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SOLUTION OF THE PROBLEM OF PLACING MEDICAL FACILITIES IN CITY DEVELOPMENT PROJECTS

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ABSTRACT

Context. The problem of rational allocation of medical facilities of inhabited locality was considered. Methods of evaluating the effectiveness of using the existing medical network and finding ways to improve it when implementing urban development projects were proposed.

Objective. The goal of the work is to build and study the procedure for solving the problem of placing medical facilities, considering the existing infrastructure of the city to fulfill the accessibility requirements.

Method. A set of factors that affect the placement of a medical facilities and allow a systematic and reasonable decision to be made in choosing a location has been formed. A method for solving the problem of the location of medical facilities, providing an increase in their accessibility level considering the population, its spatial distribution, existing in the settlement of road junction and traffic congestion is proposed. The procedure for solving the problem is presented in the form of an IDEF0 model. The method is based on geoinformation analysis of data, the results of which by spatial clustering are presented in the form of a set of cartographic models, the aggregate of which allows to form a decision about the location. The method allows to assess the accessibility level of existing medical facilities in the inhabited locality, create a list of places for their possible location, find areas of the locality that are not in the access zone.

Results. The method of choosing the location of the medical center has been improved, which makes it possible to make decisions based not only on the shortest distance from the center to the patient, but also on the level of its accessibility. For the first time, the structure of information technology for multivariate analysis of a network of city medical centers for decision support systems using GIS technologies is proposed.

Conclusions. The medical facilities location problem, which is in increasing the level of accessibility by expanding the area of medical coverage of the territory in which the city population lives by using GIS was practically fulfilled as an IDEF0 model that defines the procedure for solving the problem and choosing the location of the medical center. The practical significance of obtained results has been proven on a practical example – an analysis of the existing hospital system for the provision of emergency medical care in Kharkiv.

KEYWORDS: accessibility level, coverage area, population, patient delivery time, IDEF0 model, geoinformation technologies, network analysis, ArcGIS.

ABBREVIATIONS

GIS is a geoinformation system.

NOMENCLATURE

a – rate of housing area per person, m^2 /people;

β – statistical distance influence coefficient;

d_k – distance to the k -th patient;

$\{E_k\}$ – patient of the city plurality;

F – volume of housing;

G – target function depending on the distance from the medical center to the location of patients;

N – number of patients requiring the services of a medical institution (population of the microdistrict);

P_k – number of services that a medical institution provides for all k -patients which need services;

R – accessibility level;

S_n – area in which patients live;

S_o – medical coverage area;

S – microdistrict area, ha;

S_{norm} – normative housing density, considering the number of storeys, depending on the construction of the city zoning, m²/ha;

t – time, the value of which depends on the maximum permissible distance between the patient in need of the service and the medical center providing the service;

$t^{-\beta}$ – rate of time to cover the distance between the patient in need of the service and the medical center providing the service;

(x, y) – medical center coordinates;

(x_k, y_k) – patient location coordinates, characterizing the structure of their settlement in the city;

Z – the maximum number of patients who can be simultaneously provided with services in a medical center.

INTRODUCTION

Urban development is a natural process. City development projects are aimed at improving the industrial, economic, social sphere. However, in recent decades, the social sphere of Ukrainian cities has developed and functioned very unevenly, leading to a significant imbalance in the range of services provided to the population. This unevenness is manifested in the massive development of trade, recreation and entertainment centers, fast food enterprises. At the same time, there is stagnation and destruction in housing and communal services, consumer services, sports and medical fields, etc. The following emphasizes the particular importance and relevance of problems in this area [1], [2]:

– financing according to the “residual principle”, the lack of opportunities for decent maintenance and repair leads to the fact that many social facilities are liquidated, their purpose is changed, depreciation of fixed assets increases, the quality of services provided decreases;

– the pace of development of social infrastructure is significantly lower than the pace of socio-economic and cultural changes, which means that the existing infrastructure is not able to provide favorable living conditions, improve the quality of life, etc.;

– one of the most important characteristics of social infrastructure is the territorial distribution, which is affected not only by local social policy but also by regional and state social policy;

– the growing need of social services requires the development and implementation of national policies aimed at the development of social infrastructure, which should reflect the specifics of each city, implementing specific activities in each region and city;

– irrational spatial distribution of objects of the social sphere complicates their use by the population, which is significantly aggravated by the suboptimal work of public transport, violating the principle of “walking accessibility”, wasting of free time, etc.

The healthcare sector deserves special attention, which is a qualitative characteristic of the economically active population: the state of the nation’s health directly affects

labor productivity and the prospects for socio-economic development of society [3]. However, according to sociologists, 76.4% of those who took part in the survey see problems in the field of medical care, and every fifth considers problems in the health care system as personal [4]. All this is compounded by the ongoing medical reform in the country, the results of which, to date, have received mixed reviews, both from specialists and from the government and the population.

These reasons lead to attention level growth to the problem of finding effective ways to use the existing medical infrastructure and finding directions for its enhancement to further improve the living conditions of the population within the urban development projects.

The object of study in this work are models for evaluating the effectiveness of using the existing medical network and finding ways to improve it when implementing urban development projects.

The subject of study is the model of placing a medical facility task.

The purpose of the work is to build and study the procedure for solving the problem of placing medical facilities, considering the existing infrastructure of the city to fulfill the accessibility requirement. To achieve this goal, it is necessary to solve the following tasks:

– consider the factors affecting the choice of a medical institution, choose the most important of them;

– formulate the problem of the placement of medical facilities, considering the selected factors;

– develop a procedure for solving the problem of placement;

– evaluate the possibility of applying the procedure for solving the problem of placement in urban development projects;

– are models for evaluating the effectiveness of using the existing medical network and finding ways to improve it when implementing urban development projects.

1 PROBLEM STATEMENT

A network of health care institutions is a set of city institutions that satisfy the population’s need for medical care as a result of the professional activities of medical workers. The functioning of such a network is performed considering the requirements of the population in medical care, its timeliness and accessibility.

Accessibility level – the ability to provide patients with the necessary range of services of a certain quality with minimal time spent.

