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MODIFIED GENETIC ALGORITHM APPROACH FOR SOLVING THE TWO-STAGE LOCATION PROBLEM

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ABSTRACT

Context. Optimization of logistics processes is one of the important tasks of supply chain management in various fields, including medicine. Effective coordination in medical logistics is essential to ensure public health and prosperity. This is especially essential during global emergencies when the rapid and efficient distribution of medicines is critical. In addition, professional logistics management is critical to delivering humanitarian aid, where the timely transportation of medical supplies and resources can be lifesaving. The most advanced technologies and algorithms are being used to improve medical logistics processes. This paper considers modifying the genetic algorithm for solving the two-stage location problem in supply chain management in the distribution of medicines and medical equipment.

Objective. The work aims to build a model and develop an algorithm for solving a two-stage location problem in the context of the medical logistics problem with further analysis of their applications and performance.

Method. We propose to use a genetic algorithm to solve a two-stage logistics problem. The peculiarities of this algorithm are the modification of evaluation procedures and the use of mixed mutation, which allows for solving the problem effectively, considering irregularities in the statement regarding the subject – the limits on the centers' location at several stages of the logistic process.

Results. The paper deals with a two-stage location problem with constraints on the maximum number of centers. Considering the specific requirements of medical logistics in the transportation context of medicines and medical equipment, a mathematical model and modification of the genetic algorithm are proposed. The developed algorithm is tested on model tasks and can produce effective solutions for problems ranging in size from 25 to 1000. The solution process takes longer for larger problems with dimensions from 1001 to 2035. Additionally, the influence of increasing the maximum generations number on the time of execution is investigated. When the maximum generation value increases from 50 to 100 and from 100 to 150 generations, the algorithm's execution time increases by 45.69% and 51.68%, respectively. 73% of the total execution time is dedicated to the evaluation procedure. The algorithm is applied to the medical logistics problem in the Dnipropetrovsk region (Ukraine). An efficient solution is obtained within an acceptable execution time.

Conclusions. A mathematical model for a two-stage location problem in the context of medical logistics is introduced. It considers the peculiarities of the medical field. A solution algorithm based on a genetic approach is developed and applied to the medical logistics problem. The algorithm has been tested on model tasks of varying sizes, with a comprehensive analysis conducted on the correlation between the problem size and the algorithm's running time. In addition, it is investigated how the maximum number of generations affects the algorithm's execution time. The role of each stage in the genetic algorithm research towards the overall effectiveness of the algorithm is researched. The obtained results indicate high efficiency and wide application possibilities of the proposed mathematical model and algorithm. The developed method demonstrates high performance and reliability.

KEYWORDS: two-stage location problem, genetic algorithm, priority-based encoding, medical logistics.

ABBREVIATIONS

RCs are regional centers;
SRCs are subregional centers;
RAM is a random access memory;
OSM is an Open Street Map service.

NOMENCLATURE

M_j are the operating expenses associated with the activation of a subregional center j ($j = \overline{1, J}$);

c_{ij}^1 are the transportation costs for volume weight unit of medicines and medical equipment from regional center i to subregional center j ($i = \overline{1, I}$, $j = \overline{1, J}$);

c_{jk}^2 are the transportation costs for volume weight unit of medicines and medical equipment from subregional center j to medical warehouse k ($j = \overline{1, J}$, $k = \overline{1, K}$);

d_k is the capacity of medical warehouse k ($k = \overline{1, K}$);

I is the number of regional centers;

J is the number of subregional centers;

K is the number of medical warehouses;

L is the limit value of subregional centers that can be located;

N is the limit value of regional centers that can be located;

P_i are the operating expenses associated with the activation of a regional center i ($i = \overline{1, I}$);

r_i are the medicines and medical equipment stocks in the regional center i ($i = \overline{1, I}$);

s_j is the capacity of subregional center j ($j = \overline{1, J}$);

v_i is a boolean variable, where $v_i = 1$, if regional center i is located, $v_i = 0$ otherwise;

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x_{ij} are the volume weight units number of medicines and medical equipment transported from regional center *i* to subregional center *j*;

y_{jk} are the volume weight units number of medicines and medical equipment transported from subregional center *j* to medical warehouse *k*;

z_j is a boolean variable, where $z_j = 1$, if subregional center *j* is located, $z_j = 0$ otherwise.

INTRODUCTION

The optimization of the logistic processes is one of the critical tasks in managing supply chains across various sectors, including medicine. Effective management in medical logistics plays a pivotal role in ensuring healthcare and public welfare. It becomes particularly relevant during global crises when the quick and efficient distribution of medical supplies is crucial. Furthermore, the proper organization of logistics is vital for humanitarian aid when the timely delivery of medical resources can be life-saving. To enhance medical logistic processes, advanced technologies and algorithms are utilized. One approach gaining wide recognition is the use of genetic algorithms to solve two-stage location problems. Solving this problem allows running optimization of the distribution and location of medical facilities, regional centers, and resources. The healthcare industry can benefit greatly from the use of an application that aids providers and suppliers in making informed decisions. By doing so, the industry can experience higher levels of productivity, faster operations, and economic advantages in medical logistics.

The object of study is the process that involves locating centers of medical facilities in two stages while limiting their number.

The subject of study is the methods of modeling and solving two-stage location problems in the context of medical logistics.

The goal of study is to create a model and develop an algorithm to solve the two-stage location problem related to medical logistics issues. The next step is to analyze their application to model and practical tasks.

1 PROBLEM STATEMENT

In extremely critical situations in a region, there may arise the need for quick distribution of essential medical supplies (medicines and medical equipment) among the population. Each region has *I* regional centers (RCs) serving as primary distribution points. To facilitate the distribution process, the local government identifies a set of *J* potential subregional centers (SRCs) that can be used as intermediate nodes for transporting medicines and medical equipment. To optimize costs due to logistical difficulties and limited resources, only *N* out of *I* regional centers and *L* out of *J* potential subregional centers may be activated by the government. Activated subregional centers will receive medical goods from regional centers and then redistribute them to *K* medical warehouses distributed throughout the region. The task is to determine the most efficient combination of subregional centers and the optimal transportation plan for drugs and medical devices from subregional centers to facilities.

Let us move on to constructing the mathematical model. The objective of the problem is to minimize the total transportation costs of delivering drugs from regional centers to medical warehouses and to select optimal locations for regional and subregional centers:

$$\sum_{i=1}^{I}\sum_{j=1}^{J} c_{ij}^{1} x_{ij} + \sum_{j=1}^{J}\sum_{k=1}^{K} c_{jk}^{2} y_{jk} + \sum_{i=1}^{I} P_i v_i + \sum_{j=1}^{J} M_j z_j, \qquad (1)$$

under the following constraints:

$$\sum_{j=1}^{J} y_{jk} \le s_j z_j, \ \forall k = \overline{1,N}, \qquad (2)$$

$$\sum_{j=1}^{J} x_{ij} \le r_i, \ \forall i = \overline{1,I}, \qquad (3)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij} = \sum_{j=1}^{J}\sum_{k=1}^{K} y_{jk}, \qquad (4)$$

$$\sum_{i=1}^{I} v_i \le N, \qquad (5)$$

$$\sum_{j=1}^{J} z_j \le L, \qquad (6)$$

$$\sum_{j=1}^{J} y_{jk} \ge d_k, \ \forall k = \overline{1,N}. \qquad (7)$$

This model includes several constraints to ensure efficient medical logistics. Firstly, constraint (2) limits the capacity of subregional centers, meaning that the number of drugs transported from each subregional center should not exceed its capacity. Secondly, constraint (3) ensures that the number of drugs transported from each regional center does not exceed its stock. Constraint (4) is the balance equation between the first and second stages of medical logistics. Additionally, constraints (5) and (6) set a limit on the maximum number of regional and subregional centers. Lastly, condition (7) ensures that the number of medical supplies received by each medical warehouse does not exceed its capacity.

