Spatial Optimization of Regional Social Infrastructure Facilities

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Abstract: ***Features of resettlement in regions with a low population density (in rural areas, first of all) initially do not allow creating an adequate network of social infrastructure objects. The sufficient demand for its additional, better services is insignificant. Institutions capable of providing more sophisticated services are located in larger communities. The dispersal of objects over a vast territory creates difficulties in maintenance and repair, control and management. It was shown that studies of the provision of services in the social sphere are divided into two broad groups in foreign scientific works. Some display the process of providing services on a map, and others simulate the availability of using various services. Most of them consider optimizing the placement of medical facilities. Educational and other organizations of social infrastructure receive much less attention.***

Keywords: Regional, Social Infrastructure Facilities, Spatial Optimization.

I. INTRODUCTION

In various sectors of the social sphere over the past 20 years, there has been an intensive development of the private sector, as well as an increase in the market supply of such social services as education, medicine, culture, etc. At the same time, there were no drastic changes on the part of state participation in these sectors (primarily in terms of financing). Social guarantees promised to citizen's law have not been revised. This led to the formation of a specific imbalance between the obligations of the state in the social sphere, as well as the real opportunities for their financing. Spatial analysis methods in economic research began to be used not so long ago, as it can be said, for example, about work in the field of technical sciences. However, gradually, the use of such tools (in particular, Voronoi diagrams) becomes one of the central methodological tools in this area [1-5].

The issues of planning and financing the social sphere are always at the peak of relevance. In rural areas, where the government's ability to finance various facilities is much lower than in cities, and local budgets are almost always scarce, the level of investment in social infrastructure is continually decreasing [6]. The territorial dispersal of institutions creates additional difficulties in managing them, and their spatial location is regulated by regulations, reducing the possibilities for the flexible development of the territory.

Therefore, given the limited resources, improving social infrastructure requires the soundness of managerial decisions. This should be done while preserving all the positive characteristics of the previously existing principles of financing and managing the social sphere, identifying the mechanisms for its adaptation to the changing socio-economic and organizational-legal conditions. Improving the territorial distribution of social infrastructure plays an essential role in this process, pursuing two primary goals. From an economic point of view, the most important is a clear and rational distribution of funds and resources for their further use [7-8]. From the point of view of the social aspect, it is necessary to ensure the accessibility to the population of all the services it consumes.

The implementation of these goals implies the solution of the following particular problems: determining the criterion of socio-economic efficiency of the territorial organization of the social sphere, the capacity and forms of specialization of institutions, developing methods for choosing a specific location for a particular object.

The idea of improving the quality of life of the rural population through the development of social infrastructure and the optimal placement of its facilities requires thoughtfulness and scientific validity of actions, which emphasizes the relevance of research in this direction.

II. PROPOSED METHODOLOGY: THE SPATIAL ORGANIZATION OF SOCIAL INFRASTRUCTURE INSTITUTIONS IN TERMS OF CONSUMER TRANSPORTATION

Optimizing the placement of social institutions implies solving two critical problems. The first relates to their spatial organization. The second involves the distribution of financial and human resources between geographical units.

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In other words, it is necessary to minimize the costs associated with maintaining the facilities and transporting consumers from the place of residence to the place of service. For schools, such problems are presented in [9-11].

On the example of secondary schools, the problem of optimizing the placement of social infrastructure institutions in rural areas and a dissertation study is considered.

In the future, it can be extended to other types of institutions. To solve the optimization problem, we introduce many villages of the region $J = \{1, \dots, r\}$. If there is a school in a village $j \in J$, then it has the following characteristics:

v_j – the capacity of the school;

q_j – costs for its annual maintenance.

If there is no school in the village, then perhaps it will be necessary to deliver it. The cost of building a school is denoted by p_j. In this case, there are also costs for the annual maintenance of the newly built school and its capacity. Next, we introduce the variable j t, which is equal to 1 if it is necessary to leave the old one or to build a new school in the settlement in question, or 0 if it is necessary to close the existing one or if there is no need to build a new school in the village $J = \{1, \dots, r\}$. i.e:

$$t_j = \begin{cases} 1, if\_jth\_set\_need\_school \\ 0, if\_jth\_set\_do\_not\_need\_school \end{cases} \qquad (1)$$

We define many villages with students $I = \{1, \dots, m\}$. Therefore, n_i is the number of students living in each of the villages $i \in I$. By c_{ij} we mean transport costs for transporting schoolchildren from a village $i \in I$ to a village $j \in J$. Transportation costs consist of direct fuel costs, driver salaries, and depreciation of the school bus. Fuel costs are found by multiplying the distances between villages on both sides by one kilometre of fuel consumption and by the cost of one litre of fuel in \$. The distances between the villages are as follows: the distance on the map in pixels, taking into account the scale, translates into kilometres.