Suppose:

– all residents living in the territory under consideration are potential patients of a medical institution and form plurality of patients $\{E_k\}$ ($k = \overline{1, N}$);

– the specifics of medical services are not considered, it is believed that the medical center is able to provide any medical service that the patient needs, but the total number of services is limited;

– there is a “limit of possibilities” for a medical center, the value of which depends on the maximum number of

patients who can be provided with medical services at the same time;

- the quality of medical services, the reputation of the doctor, etc., are not considered, i.e. the decision to choose a specific medical center is affected only by its proximity to the patient;

- there is no competition for patients within the network.

The network elements – medical centers – are placed in such a way that the value of the objective function, which depends on the distances from the medical center to the location of the patients, is minimal, i.e.

$$G = \sum_{k=1}^N d_k \rightarrow \min. \quad (1)$$

Given that the level of accessibility will be maximum, i.e.

$$R = \frac{\sum_{k \in E_k} P_k}{N} \cdot 100\% \rightarrow \max, \text{ at } \sum_{k \in E_k} P_k = Z. \quad (2)$$

Under given conditions, it is necessary to obtain the coordinates of the medical center.

2 REVIEW OF THE LITERATURE

The strategic goal of state policy in the field of health is to improve the health stat of the population, increase the real availability of medical care for all its layers. Development projects of many cities are aimed at structural, organizational and functional restructuring of the medical care system by creating and/or improving the network of healthcare institutions [3]. In this regard, the goal of development projects is to increase the availability of medical center that provide diverse medical care to the urban population.

In modern literature, the accessibility of a medical center is interpreted differently [3], [5], [6], which emphasizes the multifactorial nature of this concept, its dependence on objective, subjective, external and internal factors. In conditions of equal access, considering accessibility as an opportunity to provide the necessary range of services of a certain quality with minimal time and money [3], [5], the factor of placement of a medical center as a geographical object comes out on top, emphasizing the relationship between location and medical services choice [7], [8].

Problem (1) is known in the literature as the P-median model described in 1964 by S. Hakimi, who suggested that social institutions should be located so that the sum of all the distances from demand points to point P (social service supply points) should be minimal [2].

Given that the medical center is a geographical object that has certain coordinates (x, y) , we will represent the plurality of patients of the city $\{E_k\}$ as points of Cartesian space and place them on the plane (Fig. 1).

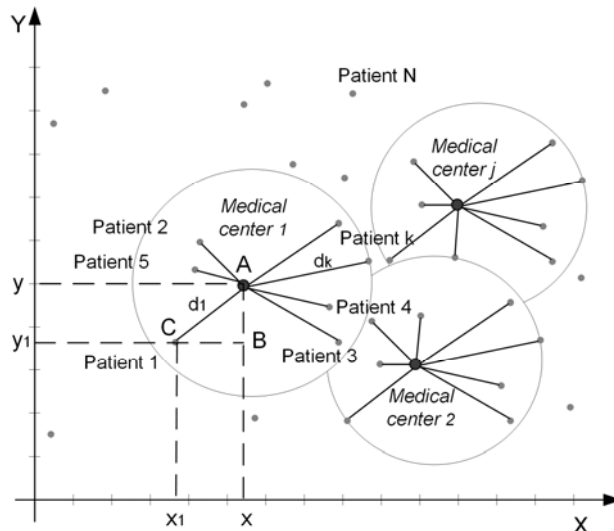


Figure 1 – Geometric interpretation of the medical center placing problem

Then the distance d_k is the distance from the center to the k -th patient, the value of which can be found as the length of the segment on the coordinate plane from the known coordinates of its ends. For example, we find the length of the segment d_1 from a right triangle ΔABC as the length of the hypotenuse:

$$d_1 = AC = \sqrt{(x - x_1)^2 + (y - y_1)^2}. \quad (3)$$

Substituting the expression (3) in the formula (1), the objective function will be represented in the form:

$$G = \sum_{k=1}^N \sqrt{(x - x_k)^2 + (y - y_k)^2} \rightarrow \min. \quad (4)$$

Wherein, it can be assumed that the set of patient coordinates (x_k, y_k) ($k = \overline{1, N}$) determines the structure of their settlement, and the obtained coordinates of the medical center form the structure of the network of medical centers in the city.

Among the main disadvantages of the multicriteria optimization task (4) the following can be noted [2], [8]:

- the high dimensionality of the problem, due to the fact that the set $\{E_k\}$ is finite, but its capacity can reach tens of thousands and even millions of units;
- in conditions of urban settlement (possibly uneven), it is difficult to consider the coordinates of all patients;
- in the statement of the problem (3) there is no concept of the “limit of possibilities” of the medical center, which leads to a unilateral consideration of the problem;
- in reality (on the ground) the “shortest” roads may be absent.

The latter was confirmed by field studies [2], [8]: the real zones of the medical services provision point location significantly differed from the results obtained using the model (4). And although it was proposed to adjust the

results using coefficients that consider transport, social, political and other factors [6], [8], but this did not help to solve the remaining problems.

A fundamentally different approach to solving the problem of the placement of social objects, focusing on spatial accessibility, was proposed by Yue Zhang et al. [9]. The authors prove that the choice of the location of the medical center is primarily affected by the population, and the level of accessibility (2), in this case, it should be regarded as the ratio of supply to demand.

Research of I. N. Sener et al. [10] show that the closer the medical center to the patient is, the more accessible it is for him. On the other hand, it was proved in [11] that the more patients assigned to this center, the less accessible it is for them. Therefore, expression (2) can be represented as follows:

$$R = \frac{\sum_{k \in E_k} P_k t_k^{-\beta}}{Nt} \cdot 100\% . \quad (5)$$

The choice of the medical center location in (5) is made from the stipulation of maximizing the demand for its services, considering the general limit of the possibilities for providing medical services. At the same time, the travel time determined by the direct relative position of the patient and the medical center is the main factor by which the place of receiving medical services is selected [9], [11]. Given the existing settlement structure and population, this factor has significant weight. However, its significance can be offset by other factors. Among such factors, one can consider the presence of communication lines and their congestion, the nature of settlement, the presence of personal transport, the available public transport routes, etc.