2 REVIEW OF THE LITERATURE

The facility allocation problem is a widespread problem in operations research and logistics. Its main goal is determining the optimal location of facilities (such as warehouses, factories and distribution centers) to serve a given set of demand points.

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A genetic algorithm is utilized to study a two-stage transportation problem involving fixed route fees and goods transportation [1]. It is worth noting the generation of the first population considering different algorithms for building plans.

In [2], an iterative algorithm to solve a two-stage transportation problem is proposed, including a procedure for shuffling customers and efficiently removing duplicates. It is shown that the algorithm works efficiently with different input data.

Paper [3] is devoted to a multi-stage reverse logistics network using a genetic algorithm with priority encoding. Computational experiments confirm the effectiveness of the algorithm.

The task of improving the spatial planning of public health services through the development of location-allocation and accessibility models is considered in [4]. The work aims to determine the optimal location of hospitals and other medical facilities, considering factors such as population demand, accessibility, and distance to other healthcare facilities. The study is based on the example of the organization of health care in Lisbon (Portugal), where the application of the proposed methods has improved the quality and efficiency of its provision.

The article [5] deals with a two-stage transportation problem that aims to minimize logistics costs, considering the cost of placing distribution centers and transportation costs between facilities.

One potential drawback of discrete location problems is their limited scalability and, as a result, finding a timely and efficient solution for larger problems can be challenging. This is especially true for problems of significant dimensionality. By applying exact methods, the problem's dimensionality is limited even more (rather small-sized problems are usually being solved). Therefore, it is crucial to take into account continuum problems. For example, [6] proves the active requirements for more research on the case of continuous multi-stage problems and gives examples from the subject area. The authors develop a class of problems in which there are several groups of objects to be placed. Each group has its own set of possible locations (in some cases, these sets may overlap), and the relationships between the objects are regulated. The authors propose a model of a two-stage continuum location-allocation problem. Continuity is considered for each stage, sometimes combined with discrete cases. At the same time, research [7] discusses how to create new mathematical models for two-stage production allocation processes and develop methods for solving them. It emphasizes the importance of ensuring resource allocation continuity and managing multiple production stages. The article also highlights the significance of experimental studies and results analysis of model problem-solving. Additionally, the article provides examples of the practical use of these models in optimizing the two-stage distribution of material flow in fuel and energy enterprises.

In the paper [8], it is proposed to solve a two-stage transportation problem using tabu search and encoding procedures. The mathematical model corresponds to a discrete formulation of a two-stage transportation problem with a limit on the enterprises' number. The reasonable planning and optimization of shelter location is considered in [9]. The main goal of the study is to reduce losses from natural disasters and improve sustainable urban development. The authors propose a sequential approach to address a two-criteria problem by making decisions that aim to optimize economic sustainability and social utility step-by-step.

A two-stage transportation problem with a fixed fee for route usage is investigated in [10]. It is proposed to use a transition to a different form of the problem, similar to the two-stage transportation problem with the transportation unit cost. It can be represented as a conditional expression depending on whether the route is used. A genetic algorithm is utilized to solve the problem. The chromosome is encoded in the form of a matrix representation.

The problem of optimal warehouse location is solved in [11]. The authors propose a new mixed integer linear programming model to solve the warehouse location problem using Euclidean distance linearization.

Paper [12] proposes an original approach to the manufacturing enterprises' location using fuzzy logic and inference systems. This study provides decision-makers in the production industry with valuable insights on utilizing fuzzy logic and inference systems to effectively address complex issues related to the location of manufacturing facilities.

The problem of allocating production capacity with differentiated convex production costs, as described in reference [13], is a variation of the traditional allocation problem. The cost of production at each plant is modeled as a convex function of its production capacity. It is proposed a fast, accurate method based on the branch-and-price approach that takes advantage of the structure of the problem and the convexity of production costs.

3 MATERIALS AND METHODS

To solve the problem (1)–(7), an algorithm based on a genetic approach with priority encoding [5] is developed. The general scheme of it is as follows.

Step 1. The population $P(t)$ is initialized using priority-based encoding. In the current step, the first generation of possible solutions to the problem is obtained.

Step 2. The fitness of each chromosome in the population is calculated.

Step 3. Chromosomes are selected for reproduction using the roulette wheel selection method.

Step 4. The selected chromosomes are crossed to produce offspring.

Step 5. Some chromosomes are affected by mutation procedure to introduce variations.

Step 6. A new population $P(t+1)$ is formed from the offspring and some individuals from the current population. The new generation replaces the old one.

Step 7. The termination condition is checked. If satisfied, proceed to the next step. Otherwise, return to Step 2 with the population value $t+1$.

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Step 8. Terminate the genetic algorithm. Decode the most effective chromosome, return the value of the objective function, and the transportation plan.

Let us move on to detail each of the procedures used in the genetic algorithm. A priority-based coding scheme can represent each transportation plan as a chromosome. In this case, each chromosome in the population consists of two parts: the first describes the transportation tree between regional and subregional centers, and the second describes the transportation tree between subregional centers and medical warehouses. Fig. 1 visualizes the transportation plan and the chromosome that corresponds to it and can be obtained using priority encoding.

The Prufer sequence is used to represent chromosomes in a population. Each chromosome is an array of integers, where each number represents a specific vertex in the graph. This encoding represents each tree in the population and has advantages, including compact representation and speed of modification during crossover and mutation processes.

Algorithm for encoding the transportation plan (using the example of the first stage).

Step 1. Priority allocation between nodes starts with the largest value for the total count of RCs (|*I*|) and SRCs (|*J*|).

Step 2. Select the node with the lowest transportation cost among the tree leaves (nodes with transportation volumes to/from equal to their stocks/capacities). The selected node is given the highest priority.

Step 3. Remove the corresponding arc from the transportation tree. It means that the selected node is no longer a leaf node.

Step 4. If all nodes have a priority, the algorithm terminates. Otherwise, select a new leaf node and repeat steps 2 and 3.

To evaluate each individual's fitness in the population, the Prufer sequence needs to be converted into a transportation plan using the decoding process. This process involves recovering a contiguity list or matrix, which can then be used to calculate different parameters for the evaluation function.

Algorithm for decoding the chromosome plan (using the example of the first stage).

Step 1. Select the SRC with the highest priority.

Step 2. Merge the selected SRC with the RC, considering the minimum transportation cost.

Step 3. Determine the transportation amount,

which is the minimum of the stock in the RC (a_i) and the capacity of the SRC (b_j). This can be expressed as $g_{ij} = \min\left\{a_i, b_j\right\}$.

