Optimization of medical institutions in Ukraine

Anna Trofymenko

***Abstract*—** In this paper, there were developed mathematical models and tasks settings of optimal placement of medical institutions in terms of health system restructuring using optimal set partitioning methods. Represented a developed program with the results of optimal partitioning of Dnepropetrovsk region to the service zones (medical districts) by hospitals of the second level.

***Keywords*—** optimization, medical institutions, mathematical methods.

I. Problem formulation

One of the priority direction of development of any country in the world is maintenance the necessary health level of its citizens. Maintenance and improvement the overall health of the population is only possible with effectively functioning health care system. Since 2011 in Ukraine there has being a health sector restructuring. The main purpose of this restructuring is improvement healthcare service. One of the main areas of sector restructuring is the health institutions network optimization through the formation of the hospital districts. Therefore, there is an urgent task of identifying the hospitals optimal location and identifying areas of service by them i. e. finding optimal medical district's zones. Moreover it is important to satisfy people needs in all types of medical care, take into account the distance to the hospitals and theirs capacity powers.

II. Analysis

The study of the state regulation problems in the health field in Ukraine and challenges of its restructuring as well as its effective operation involved the following scientists: V. Lekhan [1, 2], Y. Radysh [3], O. Schepin [4].

The problem of optimal health institutions allocation with the definition of the boundaries of service areas for the population is a multifaceted and algorithmically complex task. Usually, the problems of optimal sets partitioning are solved for the optimal firms location that produce several types of products and identifying areas where to supply these products in. Herein the total production expenditures and goods transportation are minimized and service areas are determined separately for each product. Typical representatives of continuous problems of optimal set partitioning are infinite dimensional transport problems or more general – infinite dimensional enterprises location problems with simultaneous division of a given region, constantly filled with consumers to the field of consumers, each of which is served by one enterprise in order to minimize transportation and production costs [5].

The difference of the problems of optimal medical institutions allocation lies in the fact that they should be placed, considering simultaneously all services that will be provided by each institution.

The issues of optimal sets partitioning are investigated by such scientists as A. Kiselova [5], L. Lozovskaja [6], N. Shor [7] and others.

Also, the continuous problems of optimal sets partitioning are studied by foreign authors such

A. Trofymenko, National Metallurgical Academy of Ukraine, (e-mail: missing).

as H. Corley, S. Roberts [8], R. Francis [9], J.Moreno, C.Rodriguez, N. Jimenez [10].

However, despite on considerable researches in this area, their thorough analysis showed that in scientific studies there are not deeply examined enough the questions of mathematical device application for deciding actual issues that arise during the healthcare sector restructuring.

III. The main part

The effective functioning of the health system is impacted by many factors such as validity and adaptability of solutions to national realities, interest actions by all levels of government as well as readiness and motivation of managers of health institutions.

One of the priorities of the health sector is the availability of medical services for the people that is confirmed by the Law of Ukraine about Health System. Improving the efficiency of the health system requires its reorganization. During the period of 2011-2013, the Government of Ukraine held a medical reform based on the restructuring of health care in the "pilot regions", which include Vinnitsa, Dnepropetrovsk, Donetsk regions and Kyiv [11].

Ukrainian government conducts a series of activities for the reorganization of health care system at the primary level, in which policlinics are reorganized into outpatient clinics of family type that geographically close to the places of accommodation of the population that they serve [12,13]. In order to improve the quality of specialized medical services, there are held events concerning the formation of the secondary (specialized) level of health care and the creation of hospital districts, which involves combining a network of health facilities which will provide medical assistance in case of need of specialized methods of treatment, diagnostics, rehabilitation and use of complex advanced medical technologies. Decisive place of secondary level should occupy general hospitals which provide intensive medical care (primarily emergency medical assistance) since from their activities the lives and health of patients are depended. In developed countries general hospitals make up approximately 90% of all hospitals [2].

Hospital districts may combine health facilities of several rural areas or cities and regions that depends on the density and nature of the population resettlement, takes into account the state of transport communications, logistical and staff potential of hospitals, their profiles and structure of health care services. At the same time it is important to take into account the people needs in health care, the creation of appropriate conditions for the quality care and optimal use of material, financial and human resources. It should be noted that in Europe and the United States there exist hospital districts, that allows to state rationally allocate medical resources and provide more qualitative and prompt qualified medical care.

Currently, medical care in Ukraine is divided on three levels: primary, secondary and tertiary levels.

The primary leveled centers provide primary health care. In order to improve the quality of secondary health care, it is expedient to create hospital districts, which represent a specific organizational and functional union of medical facilities and satisfy current needs of the population in specialized health care.