The variable x_{ij} will be equal to 1 if students from a village $i \in I$ are transported to a village $j \in J$ or 0 if they are not transported, that is, there is a school in a village $i \in I$. i.e:

$$t_j = \begin{cases} 1, if\_transported\_from\_i \in I\_to\_j \in J \\ 0, if\_transportatioin\_is\_not\_carry\_out \end{cases} \qquad (2)$$

In the course of solving the problem, we will consider the situation when schoolchildren can be taken from only one village to one village, and each village can have only one school. If in the locality there are initially several schools, then they are accepted for one total (total) capacity.

Such a statement of the optimization problem in terms of the ratio of the cost of maintaining schools and transportation of students, according to the current situation, leads to the need to close a significant number of schools, since the cost of transportation is significantly lower than the cost of maintaining schools. To ensure balance, a k - coefficient was introduced into our calculations, a kind of indicator of the optimal placement of social infrastructure facilities. It allows you to correlate the "\$" spent on the transportation of schoolchildren and the "\$" spent on the maintenance of the school.

Each of its changes gives a new meaning to the considered objective function - the total cost of maintaining the education sector. Without the introduction of this coefficient, a degenerate case of a minimal number of schools in the district would always result. This situation would lead to the fact that students from remote areas would be forced to spend too long on the road, as well as contribute to the degeneration of the settlements of the district. That is why the optimal solution to such a problem should be found in such a way that the change does not lead to sharp jumps in the value of the objective function.

The coefficient was considered in the interval [0,1]. For each k, the optimum was found by enumerating all possible variants of the values of this coefficient in increments of 0.1. In the course of such a search, it was taken into account that two undesirable situations are possible for the formulation and solution of the problem. They are as follows: a sharp jump in the number of schools to be opened, as well as a significant jump in the number of schools being closed. That is why it was necessary to find a range of changes in the coefficient of accessibility that would not lead to sharp jumps in the number of schools in the district. Then, already in the gap found, it was necessary to search for the optimal solution to the problem.

The graph below (Fig. 1) shows the dependence of the number of schools being closed in the A district of the B Region, where 37 schools are located and 16 school bus routes operate on the availability factor. The horizontal dashed line shows the number of existing schools: vertical - the resulting range of values for the availability factor.

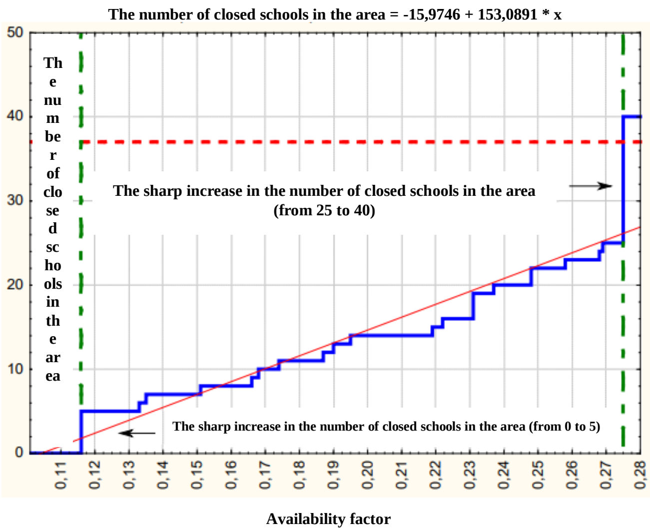

Fig. 1. Dependence of the number of schools being closed in the region B on the availability coefficient

Now in district A there are seven settlements in which there are students, but no schools. The graph above shows that a corresponding change follows each decision to close another school in accessibility ratio. This continues until the number of schools closed in the district becomes equal to 44, the number corresponding to the presence of a school in each village where there are students.

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The accessibility coefficient, at which there is no sharp jump in the schools being closed, takes values in the interval [0.116; 0.275].