Step 4. Update the values of the stock in the RC and the available capacity of the SRC using the following formulas: $a_i = a_i - g_{ij}$ and $b_j = b_j - g_{ij}$.

Step 5. If the available capacity on the SRC (b_j) equals zero, set the priority of the SRC to zero.

Step 6. Repeat steps 1–5 until all capacities of the SRC are filled.

Note that the encoding and decoding algorithms for the second stage are the same, given that the SRCs are replaced by medical warehouses and the RCs are used instead of SRCs.

Let us define the initialization algorithm.

Step 0. Assume that we are generating a population of size $U = |P|$.

Step 1. Generate random priorities for each part of the chromosome (for example, from 1 to (|*I*| + |*J*|) for the first part of the chromosome).

Step 2. Use the evaluation procedure to check whether the generated chromosome satisfies the problem's constraints. If so, insert chromosome to the population *P*. Otherwise, try to regenerate it with a second attempt. If 1000 unsuccessful attempts to generate a chromosome happen, the input data of the problem is incorrect. The genetic algorithm procedure is terminated with an error code.

Step 3. Continue to generate chromosomes until the population reaches size *U*.

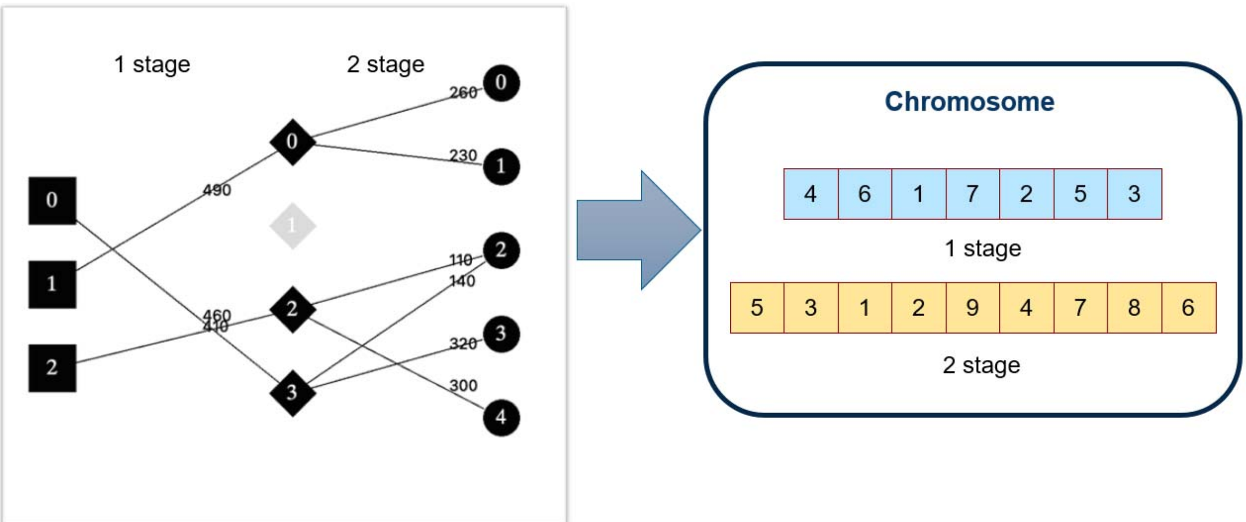

Figure 1 – Example of transportation plan encoding

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The initial population is generated randomly. This diversity is important for a genetic algorithm because it allows a wide search in the solution space. The quality of the initial population can significantly affect the convergence rate and the quality of the solution.

The second step of initialization uses the evaluation function. The algorithm is the following.

Step 1. Apply the decoding procedure and determine the transportation plan.

Step 2. If the number of regional centers exceeds *N*, discard the chromosome, otherwise proceed to the next. If the transportation volume to a subregional center is zero, do not place it. Go to the next step.

Step 4. If the total number of placed subregional centers is greater than *L* from (6), then discard the chromosome, otherwise proceed to the next step.

Step 5. If constraints (2), (3), (4), (7) are not met with the specified transportation plan (transportation volume constraints), then discard the chromosome, otherwise, go to Step 6.

Step 6. Calculate the value of the objective function using (7).

The evaluation function (or fitness function) is a solvable measure. It is always specific to the problem and calculates a fitness score for each individual in the population, with the value of the objective function calculated according to (7). Higher fitness scores correspond to better solutions.

After the initialization procedure, it is necessary to introduce a selection procedure for each iteration. For this purpose, we use the roulette wheel selection.

Step 1. Calculate the value of *S* – the sum of all values of the chromosome objective functions for the population *P(t)*.

Step 2. Create an array of probabilities, where each element p_i is defined as:

$$\mathrm{p}_i = \frac{fitness\left(chromosome_i\right)}{S}, \forall i \in \left|P\right|,$$

where $fitness\left(i\right)$ – the value of the evaluation function for some chromosome *i*.

Step 3. Randomly select the index corresponding to the chromosome from the probability array.

The roulette method is probabilistic – each individual's chance of being selected is in proportion to its fitness value. We revert the probabilities as the problem is about minimization. Thus, individuals with a lower objective function value are more likely to be selected for the next generation. This process mimics the survival of the fittest mechanism observed in natural evolution.

The weight mapping crossover is used. Here is its algorithm.

Input data: two parents v_1, v_2; chromosome length *n*.

Step 1. Randomly select a chromosome cut point $p = rand\left(1, n\right)$, where $rand\left(1, n\right)$ generates a random number from 1 to *n*.

Step 2. Determine the length of the chromosome segment after the cut point as $l = n - p$. Generate new chromosomes v_1' and v_2' by exchanging segments of parental chromosomes after the cut point:

$$v_1' = \left[v_1[1:p], v_2[p+1:n]\right],\ s_1\left[\cdot\right] = sort(v_1[p+1:n]),$$

$$v_2' = \left[v_2[1:p], v_1[p+1:n]\right],\ s_2\left[\cdot\right] = sort(v_2[p+1:n]),$$

Step 3. For each *i* from 1 to *l* and for each *j* from 1 to *l*, conditionally apply:

if $v_1'\left[p+i\right] = s_2\left[j\right]$, then $v_1'\left[p+i\right] = s_1\left[j\right]$ and

if $v_2'\left[p+i\right] = s_{1\left[j\right]}$, the $v_2'\left[p+i\right] = s_2\left[j\right]$.

This algorithm uses a random cut point to swap segments of the parent chromosomes and create new chromosomes. It then adapts the new chromosomes by replacing each value in the segment after the cut point with the corresponding value from the sorted segment of the original chromosome.

To solve the problem, we propose the use of mixed mutation: with a probability of 0.5, either a substitution or an insertion mutation is used. For the first type of mutation, two unique elements are selected from each part of the chromosomes and exchanged. For the insertion mutation, a random index is selected for each part of the chromosome, from which the element is moved to another random position.

4 EXPERIMENTS

We developed a software implementation for a two-stage location problem solution algorithm to run numerical experiments using the Python programming language and Qt5 as a user interface library. To evaluate the algorithm's performance in solving the two-stage location problem, we performed 456 tests using AMD Ryzen 7 5800X 3.8-4 GHz processor and 32 gigabytes of DD4-3200 RAM.