The problem of spatial accessibility cannot be solved within the framework of the healthcare system alone. It requires improving the quality and standards of the population living, improving and modernizing the transport infrastructure as a connecting link [6], [12]. Focusing on the transport infrastructure providing equal access to the services of the medical center, we assume that the value of the coefficient β is determined by its parameters, in particular, the existing roads and their congestion.

Analyzing fig. 1, the numerator of function (5) can be interpreted as the number of services the medical center can provide for patients living within a circle with a radius, the value of which depends on time $t^{-\beta}$. In this case, the denominator can be considered as the number of patients living within a circle with a radius, the value of which depends on the time for which the patient will overcome the maximum permissible distance from the place of residence to the medical center;

Among the main disadvantages of problem (5), we note the following:

- an indefinite algorithm for evaluating $t^{-\beta}$ and t ;
- lack of explanation in determining the coefficient β ;

– in the statement of the problem there is no notion of the medical center coordinates, which makes it difficult to solve the problem of placement.

Nevertheless, the analysis of solving the problem approaches allows you to create a set of factors affecting the placement and choice of a medical institution. These include:

- the population (as the potential number of patients) living within the territory, the size of which is determined by the maximum travel time to the medical center and the structure of their settlement;
- the number of services that a medical center can provide for patients in the territory in question;
- the norm of time to overcome the distance between the patient in need of the service and the medical center providing the service;
- really existing road junction, roads and their congestion.

These factors must be considered when constructing the procedure for solving the problem of the placement of medical institutions.

3 MATERIALS AND METHODS

In accordance with State Building Codes of Ukraine B.2.2-12:2018 “Planning and development of territories”, the population of a city district is determined depending on the housing stock and housing standards per inhabitant and is calculated according to the formula

$$N = \frac{F}{a} = \frac{S \cdot S_{norm}}{a} . \quad (6)$$

In this case, the demand for the services of a medical center is determined by the number of people (patients) living in a certain territory. Denote the area of this territory as S_n . On the other hand, the number of services a medical center provides for patients residing within a certain territory is determined by the distance that a patient travel from home to the center for a given period of time. The area, the value of which depends on this distance, we will consider as the area covered by medical services and denote S_o .

Thus, expression (5) can be represented as follows:

$$R = \frac{S_o}{S_n} \cdot 100\% . \quad (7)$$

In this case, task (7) considers the maximum number of factors affecting the placement and choice of a medical institution.

The process of solving this problem is presented in the form of a context diagram (Fig. 2), created on the basis of the IDEF 0 standard, which shows a generalized process model, defines a single point of view, subject and purpose of modeling in accordance with the requirements of current standards and norms.

The attributes of the generalized model are:

1. Input data:
 - Map of the city;

- Location of the city microdistricts;
- Coordinates of existing medical centers of the city;
- Congestion of city roads;
- City road map or transport infrastructure;

2. Control:

- Norm of living space per person;
- Normative building density;
- Requirements for the location of the medical center determined by the current legislation in the field of healthcare;
- Time standards that determine the necessary speed of patient delivery to medical center;
- Comparison criteria.

3. Output:

- Evaluation of the availability of existing medical centers;
- Recommended placements of medical center;
- The list of city areas that did not fall into availability zone.

It is easy to notice that the attributes of the model (Fig. 2) contain spatially distributed data, the effective processing of which is possible by using GIS.

GIS are information systems that allow you to collect, organize, analyze, distribute spatial information to make the necessary decisions. Spatial or GIS analysis of multicriteria decisions includes a set of methods and tools for combining geospatial data with the arguments of decision makers [13], [14]. Given the complex nature of spatial solutions, we single out a number of functional areas through which the output data set is formed. We will form an IDEF0 model of the procedure for solving the problem (7) and choosing the location of the medical center using GIS (Fig. 3). Note that for the convenience of further analysis and decision making the given IDEF0-model is provided with a representation of intermediate results in the form of cartographic models, obtained using the spatial clustering method. This method has received positive feedback among experts and has proven itself in solving environmental, social and political problems [12], [13].

The implementation of proposed procedure is possible by using the ArcGIS software suite by Esri.

ArcGIS is an effective universal solution for simultaneous work with the geospatial component, multimodal network datasets, and powerful tools of analytics, which helps to perform not only the fundamental spatial analysis, but also to obtain spatio-temporal models on a cartographic basis [12], [15].

When performing the steps, described in the IDEF0 model the ArcGIS Network Analyst extension was used, which helps to answer questions like the following:

- What is the quickest way to get from point A to point B?
- Which houses are within five minutes of a medical center?
- What are live traffic conditions like, and how do they affect network analysis results?

Public services, municipal and other organizations benefit from the ArcGIS Network Analyst extension be-

cause it helps them run their operations more efficiently and make better strategic decisions [13], [14].

In ArcGIS a network service area is a region that encompasses all accessible streets, that is, streets that lie within a specified impedance. For instance, the 10-minute service area for a facility includes all the streets that can be reached within 10 minutes from that facility. The accessibility parameter refers to how easy it is to go to a site.

In Network Analyst, accessibility can be measured in terms of travel time, distance, or any other impedance on the network. With Network Analyst, service areas around any location on a network can be found. A network service area is a region that encompasses all accessible streets, that is, streets that lie within a specified impedance. For instance, the 10-minute service area for a facility includes all the streets that can be reached within 10 minutes from that facility.

One simple way to evaluate accessibility is by a buffer distance around a point. However, considering people travel by road, this method won't reflect the actual accessibility to the site. Service networks computed by Network Analyst can overcome this limitation by identifying the accessible streets within five kilometers of a site via the road network. Once created, service networks can be used to see what is alongside the accessible streets.

4 EXPERIMENTS

The possibility of using the proposed model (7) in projects for the development of social infrastructure in Kharkiv was considered. The model was studied while solving the problem of analyzing the existing system of providing emergency care in Kharkiv. The following were used as initial data:

- Open Street Map basemap layers;
- Addresses and names of Kharkiv emergency medical institutions;
- Data on the city's road transport network (traffic congestion, road signs, lane width).
- Vector *.shp layers with the marked boundaries of the microdistricts of Kharkiv;
- Database of residential buildings storeys number (for calculating the population).

