step 7.* If the optimal function optimum is found, the algorithm stops its work, otherwise steps 4–6 are performed until the iterations run out.

Using the example of the method of forming territorial communities in Zastavnivskyi district of the Chernivtsi region (Ukraine), let's obtain the following results:

1. Let's suppose that in every village there are schools, kindergartens and a medical institution, so we will impose restrictions on checking the set of criteria for the territorial unit by the bats algorithm:

$$A_{ki}: (A_{1k} \triangleright 0, A_{2k} \triangleright 0, A_{3k} \triangleright 0 \ldots A_{nk} \triangleright 0). \tag{17}$$

Having analyzed the conditions for the inclusion of administrative units before the inspection for the administrative center, let's obtain the following population exceptions: Mitkov, Mosorivka, Onut, Pogorelivka, Prilipche, Boyanchuk, Bridok. Since there is no hospital in the mentioned settlements, the value of one of the criteria is 0.

2. It is necessary to determine the adjacency of the councils of settlements. This procedure is carried out in order to avoid the so-called «white spots» in the formation of territorial communities. Since adjacent councils can be included in two or more territorial communities, we understand that such councils depend on the established territorial communities. They also depend on the information obtained with the help of the gray wolf algorithm and are necessary for connection. Therefore, in the first place, let's consider exclusive settlements as adjacent councils, and their further inclusion in a particular territorial community is subject to the following restrictions:

$$A_n: (i \in [1,R]),\ R \le 0 \ge 1. \tag{18}$$

Councils that are corresponding value of 0 will be included in the existing potential administrative centers. Other councils that have acquired the value of 1 have the opportunity to be included in 2 or more administrative centers. Therefore, they need an additional cycle of bats (Table 3).

**Table 3**

Adjacent councils of Zastavnivsky district of Chernivtsi region (Ukraine)

| Councils | Zastavna | Verenchanka | Kadubivtsi | Rzhavintsi | Yurkivtsi |
|---|---|---|---|---|---|
| Mytkiv | 0 | 0 | 0 | 0 | 1 |
| Mosorivka | 1 | 0 | 0 | 0 | 0 |
| Onut | 1 | 0 | 0 | 0 | 0 |
| Pogorelivka | 0 | 0 | 0 | 0 | 1 |
| Prilipche | 0 | 1 | 0 | 0 | 0 |
| Boyanchuk | 0 | 0 | 0 | 0 | 1 |
| Bridok | 1 | 0 | 0 | 0 | 0 |

After completing the search cycle of administrative centers using the gray wolf algorithm among 24 administrative units, 5 potential administrative centers are identified.

Due to the ability to specify the number of iterations, even more potential administrative centers may appear with each cycle, however, the values of the criteria will be less than in the first iteration. This logic of processing of input and output data is shown in Fig. 4, will allow them to operate in any order.

This approach can be applied situationally. Let's consider an example if in search of participants of process of territorial community formation the administrative unit from other community has been included. So its participation is possible in both communities. In this case a dual connection arises. The scheme of the dual coupling is shown in Fig. 5.

If such connection arises between two objects, in this case, administrative units, which have the same set and the number of criteria, it is possible to see a very obvious dependence. Having the same parameters the message, which is sent to the system, will also be identical. This predetermines the ability to create a class, which automates this process. Also, if such a relationship arises, immediately report that there are 2 or more solutions.