The need for a hospital districts formation can be explained by the fact that for the providing of quality intensive secondary health care, institution must be fitted with appropriate medical equipment, staffed by doctors and has the ability to make the required number of interventions, which may be provided when this institution serves approximately 200 thousand people [2].

As health care institutions that needed to be placed in each district have different profiles of health care, perform medical procedures of varying complexity and are suggested to service a certain number of people, the optimal reprofiling and location of these centers in existing health care facilities is important, given the existing number of staff physicians and the number of

beds [1]. For this purpose, medical institutions, which will be included in the medical district it is expedient to choose by their capacity criterion, which is calculated as a proportion of doctors and beds in each institution relatively to the total number of doctors and beds of selected health facilities. Accordingly to this, the general hospitals may be located in the institutions with the highest capacity criterion PI (Power Indicator), in institutions with lower PI will be located other kinds of hospitals.

To determine the location of health facilities and the borders of the territories served by them, we use the model of optimal partition of [3].

To create optimal conditions for the functioning of the health sector and ensure an adequate level of health care to the population of the second level, first of all, in a given area need to optimally place the health facilities and identify areas (districts) public service by these institutions so that they do not overlap between other and meet the needs of the population for health care. Cost of service delivery and shipping costs are known. This service costs should be minimal, and the load - and the maximum capacity of all health facilities in the region should meet the needs of the total number of services.

We distinguish some types of tasks the medical institutions of the second level and formulate mathematical models of these tasks as continuous single-commodity special type of optimal partition [5]:

1. Place the second level medical institutions, determining the coordinates of their position and find the limits areas that will be served according to the institutions, taking into account the needs of the medical service at some time. A mathematical model of the problem will be as follows:

   Let Ω – limited closed set, measurable by Lebesgue that specifies the region to allocate medical institutions. It is need to be divided into N service areas $\Omega_1, \ldots, \Omega_N$ (which do not intersect with each other) of patients of *i*-th medical institution and to place centers $\tau_1, \ldots, \tau_N$ of these zones in the region Ω, i.e. find the unknown beforehand coordinates of the centers $\tau 1, \ldots, \tau N$ so that the total number of patients who served by the *i*-th institution and lives in the area Ω_i does not exceed the given volumes:

$$\mathrm{mes}(\Omega_i \cap \Omega_\kappa) = 0, \quad i \neq k, \quad i, k = 1,2,\ldots,N, \tag{1}$$

where mes(·) – the Lebesgue's measure,

$$\bigcup_{i=1}^{N} \Omega_i = \Omega, \tag{2}$$

total number of patients who are served by τi -th hospital and lives in the area Ωi does not exceed the given volumes:

$$\int_0^T \int_{\Omega_i} \rho^j(x,y,t)\,dx\,dy\,dt \le b_i^j, \; i = 1,\ldots,N, \; j = 1,2\ldots\mathrm{M}, \; t \in [0,T], \tag{3}$$

where:

$\rho^j(x,y,t)$ – the need in the *j*-th service at the point (x,y) at the moment of time $t \in [0,\mathrm{T}]$;

T – period of time for which the dynamic of the services is known if it is not known, then $\rho^j(x,y,t) = \rho^j(x,y)$;

b_i^j – maximum number of *j*-th service that is provided by the *i*-th medical institution;

and thus the total cost functional

$$F(\{\Omega_1,\ldots,\Omega_N\}, \{\tau_1,\ldots,\tau_N\})=\sum_{i=1}^{N}\int_0^T\int_{\Omega_i}\sum_{j=1}^{M}[c(x,y,\tau_i)+a_i^j]\cdot\rho^j(x,y,t)dxdydt \quad (4)$$

reached the minimum value.

Here and in the following models:

M – number of services;

N – number of centers; $c(x,y,\tau_i)$ – function of determining transport costs for one medical visit or patients' transport costs;

$\tau_i=(\tau_i^x,\tau_i^y)$ – the coordinates of the i-th center;

a_i^j – cost price of providing j-th service by i-th medical institution.

The total capacity of all health facilities must meet the second level collective need for all health care services in the region. That is, the condition:

$$R=\int_{\Omega}\sum_{j=1}^{M}\rho^j(x,y)dxdy\le\sum_{i=1}^{N}\sum_{j=1}^{M}b_i^j,\ 0<b_i^j\le R,\quad i=1,2,\ldots,N, j=j=1,2\ldots M, \quad (5)$$

where R – the total demand for health care in the region. That is, the possibility of providing medical services to all hospitals in the region should meet the total needs of the population.

