УДК 519.179.2: 656.073
UDC 519.179.2: 656.073

МЕТОДИ ВИЗНАЧЕННЯ ОПТИМАЛЬНИХ ХАРАКТЕРИСТИК ТРАНСПОРТНИХ МЕРЕЖ

Прокудін Г.С., доктор технічних наук, Національний транспортний університет, Київ, Україна, p_g_s@ukr.net, orcid.org/0000-0001-9701-8511

Чупайленко О.А., кандидат технічних наук, Національний транспортний університет, Київ, Україна, snegirevskyalexey@gmail.com, orcid.org/0000-0002-2004-0355

Дудник О.С., кандидат технічних наук, Національний транспортний університет, Київ, Україна, alex_ds@ukr.net, orcid.org/0000-0002-1980-7168

METHODS FOR DETERMINING OPTIMAL CHARACTERISTICS OF TRANSPORTATION NETWORKS

Prokudin G.S., Doctor of Technical Sciences, National Transport University, Kyiv, Ukraine, p_g_s@ukr.net, orcid.org/0000-0001-9701-8511

Chupaylenko O.A., PhD, National Transport University, Kyiv, Ukraine, snegirevskyalexey@gmail.com, orcid.org/0000-0002-2004-0355

Dudnik O.S., PhD, National Transport University, Kyiv, Ukraine, alex_ds@ukr.net, orcid.org/0000-0002-1980-7168

МЕТОДЫ ОПРЕДЕЛЕНИЯ ОПТИМАЛЬНЫХ ХАРАКТЕРИСТИК ТРАНСПОРТНЫХ СЕТЕЙ

Прокудин Г.С., доктор технических наук, Национальный транспортный университет, Киев, Украина, p_g_s@ukr.net, orcid.org/0000-0001-9701-8511

Чупайленко А.А., кандидат технических наук, Национальный транспортный университет, Киев, Украина, snegirevskyalexey@gmail.com, orcid.org/0000-0002-2004-0355

Дудник А.С., кандидат технических наук, Национальный транспортный университет, Киев, Украина, alex_ds@ukr.net, orcid.org/0000-0002-1980-7168

Introduction.

A strategic objective of scientific–technical policy in the field of transportation system of the state is achieving the world level in terms of technical parameters and services quality that are implemented in transport. In this connection, the top priority for the transport sector is to expand scientific research into creation of progressive technologies for the rational organization of cargo transportations, formation and functioning of efficient transportation system, development of fundamentally new management systems using modern information technologies [1, 2].

At present, Ukraine is beneficially different from other countries by the fact that a significant number of its cities are located along traditional transportation and communication routes of the Eurasian continent. The issue of the development of international transport corridors by Ukraine will accelerate not only achieving the strategic goals of integration into the European Community, but also solving such tasks as additional investments into development of the transportation infrastructure of the state, as well as increasing volumes of products for export [1].

Transport in Ukraine is a powerful communication system, which includes all its types (water, road, railway, pipeline, air). The main production funds of transport constitute about 20 % of the production funds of the country [1]. Creating united international transport-logistic system, geographical position of the transportation space of Ukraine, as well as existence of many international transport corridors require the following [1, 2]: separate analysis of transport hubs management; provision of coordination and interaction of all kinds of transport; implementation of modern achievements in scientific and technical progress in the transportation operation.

Designing efficient delivery of cargos with the alignment of all the links of the transportation process necessitated a large number of theoretical and experimental studies on various issues of development of transport systems [1, 2].

Relevance of the research is determined by the need to improve efficiency of the transportation of goods in international traffic through the development and implementation of models, methods and software for the rational organization of international freight traffic.

Literature review and problem statement.

Many scientific papers in the field of transportation systems, logistics and operations studies address the solution of problems to increase efficiency of cargo transportation in international traffic. The main characteristics of the transport networks [TN] include: maximum flow in the TN and the shortest distances in the TN. To solve the problem of optimization of the TN, it is necessary to reduce a network representation of the transport problem to the matrix form, for which there is practical mathematical apparatus. An analysis of the literature data that we conducted revealed the following.

The existing methods for solving the problem of maximum flow in the TN are convenient to use only for a flat network [3]. A new presented algorithm for the maximum flow allows the optimization of solution to the problem, but it does not take into account the peculiarities of transport networks [4]. To solve the problem, it is necessary to extend the method for solving the problems on the optimization of transport networks with and without restrictions of the throughput capacity.