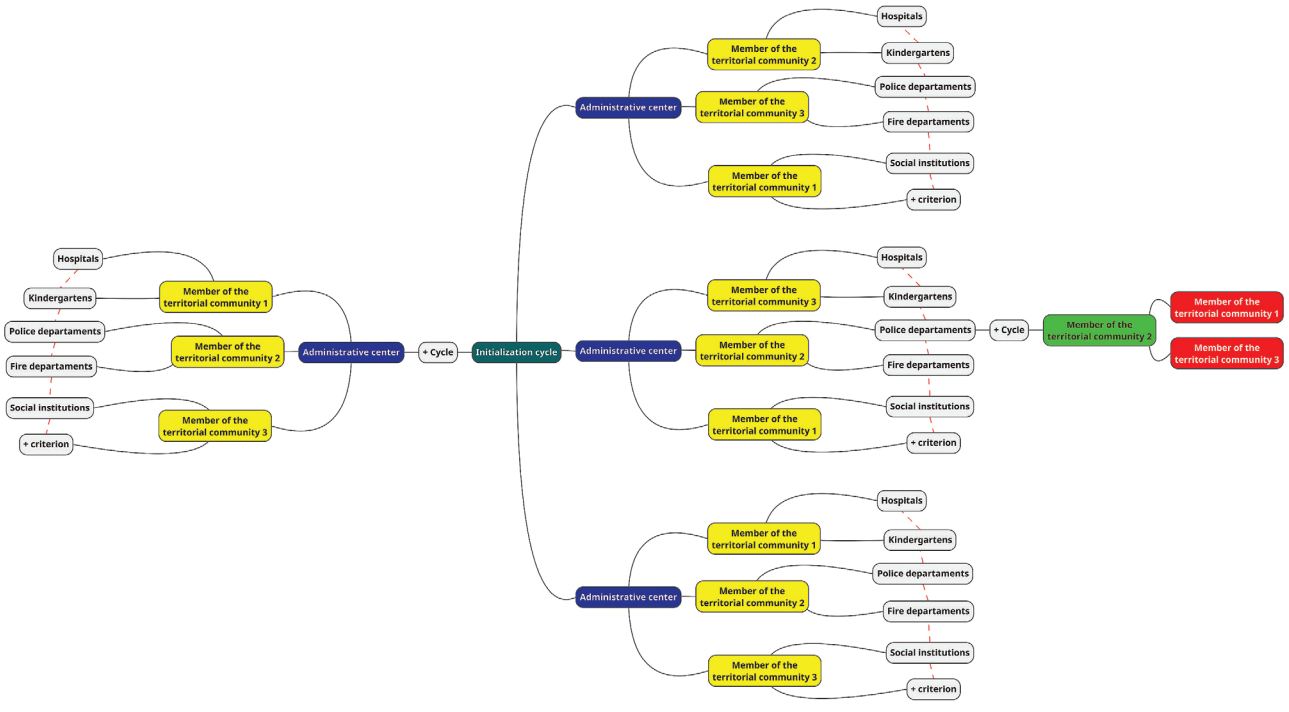


**Fig. 4.** The logic of input and output data processing

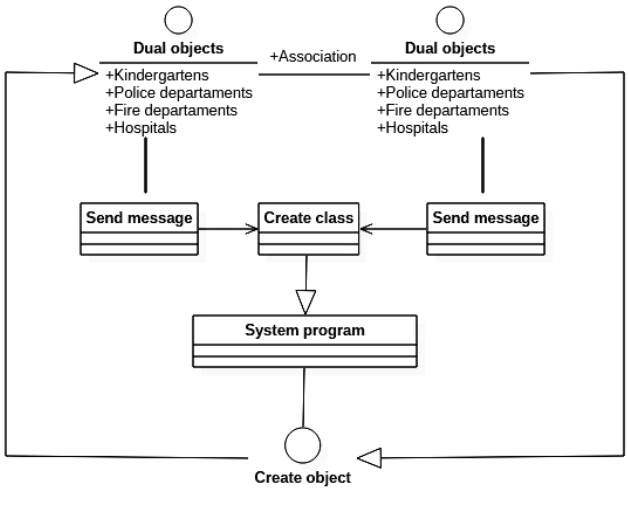


**Fig. 5.** Dual connection of administrative units

The flexibility of the proposed method allows to analyze with our own hand the advisability of including an administrative unit in a particular territorial community.