For simplicity, we consider the following problem without taking into account the dynamics of demand for services.

2. Determine the optimal limits areas served by existing health facilities. A mathematical model of the problem will be as follows:

Let Ω – properly closed sets, Lebesgue measurable by that specifies the region to accommodate medical facilities. You must break it into N service areas $\Omega_1, \ldots, \Omega_N$ patients and the first medical institution that does not intersect with each other, so that the total cost functional

$$F(\Omega_1,\ldots,\Omega_N)=\sum_{i=1}^{N}\int_{\Omega_i}\sum_{j=1}^{M}[c(x,y,\tau_i)+a_i^j]\cdot\rho^j(x,y)dxdy \quad (6)$$

reached a minimum value conditions (1-3) and (5).

Thus, developed mathematical models and tasks to them in their implementation in software environment can determine the optimal area of people medical service by existing health facilities including total maintenance costs and transportation costs for calls.

Due to the mathematical models and setting objectives for them, created software in C++ language environment Microsoft Visual Studio 2010, which allows to determine the optimal service area of population by existing medical facilities, taking into account the total cost of maintenance and transportation costs for calls. Fig. 2 shows a window with the results of its work.

If necessary, when changes in population dynamics known, the algorithm can be modified without significant complications.

Operations are tested to determine the optimal partitioning of Dnepropetrovsk region in the service area (district) hospitals the second level. On the fig. 1 hospitals provisions of the second level is represented by the points with the following coordinates, each separate service area hospital depicted by its color.

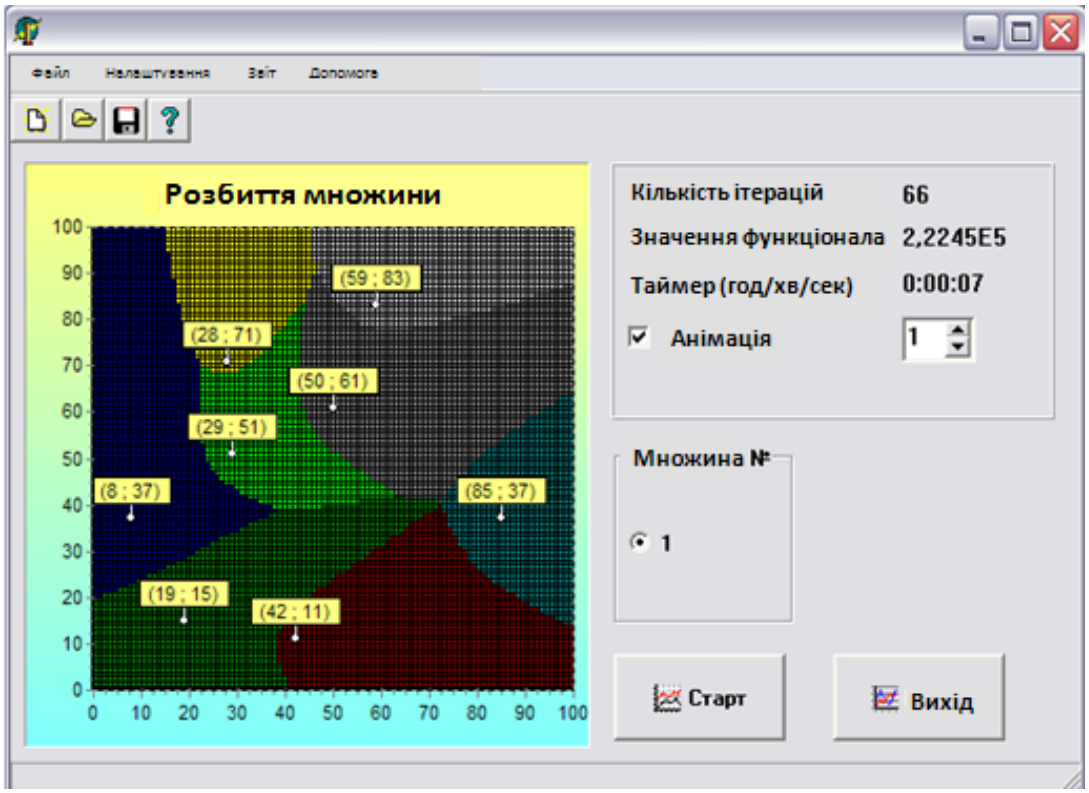

Fig. 1 Optimal service area of the second level hospitals
Source: Developed by the author.