The algorithms of mathematical programming for designing a TN are developed, which allow finding the optimal ways [5]. But such algorithms do not take into account the large number of intermediate points in the TN. The proposed characteristics of transport in the multiplex system enable the optimization, but do not allow the calculation of the shortest distances in the case of a large number of intermediate points [6].

The transportation problem in the matrix and network forms is presented by definition in equivalents [7]. However, sometimes it is more convenient to solve a network problem in matrix form [8]. But we need to improve these methods to solve complex network transportation problems using directed graphs in the Excel environment.

In general, the problem of effective control over the international freight transportation process is in the fact that the existing methods do not fully take into account specific features of their fulfillment and, consequently, there is no a unified approach to determining the methods for the determination of optimal characteristics of TN.

Improvement of the methods for reducing network representation of the transport problem to the matrix form.

The transport problem in the matrix and network forms of representation are equivalent by definition. However, sometimes it is more convenient to solve the network problem in the matrix form. There are two main ways to reduce a network problem to the matrix form [6, 7].

We propose to solve the network transport problems in the Excel environment. A directed graph is called a network, where the following are determined:

– node-source that has only the output arcs (denoted by letter *s* from "source");

– node-runoff that has only the input arcs (denoted by letter *t*, from "terminal" – final destination);

– all other nodes – intermediate (transit), interconnected by arcs, which include the input and output arcs.

Directed arcs in the network are marked with arrows, non–directed arc is replaced with two arrows facing each other. Arc with arrow and a certain value of the appropriate parameter specifies universal concept – flow that moves from the initial node of the arc to the final node. The objects of flows in practical problems are the cargos, gas, passengers, vehicles, communication signals, fluids, etc.

Most of the optimizing problems in networks are the problems on flows in the networks (*network flow problems*) [7, 8]. For the network optimization problems, a fundamental principle is the *principle of maintaining the flow* at any node, particularly, the total of flows $F_{вих}(x)$ at the node output is equal to the total of flows at its input $F_{вх}(x)$ + potential p(x) of node (+ proposal/ –demand), for example:

– node–source s: $F_{вих}(s)=0+p(s)=P$, where P is the magnitude of total flow along the network; potential $p(s)=+P$;

– node–runoff t: $F_{вих}(t)=P+p(t)=0$ because potential $p(t)=–P$;

– intermediate node x: $F_{вих}(x) = F_{вх}(x) \pm p(x)$.

A flow in each node of the network is function that satisfies linear equations and inequalities, where each arc (x_i, x_j) of the network is in line with one or more positive numbers. For example, magnitude $d(x_i, x_j)$ in the problem on maximum flow is the throughput capacity of the arc (maximum amount of product that can be delivered with node x_i to node x_j along this arc per unit of time); in the transport problem, this is the distance or the cost of transportation. Hence the magnitude of flow along arc (x_i, x_j) does not exceed throughput capacity of this arc $d(x_i, x_j)$ if it is set.

The purpose of the study is the reduction of network representation of the transport problem to the matrix form that will allow us in future to solve the problems of cargo transportation optimization. Fig. 1 displays TN without limitation for the throughput capacity; Fig. 2 presents TN with limitations for the throughput capacity.

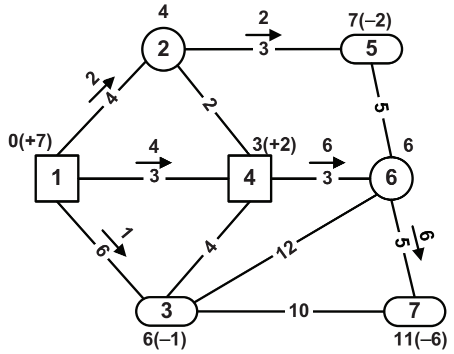


Figure 1 – Example of TN without limitation in the throughput capacity

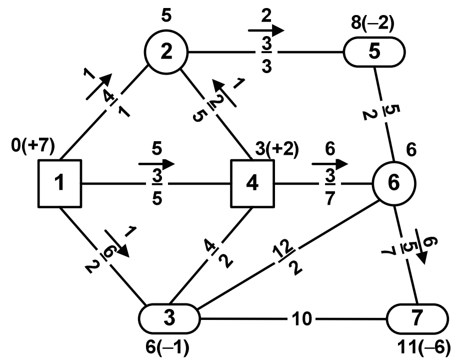


Figure 2 – Example of TN with limitation in the throughput capacity

Fig. 1, 2 display networks with 7 vertices and 11 links. Next to the corresponding vertex in parentheses is the number with a plus sign that indicates the volume of production while the volume of consumption is, respectively, denoted by the number with a minus sign. The cost of cargo transportation is written down in each arc, where the denominator of fraction demonstrates throughput capacity of separate links in the network. Fig. 1, 2 presents distributions of cargo flows and potentials.