The values of the coefficient, smaller than the lower boundary of the designated interval, lead to an increase in the number of schools being closed from 0 to 5.

Larger values will entail an even more significant jump in the number of schools being closed in the District A of the Region B (from 25 to 40 institutions).

The following figure shows the dependence of the total number of schools in district A on the availability coefficient.

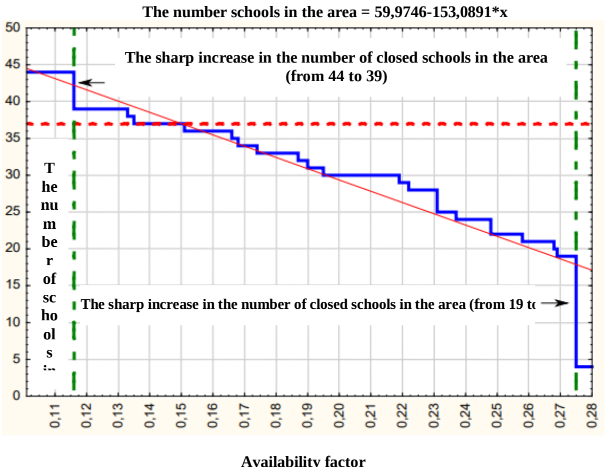

Fig. 2. Dependence of the number of schools in the region B on the availability coefficient

This schedule is built on the same principle as the previous one, except for the fact that along the ordinate axis the number of all schools in the district is postponed (including seven potential schools that are not currently in the Krasnozersky district).

The availability factor corresponding to the situation in the area is located in the range [0.135; 0.150]. The range of the k coefficient corresponding to the opening of new schools is [0.116; 0,134], the closure of existing ones - [0,151; 0.275].

Today, the affordability coefficient in the district A of the region B exists, since there is a distribution of funds spent on transporting schoolchildren from one settlement to another, as well as funds donated on maintaining schools in the district.

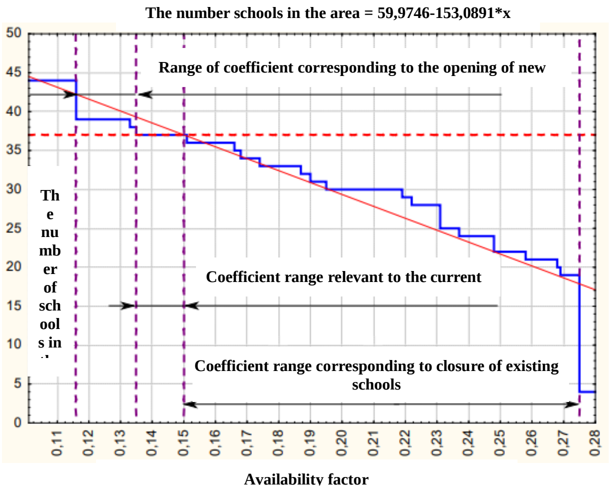

Fig. 3.Availability factor ranges relevant to the current situation, closure of existing and opening of new schools

We construct the objective function for this optimization problem. The first term $\sum_{i=1}^{m}\sum_{j=1}^{r} c_{ij}x_{ij}\left\lceil\frac{n_i}{w}\right\rceil$ is the total cost of transporting students from the villages where they live to those where they study. Since the costs are calculated for one bus, it must be borne in mind that there may be several. Therefore, the quantity n/w arises - the smallest integer greater than or equal to the number of students transported, divided by the capacity of the bus.

The second term $\sum_{j=1}^{r}(hp_j + kq_j)t_j$ is the sum of the reduced capital costs for the construction of the new school if required, and the costs of maintaining the schools, multiplied by the availability coefficient. The discount coefficient h in our case is approximately 0.11.

The existing objective function must be imposed two restrictions, which are as follows. Pupils of a village $i \in I$ are transported if there is no school in it. The total number of all local, as well as imported students, does not exceed the capacity of the school.