To verify the proposed model, we determined the population size and the area of the territory where patients live. The results obtained showed conformity with the data of the statistical office of the Kharkiv region, which made it possible to conduct an experiment to study the effectiveness of the proposed approach in real conditions and on real objects.

As a result of the experiment, the coverage areas of emergency care services provided by hospitals in Kharkiv microdistricts and nearby villages were obtained, as a result of which it became possible to assess and compare the level of accessibility of emergency hospitals. The results obtained showed a low level of logistics in the distribution of objects of the existing system of emergency care in the city.

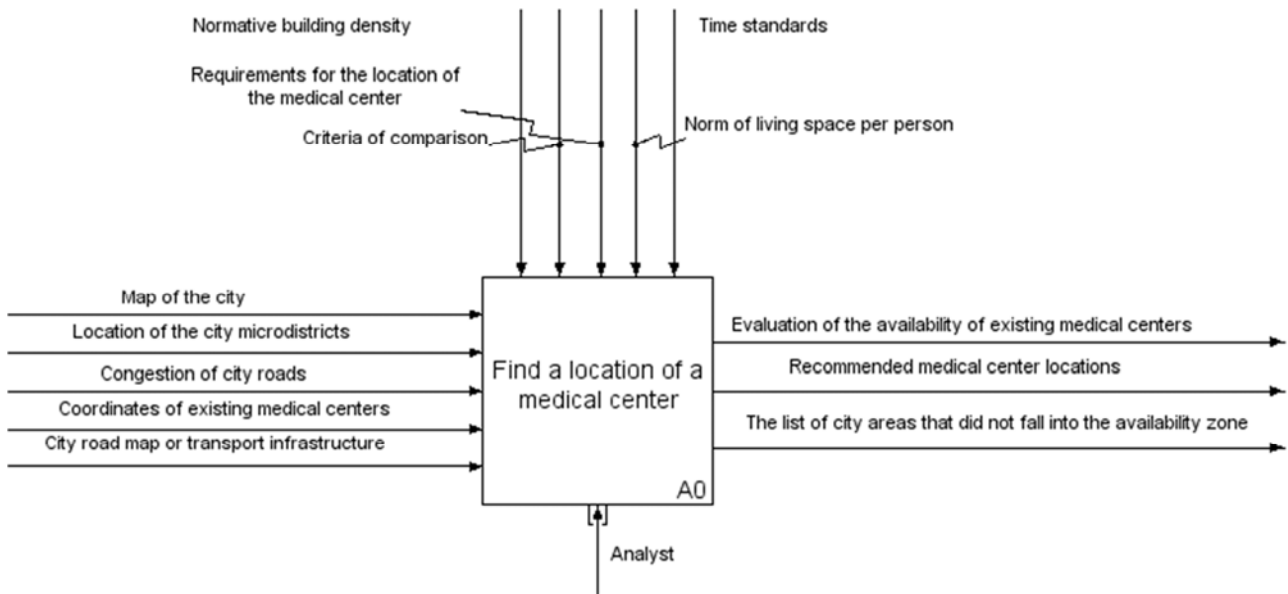


Figure 2 – Context diagram process of finding a location of a medical center

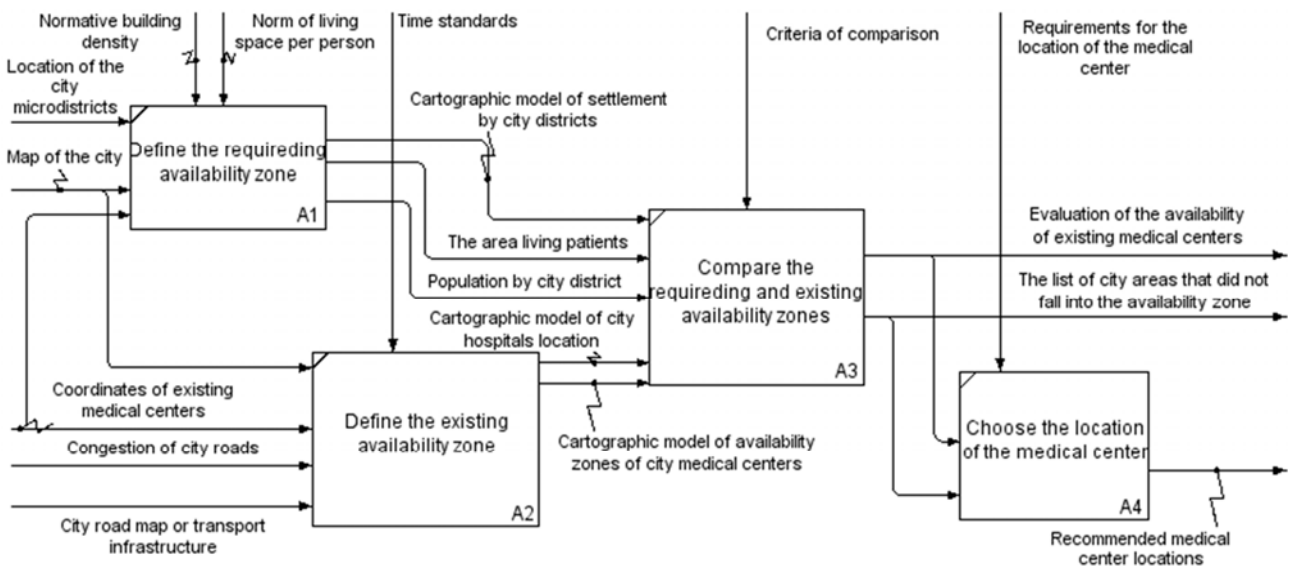


Figure 3 – IDEF0-model of the procedure for solving the problem of placing a medical center in the city

To select possible directions of development, a scenario for correcting this system by changing the location of some hospitals, considering the population size and the existing road junction, is proposed.

After the correction, assessments of the level of accessibility of emergency hospitals in Kharkiv were obtained, indicating an increase in the number of patients who will receive medical care timely.