Production volume is equal to the throughput capacity of the arc, that is,

$$a_i = d_{ij}. \tag{1}$$

For the arcs whose throughput capacity is unlimited, in particular for arcs 3–7 and 7–3, it will correspond to the known big number.

The volume of consumption for producing vertices of the network is determined by formula:

$$b_j = \sum_{j \neq i} d_{ij} - a(x). \tag{2}$$

For the vertices that consume cargo – by formula:

$$b_j = \sum_{j \neq i} d_{ij} + b(x). \tag{3}$$

For transit vertices, by formula:

$$b_j = \sum_{j \neq i} d_{ij}. \tag{4}$$

The first way is the improvement of the method Ordena [9, 10], shown in Table 1. Every vertex of the network shown in Fig. 1 is assigned with a line and a column. Thus, in our case, the table consists of seven lines and seven columns. It should always be square. In the cells of the main diagonal in Table 1, the cost of transportation is equal to 0, because the output and, at the same time, input arcs to the same vertex cannot exist.

For the vertices, interconnected by a link, in the cells of the table at the crossing of the corresponding lines and columns is the cost of transportation by this link. Other cells are blocked by the numbers that are larger than the costs of transportation (in Table 1, it is 99).

For convenience of the calculation, the value of production (consumption) volume at each vertex is added with any positive number. In Table 1, it is number 9. Thus, the volume of production in vertex 1 will equal 7+9=16; in transit vertex 2 – 9, similar to the volume of consumption; the volume of consumption in vertex 3 will equal 1+9=10, etc. Then the transport problem is solved by any known tabular method, for example, the method of potentials. In Table 1, values of the optimal plan of cargo transportation are in italics, in Fig. 1 – arrows.

The second way is improving the Wagner method [10]. It is more convenient for the networks with throughput capacity limitations. Such a network is depicted in Fig. 2, where an optimal plan of transportation is also presented. Table 2 demonstrates reducing this network to the matrix form.

Table 1 – Reducing a network transport problem to the matrix form by method Ordena

№	1	2	3	4	5	6	7	∑
1	0 / 9	4 / 2	6 / 1	3 / 4	99	99	99	1
2	4	0 / 7	99	2	3 / 2	99	99	9
3	6	99	0 / 9	4	99	12	10	9
4	3	2	4	0 / 5	99	3 / 6	99	1
5	99	3	99	99	0 / 9	5	99	9
6	99	99	12	3	5	0 / 3	5 / 6	9
7	99	99	10	99	99	5	0 / 9	9
∑	9	9	10	9	11	9	15	72

Table 2 – Reducing a network problem to the matrix form by the Wagner method

№	1	2	3	4	5	6	7	∑
1–2	0	4 / *1*	99	99	99	99	99	1
2–1	4	0 / 1	99	99	99	99	99	1
1–3	0 / 1	99	6 / *1*	99	99	99	99	2
…	…	…	…	…	…	…	…	…
6–5	99	99	99	99	5	0 / 2	99	2
6–7	99	99	99	99	99	0 / 1	5 / *6*	7
7–6	99	99	99	99	99	5	0 / 7	7
∑	1	9	107	17	7	18	113	72

Arcs here are in lines, the vertices are in columns. In the upper–left corner of the table cell is the cost of transportation along the arc. The cells that contain no digits are supposed to be blocked by the numbers that are larger than the costs of transportation (in Table 2, it is 99).

Production volume is equal to the arc's throughput capacity (1). For the arcs whose throughput capacity is unlimited, in particular, arcs 3–7 and 7–3, it corresponds (in our example) to a number of 100.

Consumption volumes for the production vertices of the network are determined by formula (2), for the vertices that consume the goods – by formula (3), and for the transit vertices – by formula (4).2

Thus, for vertex 1, the volume of consumption is equal to 1+5+2–7=1, for vertex 7 – 7+100+6=113, and for vertex 2 – 1+5+3=9.