The input data is generated pseudorandomly within the range of values obtained by solving a practical problem. The number of regional centers ranged from 3 to 8; the number of subregional centers ranged from 5 to 13. The number of warehouses ranged from 10 to 500. Additional experiments are conducted for many warehouses – from 600 to 2000.

We take time benchmarks on the following parameters:

– the total execution of the genetic algorithm;
– one iteration execution;
– chromosomes generation;
– selection procedure;
– crossover procedure;
– mutation procedure;
– fitness procedure.

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Table 1 – Expenses calculations for DAF XF (XF105) and Geely MC

Parameter	Calculating method	DAF XF (XF105)		Geely MC	
		Reference values	Result (UAH/km)	Reference values	Result (UAH/km)
Fuel cost (c_1)	Fuel consumption per km multiplied by fuel cost per liter	Fuel consumption – 0.28 l/km, fuel cost – 43.27 UAH/l	12.12	Fuel consumption – 0.07 l/km, fuel cost – 44.49 UAH/l	3.11
Driver's wage (c_2)	(Monthly salary / Average number of hours per month) / Average speed	Monthly salary – 30.000 UAH; 160 working hours. Average speed – 60 km/h	0.03	Monthly salary – 18.000 UAH 160 working hours. Average speed – 60 km/h	0.02
Depreciation (c_3)	(Vehicle cost / Average service life in km)	1.500.000 UAH / 1.000.000 km)	1.5	300.000 UAH / 200.000 km)	1.5
Maintenance expenses (c_4)	Average cost per km	0.20/km	0.20	0.10/km	0.1
Insurance cost (c_5)	cost per km	5000 UAH per year Expected mileage – 124.800 km/year	0.04	2500 UAH per year; Expected mileage – 124.800 km/year	0.02
		Total expenses per one km (c^1) = 13.89		Total expenses per one km (c^2) = 4.75	

Additionally, we introduce the value of estimate V – the very last iteration number in the genetic algorithm procedure when the improvement (decrease in the value of the objective function) occurs.

To determine the size of the problem, we use the size of the chromosome: $h_{size} = I + J + K$.

Let's consider the algorithm's application to the real medical logistic problem. The proposed mathematical model and algorithm modification can be used to solve the medical logistics problem in the Dnipropetrovsk region (Ukraine).

Before addressing the problem, we must determine the input parameters based on the model (1) – (7). To make this problem more factual, we consider a logistics scenario where the distances between different centers are crucial. To tackle this problem, we utilize the OpenStreetMap (OSM) service, which provides a comprehensive and publicly available geographic information database, including the road network. By leveraging OSM, we can obtain accurate data on the distance between medical facilities, allowing us to incorporate real-time and distance metrics into our proposed logistics optimization algorithms. Using real-world data from OSM ensures that our analysis and decision-making process is grounded on practical and reliable information.

Next, we determine the factors that affect the cost of transporting a unit. To accomplish this, we provide a breakdown of transportation costs for each kilometer of distance.

c_1 – fuel cost, which depends on the amount of fuel consumed per kilometer, the cost of fuel per liter, and the total distance;

c_2 – driver's wage, which can be calculated as the product of the driver's hourly rate and the time spent on transportation;

c_3 – vehicle depreciation, calculated as the product of the vehicle cost divided by the expected life of the vehicle in kilometers and the total distance;

c_4 – maintenance and repair costs, calculated as the product of the average maintenance and repair cost per kilometer divided by the total distance;

c_5 – insurance costs, expressed as a known coefficient.

The total cost of transportation (c) can be defined as:

$$c = c_1 + c_2 + c_3 + c_4 + c_5 .$$

When locating a regional or subregional center, it is important to factor in operating costs. These costs can be defined as follows:

$$M = M_1 + M_2 + M_3 + M_4 + M_5 + M_6 + M_7 ,$$

where M_1 – expenses on renting unloading equipment; M_2 – salaries of all employees, including taxes; M_3 – expenses on utility payments; M_4 – expenses on maintenance and repair of the building; M_5 – expenses on purchasing and maintaining the necessary equipment for the storage of medicines and medical equipment; M_6 – insurance costs for the building; M_7 – IT infrastructure costs.

The volumetric weight will be used to represent the transportation volume of medicines and medical equipment.

Next, we want to calculate the expense values considering the parameters specified in the problem statement for the subject area. The resulting calculations are available in Table 1. DAF XF (XF105) trucks with a load capacity of up to 20 tons are used for transportation from regional to subregional centers. Geely MC cars are used for transportation from subregional centers to medical warehouses.

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Moving further, let us determine the cost of activating regional and subregional centers. According to the model, the cost of activating a center depends on the possible stock of drugs and capacity. The results of calculating the activation cost of regional and subregional centers are listed in Tables 2, 3. The minimum and maximum possible values are given for each parameter value.

Table 2 – Regional centers activation expenses

Expense type	Regional center (UAH/month)	
	Drugs storage: 180 – 225 m3 volumetric weight	
	min	max
Renting unloading equipment (M_1)	30000	50000
Salaries and wages and taxes (M_2)	420000	660000
Utility payments (M_3)	60000	80000
Maintenance and repairments (M_4)	15000	25000
Maintaining the necessary equipment (M_5)	100000	200000
Insurance (M_6)	10000	20000
IT infrastructure (M_7)	8350	8350
Total (M)	643350	1043350

Table 3 – Subregional centers activation expenses

Expense type	Subregional center (UAH/month)	
	Capacity: 110 – 150 m^3 volumetric weight	
	min	min
Renting unloading equipment (M_1)	15000	15000
Salaries and wages and taxes (M_2)	210000	210000
Utility payments (M_3)	20000	20000
Maintenance and repairments (M_4)	7500	7500
Maintaining the necessary equipment (M_5)	50000	50000
Insurance (M_6)	5000	5000
IT infrastructure (M_7)	4200	4200
Total (M)	311700	708700

To determine the problem's dimensionality, we use the Ministry of Health statistical data for 2021 presented in [14]. According to form N-47 "Report on the network and activities of medical institutions", we define the size of the problem as 4x7x65.

According to the mathematical model, we have I (number of regional centers) is equals 4; J (number of subregional centers) is equals 7; K (number of medical warehouses) is equals 65; N (the limit for regional centers) is equals 3; L (the limit for subregional centers) is equals 6.

The algorithm will be applied using the input data in Table 4.

The locations of regional, subregional centers and medical warehouses are shown in Fig. 2: red markers correspond to regional centers, blue markers indicate subregional centers and green dots indicate medical warehouses.

To solve this problem, we use the previously described genetic algorithm procedure with the following parameters:

– maximum population size – 50;

– maximum generations – 100;

– the probability of applying the mixed mutation procedure – 0.15.