Input data for the medical institutions of the second level are the coordinates of existing health facilities Dnepropetrovsk region with high enough values of the capacity of the hospital PI (Power Indicator, which is calculated as a percentage of the total number of doctors and beds). As the reception centers of the second level hospitals considered: Krivorozhskaya hospital №2, for which PI = 0.093, coordinates (8, 37), Apostolove central district hospital, where PI = 0.07, coordinates (19; 15), Verkhnedneprovsk central district hospital, PI = 0.068, coordinates (28; 71), Krinichansky Central District Hospital, PI = 0.065, coordinates (29; 51), Marganetsk Central District Hospital, PI = 0.073, coordinates (42; 11), Dnipropetrovsk city Multidisciplinary Clinical Hospital № 4, PI = 0.097, coordinates (50; 61), Novomoskovsk Central Hospital, PI = 0.72, coordinates (58; 83), Intercession Central District Hospital, PI = 0.63, coordinates (85; 37).

Number of services that could be provided with hospital determined the average load on the doctor per day, which is 15 patients [16]. So №2 of city hospital could provide 2895 services a day, Apostolove Central District Hospital - 2685, Verkhnedneprovsk Central District Hospital - 1215, Krinichansky Central District Hospital - 1395, Marganetsk Central District Hospital - 2685, multi Dnipropetrovsk City Clinical Hospital №4 - 2985, Novomoskovsk Central District Hospital - 1575 and Intercession Central District Hospital - 1425 services per day. To simplify the analysis of the results, the cost of medical services in all institutions will be considered the same.

The optimal location of new second-level medical institutions and identified areas of service are showed on fig. 2. We assume that the cost of service delivery while placing new medical institutions is not changed and is the same cost of the provision of services by existing institutions.

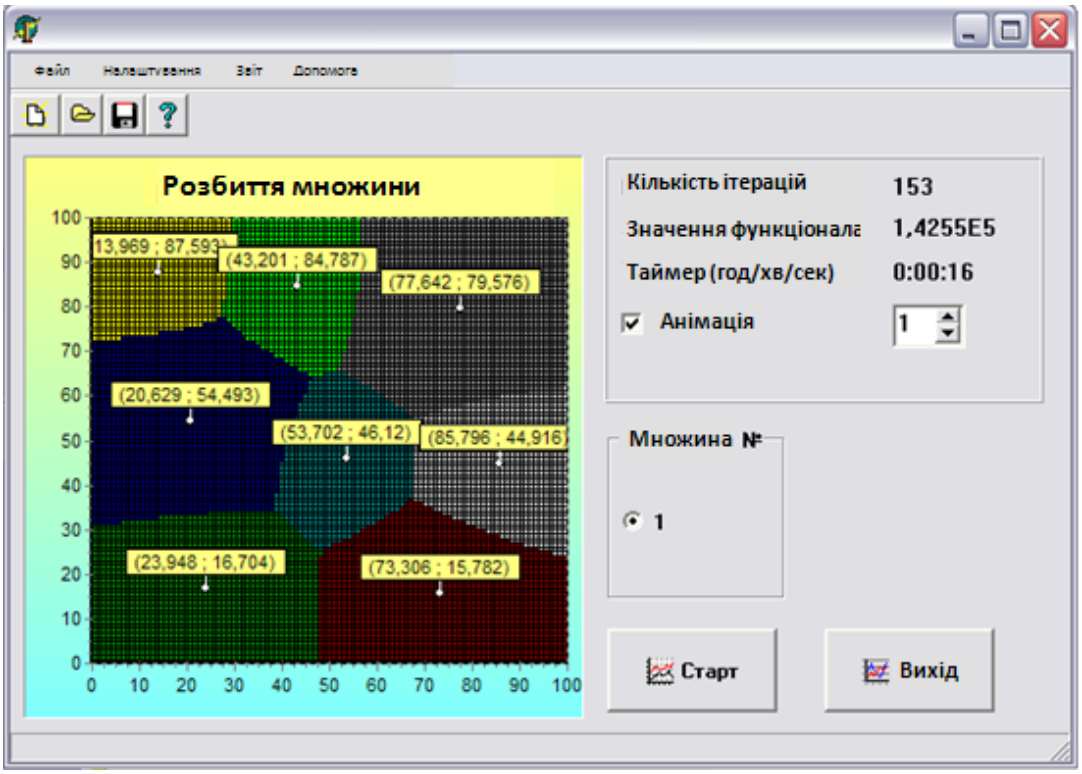

Fig. 2 Optimal location of new hospitals of the second level and their service area
Source: Developed by the author.

Thus, servicing the existing public hospitals makes functional expenses is 222 450 UAH. / Day (Fig. 1) and the placing of new medical institutions makes functional expenses 142 555 UAH./ Day (Fig. 2).