Table 2 also shows the final result of solving the problem – the optimal plan for the transportation of cargo, which is represented in the form of italicized values that correspond to the flows in Fig. 2.

Improvement of the methods of searching for the shortest distances in the TN.

Often, when solving practical problems, there is a need to show the links between certain objects. Directed and non-directed graphs, which are referred to in the scientific literature as networks, are a natural model for the implementation of such links [7, 8].

Let us consider the problem of searching for the best route in terms of the smallest distance. This problem is naturally modeled using networks, that is, we have connected network G, in which positive weight of each edge is equal to its length. Length of the path in such a network is equal to the sum of lengths of the edges that form this path. In the terms of networks, the problem is reduced to finding the shortest path between two set vertices of graph G [7, 8].

The problems on the shortest paths belong to fundamental problems of combinatorial optimization, because many of them can be reduced to finding the shortest path in a network. There are different types of problems on the shortest path: (1) between two given vertices, (2) between a given vertex and all others, (3) between each pair of vertices in the network, (4) between two given vertices to the paths that pass through one or more of the specified vertices; (5) the first, second, third, etc. shortest path in a network. Of all the described types, the most interesting for solving the network transport problems are the first three. In this case, the first two of them are realized using the Dijkstra's algorithm varieties [4], and the third one by using the Floyd algorithm [5].

Let us assume there is directed graph G=(V, E) whose all arcs have positive marks (arcs costs). It is possible to represent graph *G* in the form of map of route flights from one city to another, where each vertex corresponds to a city, and arc v→w to the shuttle route from city v to city w (Fig. 4). The mark of arc v→w is the flight time from city v to city w. In this case, one can assume that in this case the model matches a non-directed graph because the marks of arcs v→w and w→v may coincide. But the flight time is mostly different in opposite directions between two cities. In addition, assumption about coincidence of the marks of arcs v→w and w→v does not affect essentially the solution of the set problem. In this case, the solution of the problem on finding the shortest path will be minimum time of flights between different cities.

Method of graphs. Our initial data for this method are the known specified directed graph G(V, E), shown in Fig. 3. In this case, the whole set of its vertices V is divided into two subsets. The first subset includes the cities of departures (m of cities), and the second subset includes the cities of airplanes landing (n of cities).

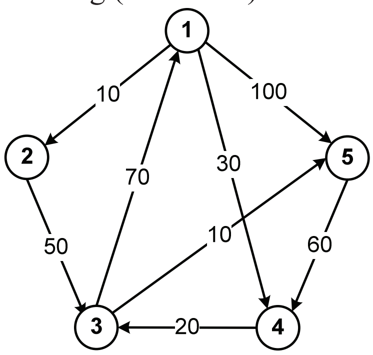


Figure 3 – Directed graph with marked arcs

Table 3 – Matrix of the shortest distances between departures and landings

Indicators	A/p of landings				
	№	1	2	. . .	n
A/p of departures	1	C_{11}	C_{12}	. . .	C_{1n}
	2	C_{21}	C_{22}	. . .	C_{2n}
	. . .	. . .	. . .	. . .	. . .
	m	C_{m1}	C_{m2}	. . .	C_{mn}

To resolve this problem, existing algorithms may not be applied because the Dijkstra's algorithm is insufficient (according to it, we find only one line from the matrix of the shortest distances), and the Floyd algorithm is excessive (it generates matrix of the shortest distances between any a/p, that is, m+n to m+n).

It is necessary to find the shortest routes for flights between the airports (a/p) of departures and landings, including landings at intermediate a/p (they can be both a/p of departures and a/p of landings of airplanes). In other words, we must receive the matrix of the shortest distances between the a/p of departures and the a/p of landings (Table 3).

That is why we consider a fundamentally new algorithm, shown in the listing of program from a pseudo code, which is presented below and in which:

```
procedure New( var D: array[1 .. m, l .. (m + n)] of real; C: array[1 .. (m + n), l .. (m + n)] of real;
          P: array[1 .. m, l .. (m + n)] of integer);
begin
(1)    for i := 1 to m do
         begin
           S := {i}; {selecting the next vertex from the subset of a/p of departures}
           for j := 1 to (m + n) do
             begin
               D[i, j] := C[i, j]; { D initialization }
               P[i, j] := i
             end
(2)          for j := 1 to (m + n –1) do
               begin
                 selecting such vertex w from set V\S that value D[i, w] minimal;
                 add w to set S;
                 for each vertex v from set V\S do
                   begin
                     if (D[i, w) + C[w, v] < D[i, v] then P[i, j] := w;
                     D[i, v] := min(D[i, v], D([i, w] + C[w, v] );
                   end
(3)            end
(4)      end
end; { New }
```