Table 4 – Input data for the problem of medical logistics in the Dnipropetrovsk region

Input data	Values
Medicines and medical equipment stocks vector for regional centers	[213, 212, 215, 212]
Capacity vector for subregional center	[102, 102, 100, 101, 101, 102, 101]
Total demand for medical warehouses	586
Regional centers' activation cost vector	[846475, 906049, 937198, 669541]
Subregional centers activation cost vector	[322878, 517037, 425303, 422976, 528656, 610396, 384027]

The result of the solution is shown in Fig. 3. The first stage routes are marked in green, the second stage routes – in blue. The centers that were not activated are highlighted in gray. The following results are obtained:

– The objective function value for the most effective solution to the problem is 5057722,23 UAH;

– 3 regional centers were activated, except for the center in Pavlohrad;

– 6 subregional centers were activated, except for the center in Tomakivka;

– total execution time of the algorithm (with visualization) equals 47 seconds.

Fig. 4 (first stage only) and Fig. 5 (second stage only) show detailed maps for each stage of the medical logistics problem. It is shown that disabled centers have no inbound and outbound routes.

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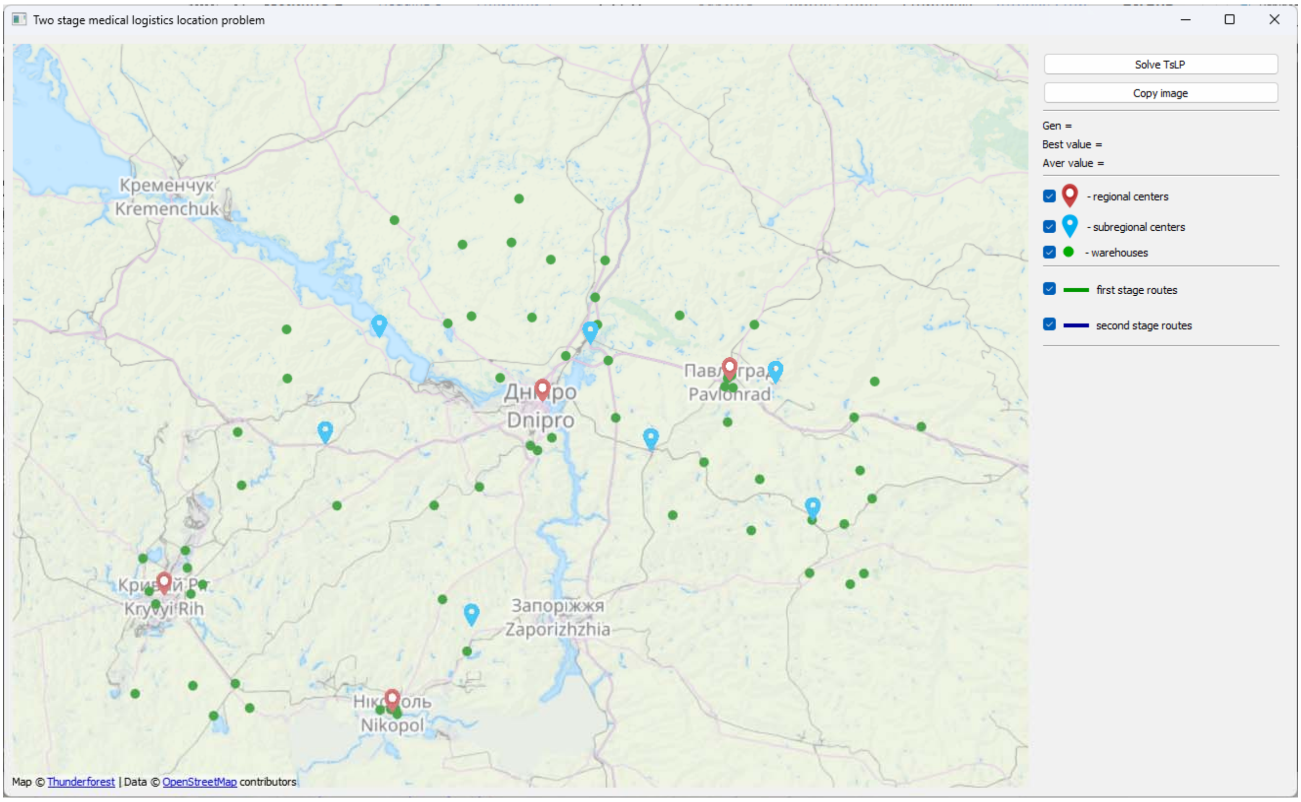

Figure 2 – Locations of the centers and medical warehouses

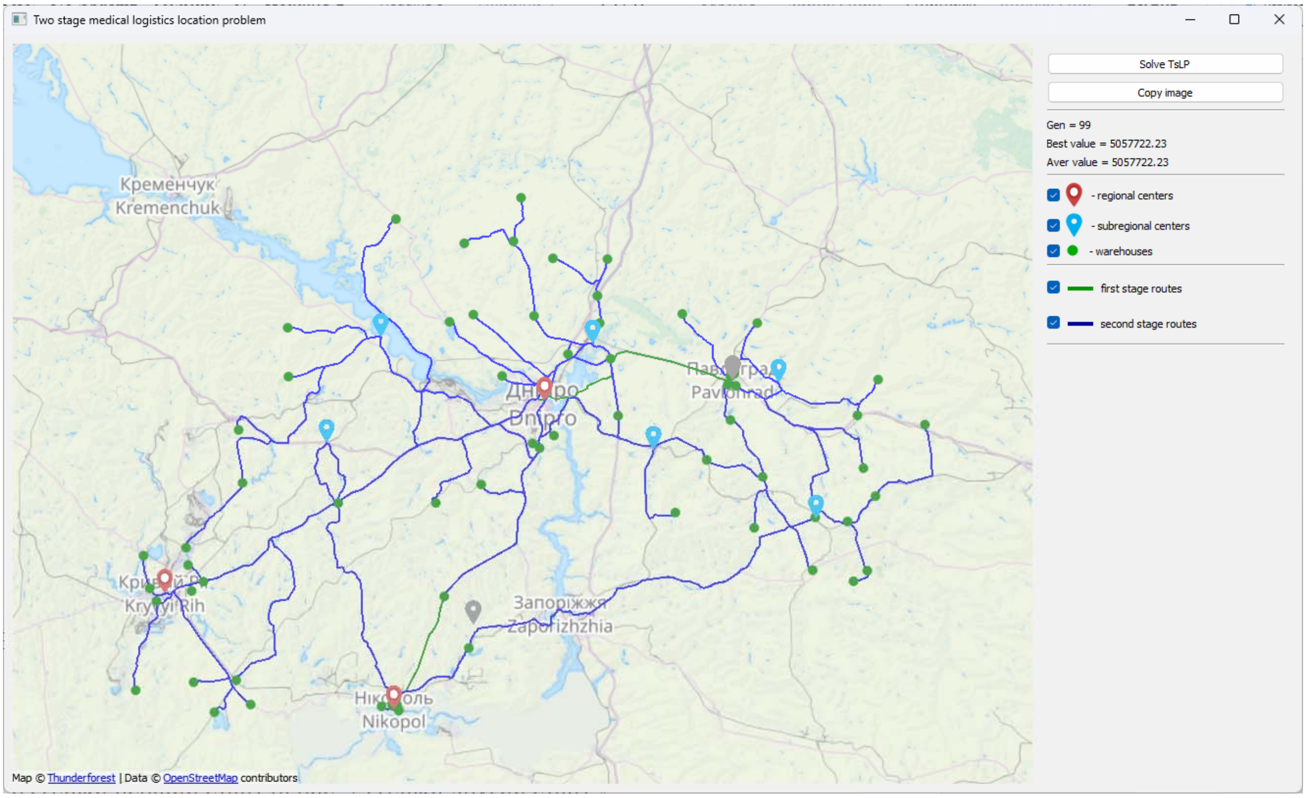

Figure 3 – Genetic algorithm results of for medical logistics in Dnipropetrovsk region