5 RESULTS

Consider the problem of analyzing the existing system of providing emergency care in Kharkiv and choosing possible directions for its solution.

In accordance with the proposed approach, the first stage (Fig. 3) of the IDEF0-model is determination of the necessary accessibility zone of the medical center. The

implementation of this stage was held in the following sequence:

1. According to the Kharkiv City Council, Kharkiv is divided into 56 microdistricts. These microdistricts and nearby villages serve 17 hospitals for emergency and ambulance medical care. Using ArcGIS, we map the regions and towns under consideration on a map of Kharkiv. Using the Database “Ambulance Hospital Addresses”, we will show the location of the hospitals on a map of the districts and get a cartographic model of ambulance hospitals location in Kharkiv city (Fig. 4).

2. Using Google Planet, we determine the area of the microdistricts of Kharkiv and adjust them considering the population of the territory. For example, in the greater part of Pomerki microdistrict, there is a plot of forest – the botanical monument “Pomerki”. In this case, the residen-

tial area of the microdistrict is only 11% (about 13.32 hectares). As a result, the total area of the territory where patients live (S_n) amounted to 356.46 km².

By the formula (6) we find the number of inhabitants of these districts. Moreover, for districts where the number of storeys is higher than five $S_{norm} = 3000$ m²/ha, with one-, two-story buildings, $S_{norm} = 1800$ m²/ha, for the mixed development zone $S_{norm} = 2300$ m²/ha. We will form the database “Population of the districts of Kharkiv”, which shows the distribution of 1.419 million people in the districts.

3. Using ArcGIS, we will construct a cartographic model of the distribution of residents among the districts of Kharkiv based on the database “Population of the Kharkiv districts”, where polygons with a larger population are darker, and the least populated areas are lighter (Fig. 5).

At the second stage (Fig. 3) of solving the objective, we determine the accessibility zones of existing ambulance and emergency care hospitals. In this case, we will consider the following.

1. Statistical data (infoportal.ua) of traffic congestion in Kharkiv shows that during the day the situation on the roads can change from light (1 point) to heavy traffic (“traffic jam” – 4 points). An analysis of the congestion of roads leading to the considered hospitals showed that on

average the worst situation (“obstructed” – 3 points) is observed from 8:00 to 9:00, from 12:00 to 13:00, from 16:00 to 17:00. In availability assessment we will consider precisely these time intervals.

2. The existing time standards determine that the patient must be delivered to the hospital within 10 minutes. For example, in [16] it is noted that transportation for a period of more than 10–20 minutes shifts the severity of the victim up one category. So, a slightly wounded person within 20–30 minutes of transportation is likely to go into the category of victims of medium severity. Therefore, when assessing the availability, we will consider the delivery time of 5 and 10 minutes.

3. Under the assumptions made, in ArcGIS Network Analyst we will create cartographic models of hospital access zones (Fig. 6). Using the function “service areas” (availability zones) for vehicles we define the area of coverage with medical services (S_o) for the selected time intervals, considering different transportation times (table 1) [12], [17].

At the third stage (Fig. 2), we compare the obtained results and by using (6) we find the level of accessibility of emergency hospitals for the selected time period by vehicles (Table 2).

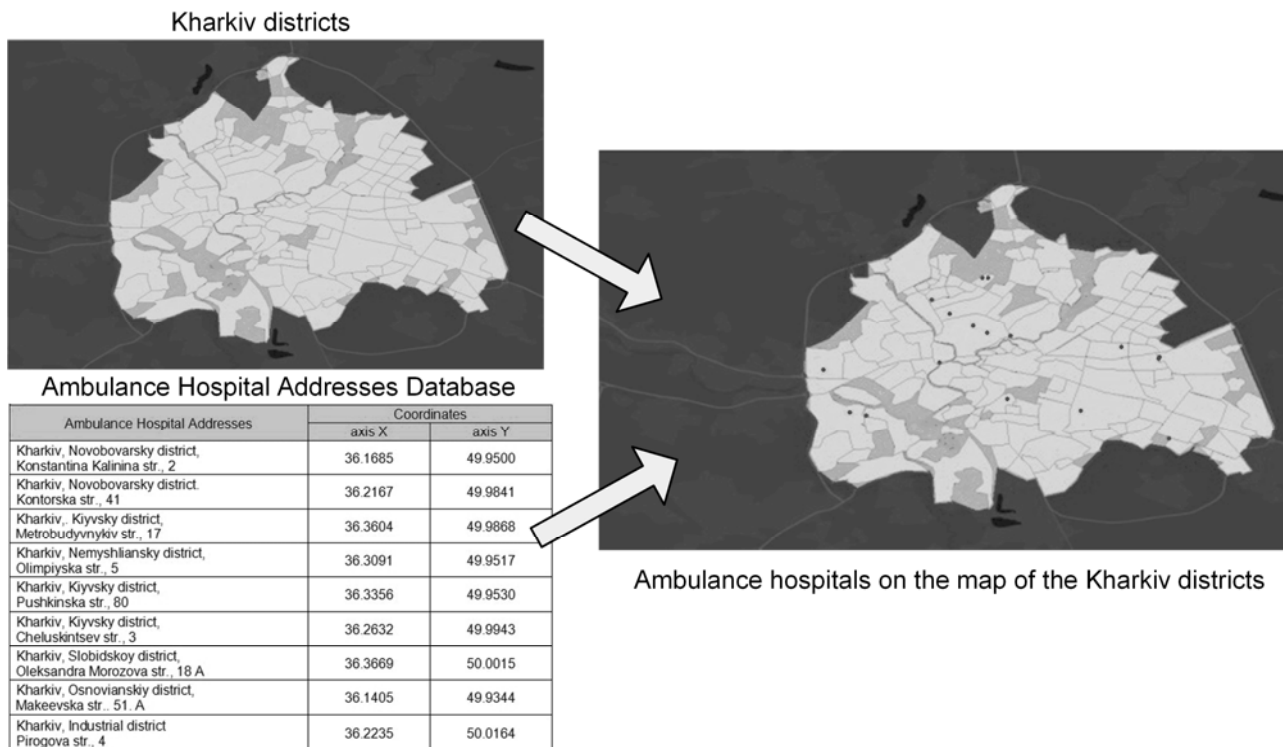


Figure 4 – Cartographic model of ambulance hospitals location in Kharkiv city

Database "Population of the Kharkiv districts "