– array D is the resulting matrix of the shortest distances, and at every step element D[i, v] contains length of the current shortest path from vertex i to vertex v;

– array C specifies distances of the flights, where element C[i, j] is equal to the cost of arc i→j. If arc i→j does not exist, then C[i, j] equals ∞ (infinity), that is, larger than any actual cost of arcs;

– element of array P[i, v] contains the number of vertex, preceding vertex v in the shortest path from vertex i;

– set S means the same as in the Dijkstra's algorithm, namely a sequence of vertices of the "special" shortest path.

In the external loop (lines 1–4), we sequentially select all a/p of departures, and in the internal one (lines 2–3) we find the shortest routes from these a/p to all others, and if, along this route, the intermediate vertices are available, they are remembered.

An analysis of the commonly known network algorithms for constructing the shortest paths between the vertices of directed graph reveals that the proposed new method for constructing the shortest paths between specified sets of vertices in the network has the following advantages:

– it fully solves the set problem that could not fundamentally be solved using the Dijkstra's algorithm, due to the lack of obtained results;

– it solves the problem of finding the shortest paths between the given infinities of vertices in the network more effectively, that is, easier and faster, compared to, though adequate but redundant, results, that we receive, using the Floyd algorithm.

The new algorithm for constructing the shortest paths between specified sets of vertices in the network was implemented in the form of software package, which was verified at a large number of examples, thus proving its reliability and universality in the network transport tasks of large dimensions.

The matrix method. First, we compile adjacency matrix S of the known graph G=(V, E) shown in Fig. 3. The lines of matrix S correspond to vertices V_i $(i=\overline{1,5})$, columns – vertices V_j $(j=\overline{1,5})$. Element S_{ij}, which is located at the intersection of the i–th line and the j–th column, is assigned equal to the value that is set on the corresponding arc E_{ij} between vertices V_i and V_j and 0 – in the absence of direct link between them (Table 4).

Next we determine matrix S^2=S+S by the following rule of adding elements of matrices S:

$$S^2_{ij}=\min\left\{\sum_{k=1}^{n}(S_{ik}+S_{kj})\right\},\text{provided } ((S_{ik}\times S_{kj})\neq 0)(i=\overline{1,n};j=\overline{1,n})\ . \qquad (5)$$

Upon completion of the formation of all matrices S^m, we define matrix D – resulting matrix of the shortest paths between vertices V_i and V_j of graph G whose elements are calculated by the following formula:

$$D_{ij}=\min\left\{S^1_{ij}\cdots S^m_{ij}\right\},\text{при } S^1_{ij}\cdots S^m_{ij}\neq 0\ . \qquad (6)$$

Table 4 – Matrix S

№	1	2	3	4	5
1	0	10	0	30	10
2	0	0	50	0	0
3	70	0	0	0	10
4	0	0	20	0	0
5	0	0	0	60	0

Described new method for finding the shortest paths on directed weighted graph by its functional capabilities is fully comparable to the Floyd method. It should also be noted that the new method described, similar to the Dijkstra's algorithm with its various modifications and the Floyd algorithm, may also be used when processing the network models of representation of cargo transportation in TN of various structure [8, 11].

A new method for constructing the shortest paths between different sets of vertices on a graph, which we examined, is also implemented as a software package.

The method of graphs. Tables 5–7 present matrices C, D and P, respectively, obtained by using a new algorithm for directed graph, shown in Fig. 3, which mean the following:

– array C assigns distances of flights;

– array D is the resulting matrix of the shortest distances;

– element of array P[i, v] contains the number of the vertex, preceding vertex v along the shortest path from vertex i.