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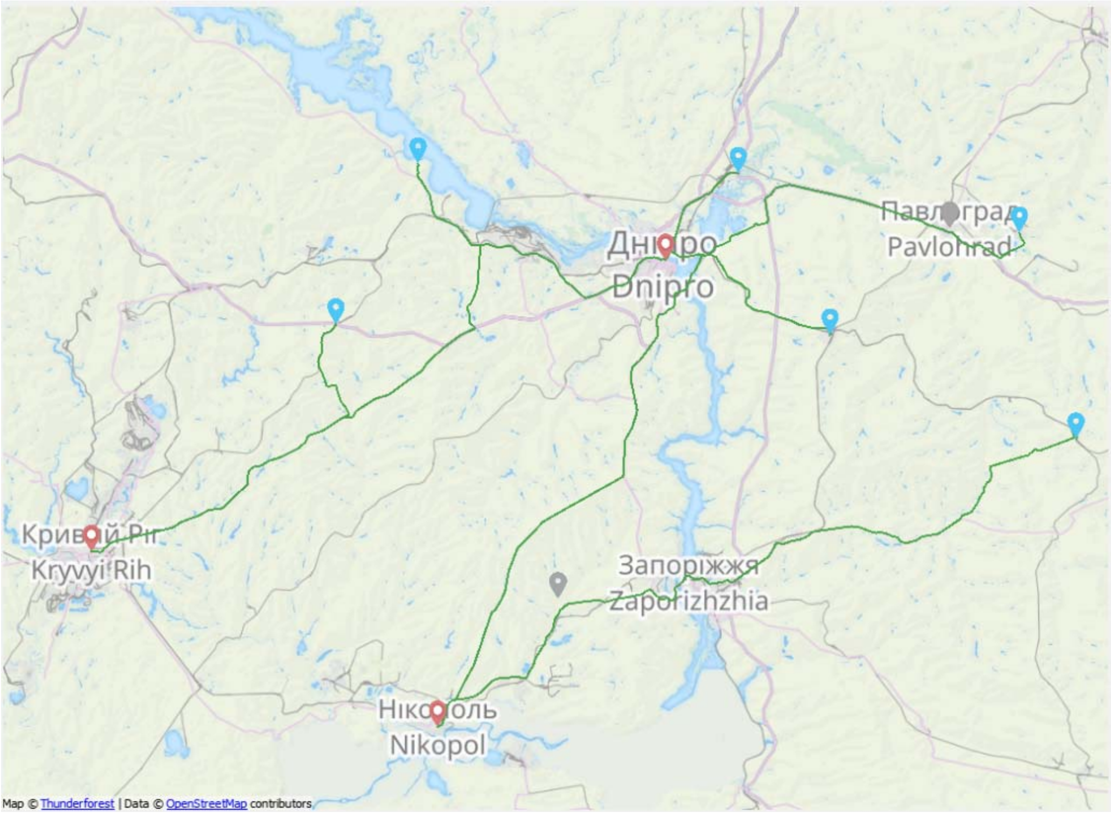

Figure 4 – Visualization of the first stage of the solution

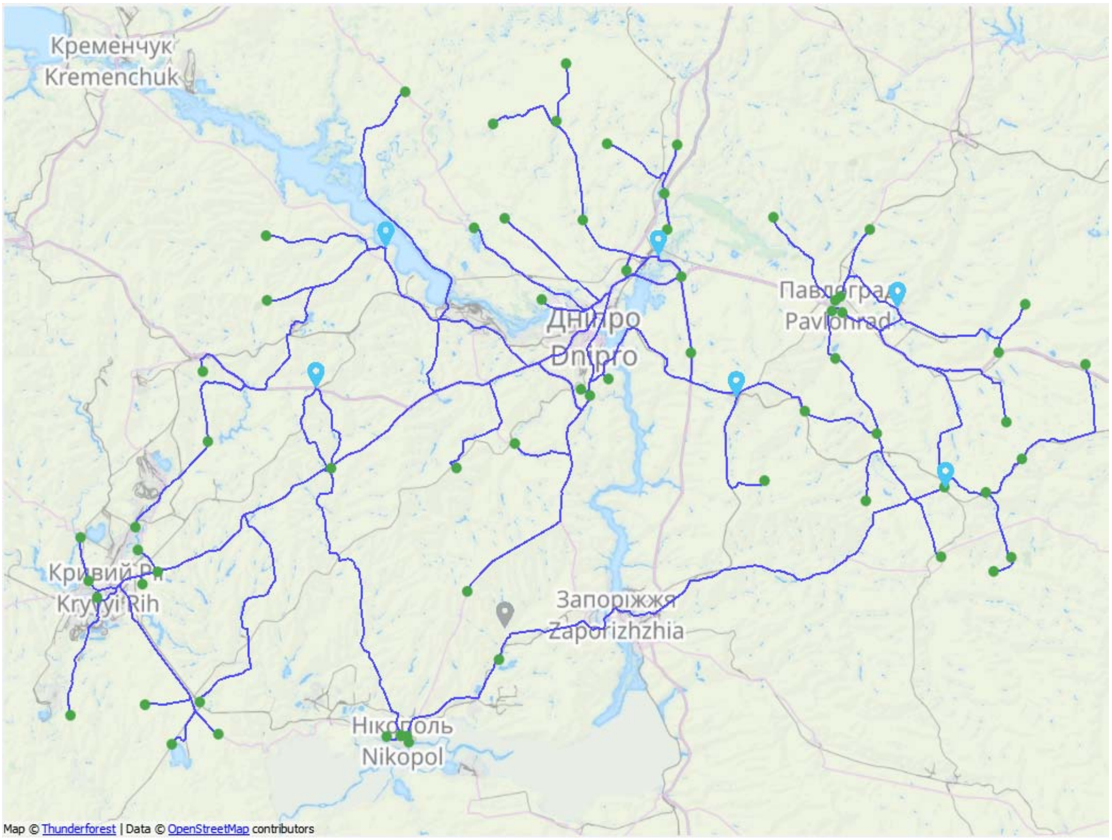

Figure 5 – Visualization of the second stage of the solution

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5 RESULTS

Fig. 6 illustrates a graph of the dependence of the total execution time of the algorithm on the size of the problem. The results are compared for different limits for generations.

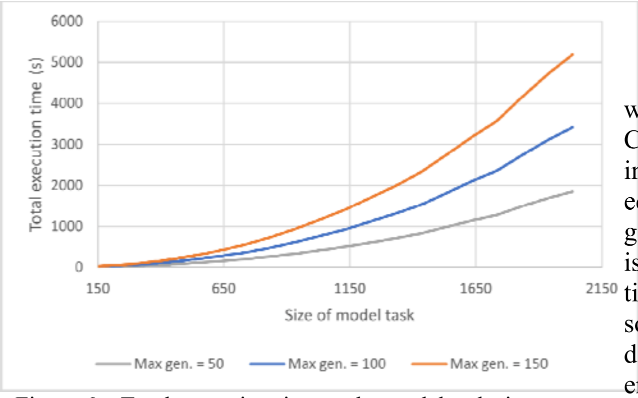

Figure 6 – Total execution time to the model task size

Fig. 7 shows a diagram containing the average time spent on each of the 456 tests. The value of the total time is taken as 100%. The benchmarks also contain the percentage of each procedure time execution of the algorithm.