Thus, the optimal placement of new hospitals, the difference in transport costs and costs of medical services is 36% (((222450-142550) / 222450) * 100%), which, in turn, allows us to provide the most efficient high level of required quality health care for the population in the region.

These results do not include the cost of construction. Despite on the fact that the effectiveness of the location of new medical institutions is high enough and the target functional costs much less, in real terms the construction of new hospitals is unprofitable because it requires the transportation of all hospitals to new places.

This approach of the optimal location of new centers can be used in making decisions on the construction of hospitals in the area where the second level health facilities do not exist (for example, in the new residential area) or they do not meet the medical standards and require demolition.

Thus, the division of given territory into spheres of influence zones by existing hospitals on condition of their redevelopment is more appropriate.

Obviously, these results are approximate, because the actual situations which develop such models of optimal partitioning sets are often characterized by some degree of uncertainty due to lack of reliability of information and based on which the selection decision is done.

IV. Results

In the article is it discussed the urgent issue of improving the provision of medical care by reorganizing health care on the secondary level accompanied by optimization of the network of health institutions and the formation of hospital districts. Methods of optimal partitioning sets have been used to solve this problem. Implementation in practice developed models of health facilities optimal location problems can reduce transport costs and costs of medical services by finding the optimal location of new health facilities taking into account certain restrictions, allowing more efficient use of available sector resources and provide the appropriate level of medical services.

Thus, the models of the selected types of problems allow place medical institutions of the second level optimally given into account the existing restrictions on the distance to the farthest point of the served territory, the capacity of medical institutions, change the demand for services in time, uncertainty in need of medical care and calls transportation costs.

References

[1] Lekhan V. “Main ways of further development of health care in Ukraine”, For the Society, Publisher Rajewski, 2005. - P. 74.

[2] Lekhan V. “Development strategy of the health system: Ukrainian Dimension”, [electronic resource], News of medicine and pharmacy. - 2010. - 5 (311). – Access regime: http://www.mif-ua.com/archive/issue11757/article11795/.

[3] Radysh J. “State Department of Health in Ukraine: genesis, problems and reforms: Monograph”, Publishing UAPA, 2001. - 360 p.

[4] Shchepin O. “About state health reform mechanisms”, Problems of social hygiene and the history of medicine, № 1, 1997, P. 34-38.

[5] Kiseleva E. “Continuous problem of optimal partitioning of sets: Theory, Algorithms, Applications: monograph”, Naukova Dumka, 2005. - 564 p.

[6] Lozovskaya L. “Models and methods for solving problems of optimal continuous decomposition sets in incomplete information”, The dissertation, - Dnepropetrovsk, 1994. – 149 p.

[7] Shor N. “Using the r-modification algorithm for finding the minimum polynomial functions”, Cybernetics and Systems Analysis, № 4, 1997, P. 28-49.

[8] Corley H. W., Roberts S.D. “A partitioning problem with applications in regional design”, Operat. Res.,Vol. 20. №5, 1972, P.1010–1019.

[9] Francis R. L. “Sufficient conditions for some optimum-property facility design” Operat. Res., V. 15. №3, 1967, P. 448–466.

[10] Moreno J., Rodriguez C., Jimenez N. “Heuristic cluster algorithm for multiple facility location – allocation problem. – Operations research”, Vol.25, №1, 1991, P. 97–107.

[11] The Cabinet of Ministers of Ukraine “On approval of the establishment of hospital districts in Vinnytsia, Dnipropetrovsk, Donetsk and the city. Kiev” of 24 October 2012 p. № 1113 [electronic resource]. – Access: http://zakon2.rada.gov.ua/laws/show/1113-2012-%D0%BF.

[12] MON Ukraine of 23.02.2000 № 33 “On staffing ratios and standard staffing of health facilities” (amended) [electronic resource]. – Access: http://www.moz.gov.ua/ua/portal/dn_20000223_33n.html.

[13] The new European policy for health – Health 2020: Vision, values, main directions and approaches: Regional Committee for Europe EUR / RC61 [Electron resource]: according to the World Health Organization / Regional Office for Europe. – Access: http://www.euro.who.int/ru/health-topics/health-policy/health-2020-the-european-policy-for-health-and-well-being/about-health-2020.

Co-funded by the Tempus Programme of the European Union

This publication is the result of the project implementation: TEMPUS CERES: Centers of Excellence for young RESearchers. Reg.no.544137-TEMPUS-1-2013-1-SK-TEMPUS-JPHES