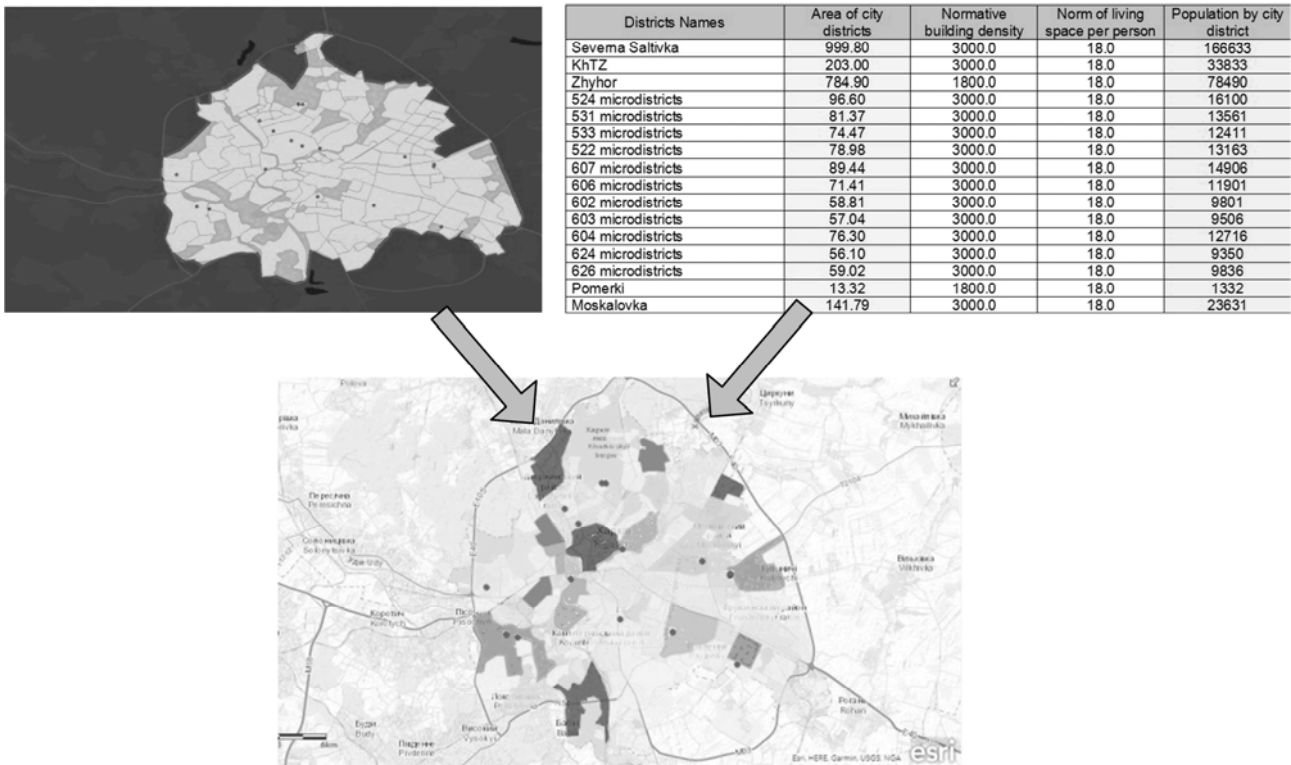


Figure 5 – Cartographic model of settlement by Kharkiv city

Table 1 – The services of emergency hospitals in the districts of Kharkov and nearby villages coverage area

Norm of patient delivery time, min	Time period		
	8-00	12-00	16-00
5	76.02 km ²	65.9 km ²	66.86 km ²
10	219.9 km ²	211.7 km ²	211.01 km ²

Table 2 – The level of accessibility of emergency hospitals in Kharkiv

Norm of patient delivery time, min	Time period		
	8-00	12-00	16-00
5	21.33 %	18.49 %	18.76 %
10	61.69 %	59.39 %	59.20 %

The data obtained (Fig. 6) make it possible to find the districts of Kharkiv and nearby villages that did not fall into the accessibility zone of the considered hospitals. Seven districts fell here: Zhyhor with a population of 78,900 people, Pyatikhatki with a population of 9,800 people, Bolshaya Danilovka (6,000 people), Bolshaya Panasovka (2,934 people), Guty (1,007 people), Novy Korotich (840 people) and Tyschenky (112 people). Figure 7 shows how, using the obtained cartographic models, for the 15-minute drivetime accessibility zone, the regions that did not fall into the accessibility zone were determined.

The results obtained are the basis for the analysis of the effectiveness of the existing medical infrastructure of the city. However, in the IDEF0 model, the fourth stage is foreseen, related to the medical center location selection process.

Based on the results, we assume that it is possible to change the location of some hospitals, for example, by organizing a feldsher-midwife station or branch of a hospital to provide emergency medical care. Considering

population and existing denouement, three hospitals “moved” closer to the ring road.

Repeating the second and third stages of the procedure for solving the placement objective (Fig. 3), new values were obtained for the coverage area and the level of accessibility of hospitals (Table 3).