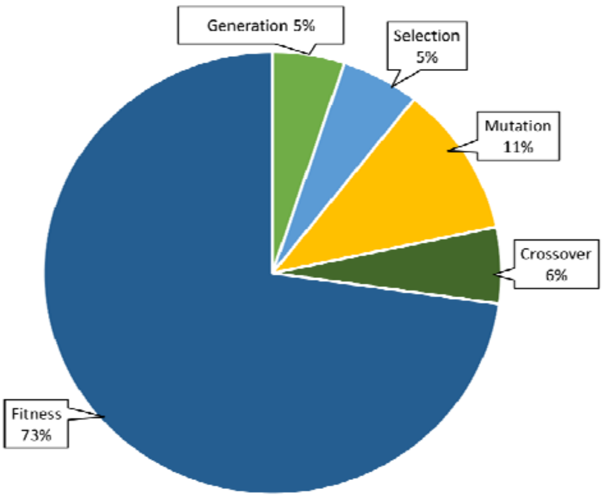

Figure 7 – Time execution of the genetic algorithm split by each procedure

6 DISCUSSION

The results from Fig. 6 demonstrate that, on average, the total execution time of the algorithm increases by 45.69% when the maximum number of generations is increased from 50 to 100. When increasing it from 100 to 150, the algorithm execution time increases by 51.68%. If the maximum generation limit is set at 150, it is improbable for value *V* to reach the highest number of iterations possible. Using higher values for the maximum number of generations will unlikely result in improvements. The algorithm's running time for problems of size 25 to 1000 is, at most, 17 minutes. For problems of size 1001 to 2035, the solution process takes much longer than those of smaller dimensions.

From the diagram in Fig. 7, we can conclude that most of the time is spent on the evaluation procedure, which includes decoding the transportation plan and checking all constraints.

CONCLUSIONS

The paper deals with a two-stage location problem with constraints on the maximum number of centers. Considering the specific requirements of medical logistics in the transportation context of medicines and medical equipment, a mathematical model and modification of the genetic algorithm are proposed. The developed algorithm is tested on model tasks and can produce effective solutions for problems ranging in size from 25 to 1000. The solution process takes more time for larger problems with dimensions from 1001 to 2035. Additionally, the influence of increasing the maximum generations number on the time of execution is investigated. When the maximum generation value increases from 50 to 100 and from 100 to 150 generations, the algorithm's execution time increases by 45.69% and 51.68%, respectively. 73% of the total execution time is spent on the evaluation procedure. The algorithm is applied to the medical logistics problem in the Dnipropetrovsk region (Ukraine). An efficient solution is obtained within an acceptable execution time.

The results of computational experiments demonstrate the proposed algorithm's correctness, high efficiency and wide application possibilities.

The scientific novelty of obtained results is that the mathematical model for a two-stage location problem with constraints on the maximum number of centers is proposed. An algorithm for solving this problem based on a genetic approach has been developed.

The practical significance of obtained results is that, based on research results, we recommend utilizing the developed algorithm and software implementation for medical logistics and other location problems in practical environments.

Prospects for further research are to study problems of higher dimensions and to extend the proposed approach to continuum two-stage location problems.

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REFERENCES

1. Antony Arokia Durai Raj K., Rajendran Chandrasekharan A genetic algorithm for solving the fixed-charge transportation model: Two-stage problem, *Computers & Operations Research*, 2012, Vol. 39, No. 9, pp. 2016–2032. DOI: 10.1016/j.cor.2011.09.020

DOI 10.15588/1607-3274-2023-3-16

2. Cosma O., Pop P., Sabo C. An efficient solution approach for solving the two-stage supply chain problem with fixed costs associated to the routes, *Procedia Computer Science*, 2019, Vol. 162, pp. 900–907. DOI: 10.1016/j.procs.2019.12.066
3. Lee J.-E., Gen M., Rhee K.-G. Network model and optimization of reverse logistics by hybrid genetic algorithm, *Computers & Industrial Engineering*, 2009, Vol. 56, No. 3, pp. 951–964. DOI: 10.1016/j.cie.2008.09.021
4. Polo Gina [et al.] Location-Allocation and accessibility models for improving the spatial planning of public health services, *Plos One*, 2015, Vol. 10, No. 3, pp. 1–14. DOI: 10.1371/journal.pone.0119190
5. Gen M., Altiparmak F., Lin L. A genetic algorithm for two-stage transportation problem using priority-based encoding, *Or Spectrum*, 2006, Vol. 28, No. 3, pp. 337–354. DOI: 10.1007/s00291-005-0029-9
6. Us S. A., Koriashkina L. S., Stanina O. D. An optimal two-stage allocation of material flows in a transport-logistic system with continuously distributed resource, *Radio Electronics, Computer Science, Control*, 2019, No. 1, pp. 256–271. DOI: 10.15588/1607-3274-2019-1-24
7. Stanina O., Us S., Koriashkina L. Modeli ta metody rozviazannia zadach optymalnoho rozmishchennia dvoetapnoho vyrobnytstva z neperervno rozpodilenym resursom. Dnipro, Harant, 2021, 200 p.
8. Salman M. Using tabu search algorithm for solving two-stage transportation problem based on decoding procedure, *Sci.Int.*, 2018, Vol. 30, No. 4, pp. 643–651.
9. He L., Xie Z. Optimization of urban shelter locations using bi-level multi-objective location-allocation model, *International Journal of Environmental Research and Public Health*, 2022, Vol. 19, No. 7, pp. 4401. DOI: 10.3390/ijerph19074401
10. Calvete H. I. [et al.] // A matheuristic for the two-stage fixed-charge transportation problem, *Computers & Operations Research*, 2018, Vol. 95, pp. 113–122. DOI: 10.1016/j.cor.2018.03.007
11. You M. [et al.] Optimal mathematical programming for the warehouse location problem with Euclidean distance linearization, *Computers & Industrial Engineering*, 2019, Vol. 136, pp. 70–79. DOI: 10.1016/j.cie.2019.07.020
12. Paul S. K. [et al.] An advanced decision-making model for evaluating manufacturing plant locations using fuzzy inference system, *Expert Systems With Applications*, 2022, Vol. 191, pp. 116378. DOI: 10.1016/j.eswa.2021.116378
13. Christensen T. R. L., Klose A. A fast exact method for the capacitated facility location problem with differentiable convex production costs, *European Journal of Operational Research,* 2020. DOI: 10.1016/j.ejor.2020.11.048
14. Tsentr medstatystyky – Statystychni dani systemy MOZ [Elektronnyi resurs], *Tsentr medstatystyky*. Rezhym dostupu: http://medstat.gov.ua/ukr/statdanMMXIX.html (data zvernennia: 01.07.2023). – Nazva z ekrana.