Table 5 –Matrix C

Indicators	A/p of departures and landings					
A/p of departures and landings	№	1	2	3	4	5
	1	∞	10	∞	30	10
	2	∞	∞	50	∞	∞
	3	70	∞	∞	∞	10
	4	∞	∞	20	∞	∞
	5	∞	∞	∞	60	∞

Table 6 – Matrix D

Indicators	A/p of departures and landings					
A/p of	№	1	2	3	4	5

departures	1	∞	10	50	30	60
	2	12	∞	50	12	60

Table 7 –Matrix P

Indicators	A/p of departures and landings					
	№	1	2	3	4	5
A/p of departures	1	∞	10	∞	30	10
	2	∞	∞	50	∞	∞

Using data from matrix P, it is possible to build the routes of flights from each a/p of departures (1 and 2) to each of the a/p of landings (3, 4 and 5):

$1 \xrightarrow{30} 4 \xrightarrow{20} 3 = 50$ $\quad$ $1 \xrightarrow{30} 4 = 30$ $\quad$ $1 \xrightarrow{30} 4 \xrightarrow{20} 3 \xrightarrow{10} 5 = 60$

$2 \xrightarrow{50} 3 = 50$ $\quad$ $2 \xrightarrow{50} 3 \xrightarrow{10} 5 \xrightarrow{60} 4 = 120$ $\quad$ $2 \xrightarrow{50} 3 \xrightarrow{10} 5 = 60$

The matrix method. Using formula (5), we determine matrices S^2=S+S, S^3=S+S^2 and so on, until the last resulting matrix does not contain any zero (Tables 8, 9).

Table 8 – Matrix S^2

№	1	2	3	4	5
1	0	0	50	160	0
2	120	0	0	0	60
3	0	80	0	70	170
4	90	0	0	0	30
5	0	0	80	0	0

Table 9 – Matrix S^{10}

№	1	2	3	4	5
1	430	310	520	300	370
2	620	470	320	460	560
3	340	580	430	570	280
4	590	440	290	430	530
5	490	340	580	330	430

Elements of matrix S^m_{ij} determine length of the shortest path between vertices V_i and V_j that contains m links (arcs).

In the process of forming matrices S^m, we obtain matrix P whose elements are the quantities of arcs that make up the shortest paths between vertices V_i and V_j of graph G (Table 10).

Upon completion of the formation of all matrices S^m, we define matrix D (Table 11) – the resulting matrix of the shortest paths between vertices V_i and V_j of graph G, whose elements are calculated by formula (6).

In the end, by analyzing the contents of Tables S…S^m, P and D, we build routes for the shortest paths between all vertices V_i and V_j of graph G.

Table 10 – Matrix P

№	1	2	3	4	5
1	3	1	2	1	3
2	2	3	1	3	2
3	1	2	3	2	1
4	2	3	1	3	2
5	3	4	2	1	3

Table 11 – Matrix D

№	1	2	3	4	5
1	120	10	50	30	60
2	120	130	50	120	60
3	70	80	90	70	10
4	90	100	20	90	30
5	150	160	80	60	90

Improvement of the method for maximum flow.

Improvement of the method for maximum flow is conveniently resolved by the method of trees [9, 10]. Let us explore this method on the example of TN with a node–source and a node-runoff (Fig. 4).

It is necessary to find maximum flow from point 1 to point 6.

Let the links of the network experience permissible two–way motion and their throughput capacity in both directions of motion is the same. The entire network is divided arbitrarily into two trees. One is point 1 (source) and the other one is point 6 (runoff). In Fig. 5 one tree consists of four edges 1–2, 1–3, 1–4 and 3–5; the second one is from one vertex 6.

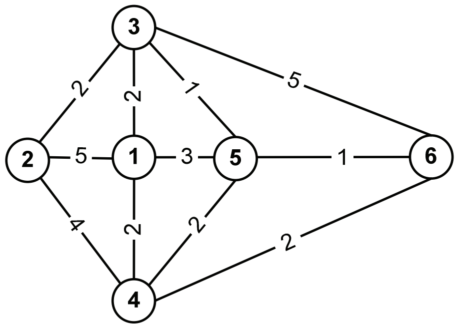
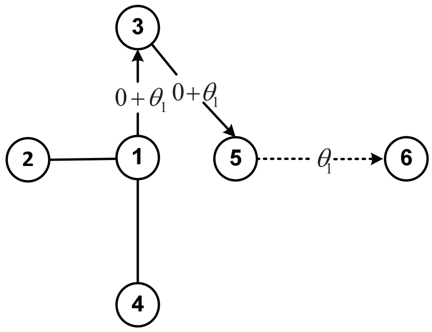


Figure 4 – Transport network with node–source (1) and node–runoff (6)



Figigure 5 – Step 1 of finding maximum flow in TN by the tree method

First, let the flow between vertices 1 and 6 equals zero. Then the trees are connected by arc shown in dotted line 5–6 (Fig. 5). In this regard, from vertex 1 to vertex 6, flow Θ_1 may pass, equal to the minimum throughput capacity of one of the arcs. In Fig. 5, there are 2 links with minimal throughput capacity – 3–5 and 5–6. Let the flow equal to 1 pass along route 1–3–5–6. Next, one of the links (we select, for example, 5–6) is eliminated from the network, and we marking this action with a cross in Fig. 6.