6 DISCUSSION

Summarizing the results, we can draw the following conclusions. Preliminary estimates of the area of the territory where patients live (S_n) and the population (N) obtained at the first stage of the IDEF model do not contradict the data of the Main Regional Statistics Office of Kharkiv (<http://kh.ukrstat.gov.ua/>), which indicates a high reliability of the results. In particular, the error in determining the value was about 1.8% (upward), in the definition of N value – 1.7% (downward). At the same time, the used spatial clustering method depends only on distance, generates repeatable results, is free from subjectivity and does not depend on the experience of observers. That is why, its further application at the second stage of the

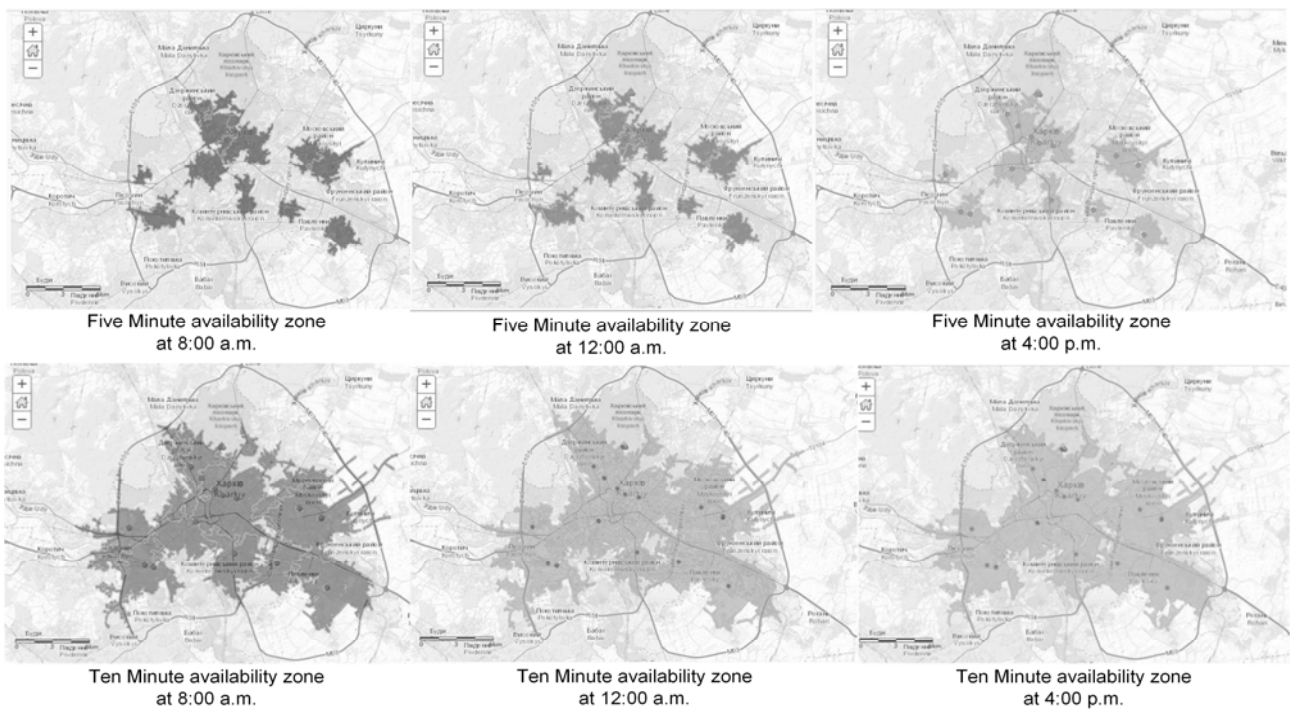


Figure 6 – Cartographic model of availability zones of ambulance hospitals by Kharkiv city

Table 3 – Coverage area and accessibility level of emergency hospitals in Kharkiv after adjusting the location of some of them

Norm of patient delivery time, min	Hospital services coverage			Hospital accessibility level		
	Time period			Time period		
	8-00	12-00	16-00	8-00	12-00	16-00
5	83.62 km ²	75.16 km ²	75.45 km ²	23.46 %	21.08 %	21.17 %
10	346.14 km ²	329.08 km ²	329.22 km ²	97.10 %	92.32 %	92.36 %

IDEF model is justified and allows us to accept the obtained values of the medical services coverage area (S_o).

We also note that the efficiency and high accuracy of the spatial clustering method, the wide use of which is proposed in the IDEF model, is confirmed by foreign studies conducted in various fields [12], [13]. Thus, the results can be considered reliable, and such that they do not contradict international experience.

The results of the study showed unevenness in the resettlement and location of existing medical centers. In particular, the most populated microdistricts are Severnaya Saltovka (166633 people), Alekseyevka (100500 people), Nagorny (82850 people), located on the periphery of Kharkov, most of the hospitals providing emergency care are located in the center. These results can be used to optimize and develop the existing medical infrastructure and can be the subject of a separate study.

The obtained estimates of the accessibility level also do not contradict foreign studies [9], [10]: the greater the coverage of hospitals, the higher their level of accessibility. However, accounting the existing transport infrastructure and traffic congestion showed:

- hospitals are most accessible at 8 o'clock in the morning, least accessible – at 12 o'clock in the afternoon;
- in the same conditions of traffic congestion, an increase in the permissible delivery time increases the coverage area by an average of 3 times;

– the maximum coverage area is 219.9 km² (at 8:00 with a patient delivery time norm of 10 minutes).

At the same time, the widespread use of cartographic data and models made it possible to identify seven districts that are not included in the considered zone of accessibility of emergency hospitals. According to estimates, 98764 residents will not be able to receive medical care on time, which can also become a separate subject of research in the context of ongoing medical reform in Ukraine.

Correction of the network of existing medical centers on a model, a justified change in the position of only 3 hospitals led to the fact that the coverage area and the level of accessibility of hospitals increased significantly. For the 10-minute delivery zone, the access level is almost 97%, which significantly increases the number of people who will get timely medical care.

CONCLUSIONS

The current situation in the field of health has once again emphasized the need to improve and develop the medical sphere. Urban development projects should be aimed at finding effective ways to use the existing medical infrastructure and identifying areas for its improvement to further uplift the living conditions of the population. Therefore, of particular importance and relevance is the solution to the problem of the placement of medical facilities.

The scientific novelty: the method of choosing the location of the medical center as a geographic object has been improved, considering the number of patients, who need the services of the center, transport infrastructure and road congestion, which, unlike existing ones, allows making decisions based not only on the shortest distance from the center to the patient, but also on the level of its availability.

For the first time, a structure of information technology for multivariate analysis of a network of city medical centers is proposed, the use of which in decision support systems allows to form objective conclusions based on the results of the implementation of the method of spatial clustering using GIS technologies.