## 6. Research results

The developed method for the formation of territorial communities is formed on the basis of research and analysis of the Zastavnivskyi district of the Chernivtsi region (Ukraine) statistics department, as well as the characteristics of the existing cultural and community service potential of the village settlement network as of 01.03.2016. For the formation of the territorial community in Zastavnivsky district, swarm algorithms, such as the bats algorithm, as well as the gray wolf algorithm are applied. After completing the cycles of the search for participants in the formation of territorial communities by the algorithm depicted in Fig. 6, 24 settlements are identified. The number of adjacent councils is 7, so when checking for administrative center with the bats algorithm, 17 settlements are taken into account. They are shown in Fig. 7.

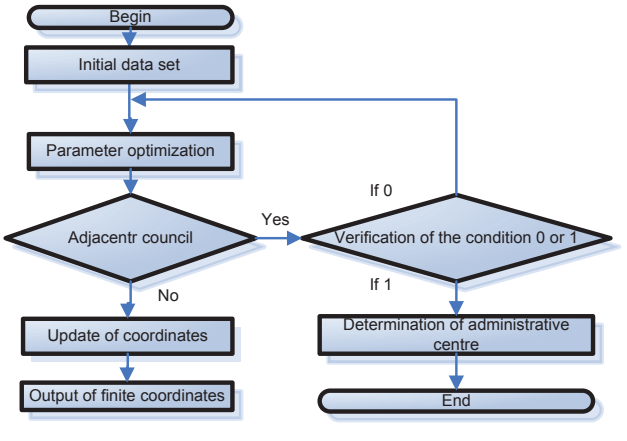


**Fig. 6.** Algorithm for the formation of territorial communities

Applying the proposed algorithm for the formation of territorial communities, obtain the following map of potential territorial communities (Fig. 7).

The map identifies 5 potential territorial communities with the corresponding color:

1. Zastavnivsky territorial community (red).
2. Kostryzhivska territorial community (green).
3. Kadubivska territorial community (yellow).
4. Rzhavynska territorial community (blue).
5. Malokuchurivska territorial community (orange).

The settlements that are part of the territorial community with the proposed administrative center are listed in Table 4.

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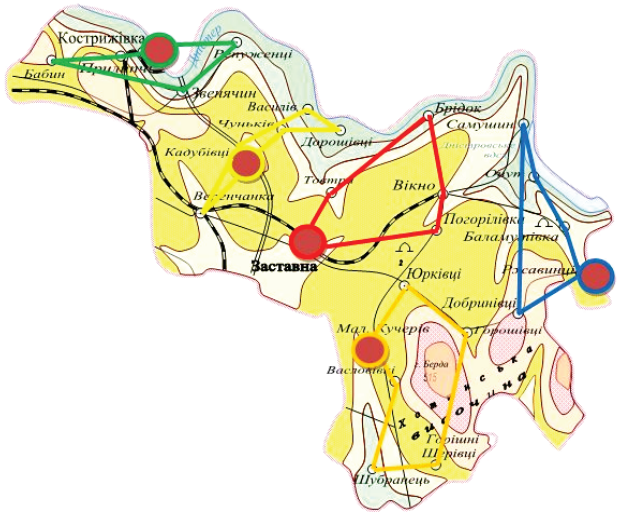


**Fig. 7.** Map of potential territorial communities

**Table 4**

Proposed territorial communities

| Number of territorial community | Councils in the territorial community | Proposed center of territorial community |
|---|---|---|
| 1 | Tovtry, Bridok, Vikno, Pogorelivka | Zastavna |
| 2 | Prilipche, Babyn, Repuzhentsi, Zveniachyn | Kostryzhivka |
| 3 | Verenchanka, Chunkiv, Vasyliv, Doroshivtsi | Kadubivtsi |
| 4 | Samushyn, Dobrynivtsi. Onut, Balamutivka | Rzhavintsi |
| 5 | Yurkivtsi, Goroshivtsi, Vaslovivtsi, Shubranets, G. Sherivtsi | Malyi Kuchuriv |

The proposed method can be applied to any region of Ukraine or a foreign country with a similar territorial division of state land ownership. The flexibility of the proposed method makes it possible to effectively identify the main components of the design of territorial division. On administrative points, it is possible to have evaluation criteria not only for kindergartens, fire departments, police departments, social institutions, etc., but also according to economic and environmental criteria.