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МОДИФІКАЦІЯ ГЕНЕТИЧНОГО АЛГОРИТМУ ДЛЯ РОЗВ’ЯЗАННЯ ДВОЕТАПНОЇ ЗАДАЧІ РОЗМІЩЕННЯ

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АНОТАЦІЯ

Актуальність. Оптимізація логістичних процесів є одним із важливих завдань управління ланцюгами поставок у різних сферах діяльності, включаючи медицину. Ефективна координація у сфері медичної логістики має важливе значення для забезпечення громадського здоров’я та процвітання. Це стає особливо актуальним в умовах глобальних надзвичайних ситуацій, коли швидке та ефективне розповсюдження медикаментів має вирішальне значення. Крім того, вміле управління логістикою має першорядне значення для доставки гуманітарної допомоги, у випадку, коли своєчасне транспортування медичних препаратів і ресурсів може стати рятівним для життя. Задля вдосконалення процедур у медичній логістиці використовуються найсучасніші технології та алгоритми. У роботі розглянута модифікація генетичного алгоритму для розв’язання двоетапних задач розміщення у контексті управління ланцюгами поставок при дистрибуції ліків та виробів медичного призначення.

Мета. Метою роботи є побудова моделі та розробка алгоритму для розв’язання двоетапної задачі розміщення у контексті проблеми медичної логістики з подальшим аналізом їх застосування на модельних та прикладних задачах.

Метод. Запропоновано використання генетичного алгоритму для розв’язання двоетапної задачі логістики. Особливостями цього алгоритму є модифікація процедур оцінювання та використання змішаної мутації, що дозволяють ефективно розв’язувати проблему, враховуючи особливості предметної постановки – розміщення центрів на декількох етапах логістичного процесу.

Результати. Авторами запропоновано математичну модель і алгоритм, що враховують необхідність розміщення центрів на різних етапах з використанням модифікованих процедур мутації та оцінювання. Алгоритм протестовано на модельних задачах, досліджено вплив розмірності задачі на час його виконання. Розглянуто модельні задачі із розмірністю від 25 до 2035. Для задач розміром від 1001 до 2035 процес розв’язання займає значно більший час порівняно із задачами менших розмірностей. При збільшенні можливого обсягу популяції від 50 до 100 та від 100 до 150 поколінь, час виконання алгоритму збільшується на 45,69% та 51,68% відповідно. Найбільший час витрачається на процедуру оцінювання і становить 73% часу від загального часу розв’язання

Висновки. Введено математичну модель для двоетапної задачі розміщення у контексті медичної логістики з врахуванням особливостей галузі. Розроблено алгоритм розв’язання, що базується на генетичному підході та застосований для вирішення проблеми медичної логістики. Алгоритм досліджено на модельних задачах різних розмірів та проаналізовано

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залежність часу роботи алгоритму від розміру задачі. Додатково розглянуто залежності часу роботи алгоритму від значення обсягу популяцій. Наведено аналіз частки участі кожного з етапів генетичного алгоритму у загальній роботі алгоритму. Отримані результати свідчать про високу ефективність та широкі можливості застосування запропонованої математичної моделі та алгоритму. Розроблений метод демонструє високу продуктивність та надійність, особливо для задач середньої та великої розмірності, підтверджуючи свою перспективність та універсальність.

КЛЮЧОВІ СЛОВА: двоетапна задача розміщення, генетичні алгоритми, кодування на основі пріоритетів, медична логістика.

ЛІТЕРАТУРА

1. Antony Arokia Durai Raj K. A genetic algorithm for solving the fixed-charge transportation model: Two-stage problem / K. Antony Arokia Durai Raj, Chandrasekharan Rajendran // Computers & Operations Research. – 2012. – Vol. 39, No. 9. – P. 2016–2032. DOI: 10.1016/j.cor.2011.09.020
2. Cosma O. An efficient solution approach for solving the two-stage supply chain problem with fixed costs associated to the routes / Ovidiu Cosma, Petrica Pop, Cosmin Sabo // Procedia Computer Science. – 2019. – Vol. 162. – P. 900–907. DOI: 10.1016/j.procs.2019.12.066
3. Lee J.-E. Network model and optimization of reverse logistics by hybrid genetic algorithm / Jeong-Eun Lee, Mitsuo Gen, Kyong-Gu Rhee // Computers & Industrial Engineering. – 2009. – Vol. 56, No. 3. – P. 951–964. DOI: 10.1016/j.cie.2008.09.021
4. Location-Allocation and accessibility models for improving the spatial planning of public health services / Gina Polo [et al.] // Plos One. – 2015. – Vol. 10, No. 3. – P. 1–14. DOI: 10.1371/journal.pone.0119190
5. Gen M. A genetic algorithm for two-stage transportation problem using priority-based encoding / Mitsuo Gen, Fulya Altiparmak, Lin Lin // Or Spectrum. – 2006. – Vol. 28, No. 3. – P. 337–354. DOI: 10.1007/s00291-005-0029-9
6. Us S. A. An optimal two-stage allocation of material flows in a transport-logistic system with continuously distributed resource / S. A. Us, L. S. Koriashkina, O. D. Stanina // Radio Electronics, Computer Science, Control. – 2019. – No. 1. – P. 256–271. DOI: 10.15588/1607-3274-2019-1-24
7. Станіна О. Моделі та методи розв'язання задач оптимального розміщення двоетапного виробництва з неперервно розподіленим ресурсом / О. Станіна, С. Ус, Л. Коряшкіна. – Дніпро : Гарант, 2021. – 200 с.
8. Salman M. Using tabu search algorithm for solving two-stage transportation problem based on decoding procedure / M. Salman // Sci.Int. – 2018. – Vol. 30, No. 4. – P. 643–651.
9. He L. Optimization of urban shelter locations using bi-level multi-objective location-allocation model / Lei He, Ziang Xie // International Journal of Environmental Research and Public Health. – 2022. – Vol. 19, No. 7. – P. 4401. DOI: 10.3390/ijerph19074401
10. A matheuristic for the two-stage fixed-charge transportation problem / Herminia I. Calvete [et al.] // Computers & Operations Research. – 2018. – Vol. 95. – P. 113–122. DOI: 10.1016/j.cor.2018.03.007
11. Optimal mathematical programming for the warehouse location problem with Euclidean distance linearization / Meng You [et al.] // Computers & Industrial Engineering. – 2019. – Vol. 136. – P. 70–79. DOI: 10.1016/j.cie.2019.07.020
12. An advanced decision-making model for evaluating manufacturing plant locations using fuzzy inference system / Sanjoy Kumar Paul [et al.] // Expert Systems With Applications. – 2022. – Vol. 191. – P. 116378. DOI: 10.1016/j.eswa.2021.116378
13. Christensen T. R. L. A fast exact method for the capacitated facility location problem with differentiable convex production costs / Tue Rauff Lind Christensen, Andreas Klose // European Journal of Operational Research. – 2020. DOI: 10.1016/j.ejor.2020.11.048
14. Центр медстатистики – Статистичні дані системи МОЗ [Електронний ресурс] // Центр медстатистики. – Режим доступу: http://medstat.gov.ua/ukr/statdanMMXIX.html (дата звернення: 01.07.2023). – Назва з екрана.

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