Therefore, we obtain an optimization model:

$$\sum_{i=1}^{m}\sum_{j=1}^{r} c_{ij}x_{ij}\left\lceil\frac{n_i}{w}\right\rceil + \sum_{j=1}^{r}(hp_j + kq_j)t_j \to \min_{x_{ij},t_j} \quad (3)$$

with restrictions:

$$\sum_{j=1}^{r} x_{ij} = 1 - t_i, i \in I \quad (4)$$

$$\sum_{i=1}^{m} x_{ij}n_j \leq (v_j - n_j)t_i, j \in J \quad (5)$$

where:

$x_{ij} \in \{0,1\}$;

$t_j \in \{0,1\}$;

$n_j \in N$;

$v_j \in N$;

$k \in [0,116; 0,275]$

III. RESULT AND DISCUSSION

Initially, the problem was considered by us in a different setting. The variable t_j denoted the number of schools in the village $j \in J$, and the variable x_{ij} is the number of schoolchildren transported from the village $i \in I$ to the school of the village $j \in J$, and $t_j, x_{ij} \in N$.

Such a task is the task of integer linear programming. At first glance, the most common method for solving this type of problem is the rounding method, the implementation of which consists of two stages. At the first stage, an optimal solution to the linear programming problem with real variables is found. On the second - the values of the variables in the optimal solution that are not integers are rounded so as to obtain a feasible solution with integer values.

This method has been tried. At the first stage, the problem was solved by the method of internal points.

However, the practical implementation of the rounding method led to an acceptable solution in which the rounding error turned out to be significant, and we were forced to abandon this method.

From the initial statement of the problem, we proceeded to the Boolean programming problem, which we continued to solve with the most used combinatorial method – the branch and bound method. Considering the different values of the coefficient of accessibility, we can get different benefits of the number of schools in the district. Application of elements of the method of weighted amounts with a point-wise estimation of weights allows us to consider the optimal procedure for opening and closing schools in a district, as well as to identify what changes in costs will entail opening or closing a school in a particular village:

$$\Delta = \frac{ZN - ZV}{ZN} * 100\% \qquad (6)$$

where ZN – the value of the educational infrastructure of the district at the moment;

ZV – the possible costs of the educational infrastructure of the district, which may result from the opening or closing of schools in the district.

Each school closure entails the emergence of new bus routes. The buses that drove students to a closed school will now take them to other schools. The transportation routes will lengthen since initially, the bus takes the students to the nearest school, which can accept a certain number of students. Besides, a new school bus route will appear from the locality where the school was closed.

The following figure shows the placement of schools in District A of Region B.

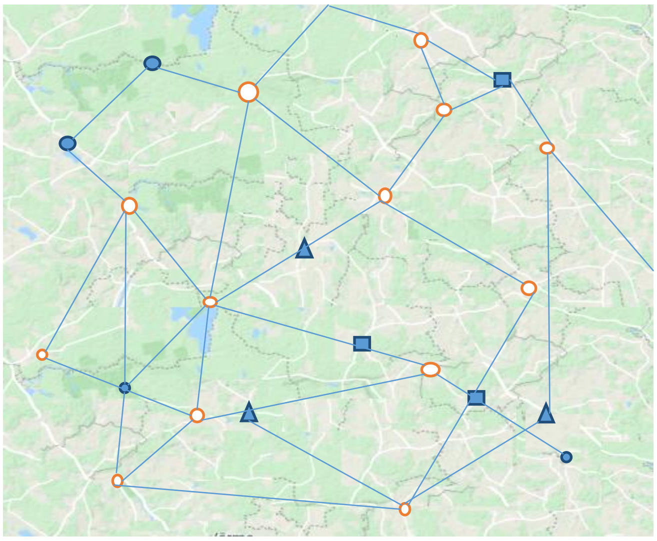

Fig. 4. Placement of schools in the district A of the region B

Roads are represented by clear lines. Shaded circles indicate villages in which there are no schools either in the current situation or in the optimal solution of the problem.

The squares indicate the settlements in which there are schools now, but in the optimal solution they should be closed.

Triangles are villages without schools, but in which they should be open for the optimal distribution of schoolchildren in the area.

Next, the task will be to optimize the placement of schools, taking into account the deterioration of buildings and the need for investment in new construction.

IV. CONCLUSION

The result obtained during the study is purely recommendatory in nature. This means that the solution of the problem allows you to answer the question in which settlement of the considered area it is more expedient to open or close the institution of social infrastructure if the administration made the appropriate decision. However, other factors must also be considered. For example, the school is a centre for the revival, preservation and development of the village. Also, important factors may be her merits, the average score of graduates, the qualifications of specialists working in it, and others. Therefore, the proposed model-software complex is only an auxiliary tool for the work of experts. In the future, it is planned to improve the developed system with additional functions for combining and repairing social infrastructure institutions.

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