The practical significance of obtained results has been proven on a practical example – an analysis of the existing hospital system for the provision of emergency medical care in Kharkiv. Based on the assumptions made, it is shown that the level of access to medical care does not exceed 62%. As an option to improve the existing situation, a hypothetical example of improving the existing medical infrastructure is considered by correcting the network of existing medical centers and reasonably changing the position of some of them, which increases the level of accessibility by 1.5 times.

Prospects for further research – It is advisable to conduct further research in the direction of managing medical institution networks nationwide in order to optimize and rationalize the functioning of the medical industry in the country. This will increase the effectiveness of emergency departments, as well as help optimize the tasks of transplantology, where time is also a key factor.

This approach allows the most efficient distribution of budgetary funds for the creation of modern networks of medical infrastructure and monitoring the effectiveness of existing networks of medical institutions in order to improve them. It is obvious that geospatial analysis of the city's network infrastructure can also be applied not only in the field of healthcare, but also in any other areas related to interaction with a large number of people.

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ВИРІШЕННЯ ПРОБЛЕМИ РОЗМІЩЕННЯ МЕДИЧНИХ ОБ'ЄКТІВ У ПРОЕКТАХ РОЗВИТКУ МІСТ

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АНОТАЦІЯ

Актуальність. Розглянуто проблему раціонального розміщення медичних установ населеного пункту. Запропоновано методи оцінки ефективності використання існуючої медичної мережі та пошуку шляхів її покращення при реалізації проєктів міського розвитку. Метою роботи є побудова і вивчення порядку вирішення проблеми розміщення медичних установ з урахуванням існуючої інфраструктури міста для виконання вимог доступності.

Мета. Метою роботи є побудова та вивчення процедури вирішення проблеми розміщення медичних закладів із врахуванням існуючої інфраструктури міста для виконання вимог щодо доступності.

Метод. Сформовано набір факторів, які впливають на розміщення медичних установ і дозволяють прийняти систематичне і раціональне рішення при виборі місця. Запропоновано метод вирішення проблеми розміщення медичних установ, що забезпечує підвищення рівня їх доступності з урахуванням щільності населення, його просторового розподілу, існуючої в населеному пункті транспортної розв'язки і пробок на дорогах. Процедура вирішення завдання представлена у вигляді моделі IDEF0. Метод заснований на геоінформаційному аналізі даних, результати якого шляхом просторової кластеризації представлені у вигляді набору картографічних моделей, сукупність яких дозволяє сформулювати рішення про місце розташування. Метод дозволяє оцінити рівень доступності існуючих медичних установ в населеному пункті, створити список місць для їх можливого розташування, виявити райони місцевості, що не входять в зону доступності.

Отримані результати. Удосконалено метод вибору місця розташування медичного центру, що дає можливість прийняти рішення, спираючись не лише на найкоротші відстані від центру до пацієнта, а й на рівні його доступності. Вперше запропоновано структуру інформаційної технології багатофакторного аналізу мережі медичних центрів міста для систем підтримки прийняття рішень за допомогою ГІС-технологій.

Висновки. Проблема розміщення медичних установ, яка полягає в підвищенні рівня доступності за рахунок розширення зони медичного охоплення території, на якій проживає населення міста, з використанням ГІС, була вирішена практично і представлена у вигляді моделі IDEF0, яка визначає процедуру вирішення проблеми і вибору місця розташування медичного центру. Практична значимість отриманих результатів була доведена на практичному прикладі – аналізі існуючої системи закладів надання невідкладної медичної допомоги в Харкові.

КЛЮЧОВІ СЛОВА: рівень доступності, зона охоплення, населення, час доставки пацієнта, модель IDEF0, геоінформаційні технології, мережевий аналіз, ArcGIS.

РЕШЕНИЕ ПРОБЛЕМЫ РАЗМЕЩЕНИЯ МЕДИЦИНСКИХ ОБЪЕКТОВ В ПРОЕКТАХ РАЗВИТИЯ ГОРОДОВ

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АННОТАЦИЯ

Актуальность. Рассмотрена проблема рационального размещения медицинских учреждений населенного пункта. Предложены методы оценки эффективности использования существующей медицинской сети и поиска путей ее улучшения при реализации проектов городского развития. Целью работы является построение и изучение порядка решения проблемы размещения медицинских учреждений с учетом существующей инфраструктуры города для выполнения требований доступности.

Цель. Целью работы является построение и изучение порядка решения проблемы размещения медицинских учреждений с учетом существующей инфраструктуры города для выполнения требований доступности.

Метод. Сформирован набор факторов, которые влияют на размещение медицинских учреждений и позволяют принять систематическое и рациональное решение при выборе места. Предложен метод решения проблемы размещения медицинских учреждений, обеспечивающий повышение уровня их доступности с учетом численности населения, его пространственного распределения, существующей в населенном пункте транспортной развязки и пробок на дорогах. Процедура решения задачи представлена в виде модели IDEF0. Метод основан на геоинформационном анализе данных, результаты которого путем пространственной кластеризации представлены в виде набора картографических моделей, совокупность которых позволяет сформировать решение о местоположении. Метод позволяет оценить уровень доступности существующих медицинских учреждений в населенном пункте, создать список мест для их возможного расположения, обнаружить районы местности, не входящие в зону доступности.

Полученные результаты. Усовершенствован метод выбора места расположения медицинского центра, дающий возможность принятия решений, основываясь не только на кратчайшем расстоянии от центра до пациента, но и на уровне его доступности. Впервые предложена структура информационной технологии многофакторного анализа сети медицинских центров города для систем поддержки принятия решений с помощью ГИС-технологий.

Выводы. Проблема размещения медицинских учреждений, которая заключается в повышении уровня доступности за счет расширения зоны медицинского охвата территории, на которой проживает население города, с использованием ГИС, была решена практически и представлена в виде модели IDEF0, которая определяет процедуру решения проблемы и выбора расположения медицинского центра. Практическая значимость полученных результатов была доказана на практическом примере – анализе существующей системы учреждений оказания неотложной медицинской помощи в Харькове.

КЛЮЧЕВЫЕ СЛОВА: уровень доступности, зона охвата, население, время доставки пациента, модель IDEF0, геоинформационные технологии, сетевой анализ, ArcGIS.

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