## 7. SWOT analysis of research results

*Strengths.* The strength of this research is the analysis of information technologies and algorithms that are used in the formation of administrative and territorial communities in Ukraine. It is also important to create a new method of forming administrative-territorial communities based on modern methods and swarm algorithms.

Using the combination of the bats algorithm, the gray wolf algorithm and the method of multi-criteria optimization in designing the method of forming administrative-territorial communities, the objectives of the research are achieved and the existing problems are solved. Such problems arise when one algorithm is used to solve problems of this type.

*Weaknesses.* The weak side is that the information data, based on which geo-information maps are built, should be the most relevant. This is due to the fact that in order to obtain a more accurate result in the formation of territorial communities, it is necessary to use up-to-date data.

*Opportunities.* The opportunities for further research are the adoption of the experience of the EU countries in the formation of administrative-territorial communities, the study of technologies and methods used in the study of this issue for introduction to the flexibility method. That is, the ability to adjust the method for different types of administrative-territorial division of a country.

*Threats.* The difficulty in implementation or the research results is that in Ukraine there are many changes at the level of society, changing the needs of the population, carrying out many reforms of various types in connection with the integration of Ukraine into the European Union. All the aspects listed below influence the expediency of the proposed method of forming territorial communities, since there are different types of territorial organization.

Thus, SWOT analysis reveals the need to improve the system of flexibility of the created method of forming administrative-territorial communities for the possibility of introducing the proposed method with different types of administrative-territorial structure.

## 8. Conclusions

1. A mathematical model of the process of a territorial community formation with the help of gray wolf and bats algorithms is constructed. The bats algorithm determines the participants of the future community, and the gray wolf algorithm is determined by the administrative center. The parameters of territorial units are optimized using the multi-criterion optimization method. The evaluation criteria for the administrative center are determined. The created set of criteria for each participant of the territorial community is the necessary information for further accession.

2. Information and a set of evaluation criteria for regulating the accession process to the territorial community are determined and interrelated with the bats algorithm. Thus formed roosts regulate itself the accession process, in particular the appropriateness of including the settlement in a particular community.

3. The establishment of the administrative center's position in the territorial community is carried out using the gray wolf algorithm. After the completion of the audit cycles for the administrative center of all participants in the formation of the society, the administrative center is determined as the final decision.

4. The proposed method is tested using the example of the formation of territorial communities in Zastavnivskyi district of the Chernivtsi region (Ukraine). The result of testing is identified 5 potential administrative centers among 24 candidates, 7 of which are adjacent councils. The proposed centers of territorial communities meet the requirements of the task and have a full set of evaluation criteria.

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## РАЗРАБОТКА МЕТОДА ФОРМИРОВАНИЯ ТЕРРИТОРИАЛЬНЫХ ОБЩИН НА ОСНОВЕ МНОГОКРИТЕРИАЛЬНОГО ПОДХОДА РОЕВЫХ АЛГОРИТМОВ

Предложен подход к формированию территориальных общин при помощи алгоритма летучих мышей и серых волков. Разработана математическая модель метода формирования территориальных общин. Исследована эффективность работы метода на примере формирования территориальных общин в Черновицкой области (Украина). Тестирование предложенного метода исполняется на базе ГИС технологий и данных статистики.

**Ключевые слова:** алгоритм летучих мышей, алгоритм серых волков, формирования территориальных общин, критерии оценивания.

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