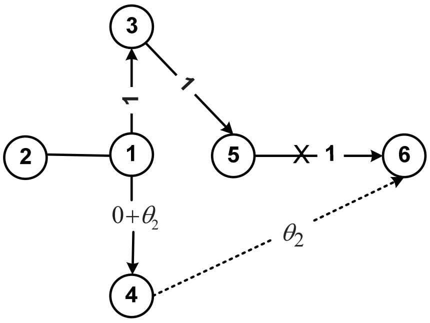


Figure 6 – Step 2 of finding maximum flow in TN by the tree method

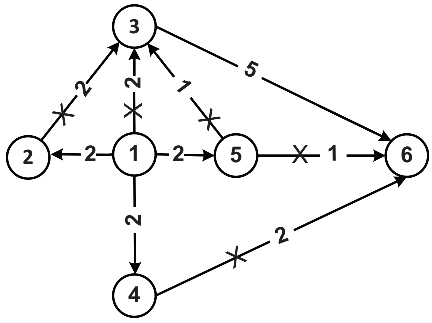


Figure 7 – Step 7 of finding maximum flow in TN by the tree method

The network is again split into two trees. The first one includes vertices 1, 2, 3, 4, 5, and the second one – vertex 6. Let us connect them by link 4–6 (Fig. 6), along which additional flow Θ_2 may pass. Its size, due to the minimal throughput capacity of links of route 1–4–6, is equal to 2. Let this flow pass and then exclude in subsequent transformations link 4–6 from the network.

By continuing the same transformations over TN links, we receive at the last step 7 in Fig. 7 the maximum flow in the network, equal to 8. The crossed out links determine minimum section in the network that separates source (vertex 1) and runoff (vertex 6) and whose throughput capacity equals the maximum flow.

Discussion of results of the research into the impact of indicators of TN on the solution of the problems on maximum flow and the shortest paths in TN.

Improvement of the method for maximum flow is conveniently resolved by the method of trees. The solution can be applied to the problem with multiple sources and runoffs. This will solve problems for the optimization of transportation networks with and without limitations of their throughput capacity.

The improvement of the method for the shortest paths is resolved by using the modified Dijkstra's algorithm. Solving the problem on finding the shortest path, in addition to the value of the shortest distance from a given vertex to all others, we obtain the shortest route, in particular, a list of vertices that it passes. It might be used for imposing flows on the networks. By having matrix of correspondences of freight traffic from each vertex to all others, we build a tree of the shortest paths and then, returning from each point of unloading by the shortest route, we summarize flows at the arcs of the network. Going from one vertex to another vertex, we receive density of traffic in the network without limitation in the throughput capacity. This technique might be used to determine actual density of traffic in the network in the static state.

The improvement of the methods for reducing a network representation of the transport problem to the matrix form is carried out by the more effective modified Dijkstra's method that has algorithmic and software provision of its implementation [12].

Studies we conducted were performed within the framework of implementation of applied work by requests from motor transport enterprises of the Association of International Automobile Carriers of Ukraine. The results might be used to optimize the routes of transportation of cargoes and the optimization of carriers' loading. Further studies may be extended in the direction of optimization of multimodal transportation of goods by different types of transport.

Conclusions.

1. It is proposed to improve the method for maximum flow in the transportation network through the use of the method of trees. The solution can be applied to a problem with multiple sources and runoffs. This will solve the problems on the optimization of transportation networks with and without limitations in throughput capacity.

2. We proposed an improved method for building the shortest paths in a transport network between different sets of vertices on the graph, namely, sets of providers and consumers. The method is implemented in the form of software package that might be used for the transport problems of large dimensionality.

3. We defined a conversion mechanism for the network models of the process of cargo transportation in the matrix model, which are set in the form of directed graphs and which allow the transportation of cargo through intermediate transportation nodes.

ПЕРЕЛІК ПОСИЛАНЬ

1. Прокудін, Г.С. Оптимізація перевезень на дорожньо-транспортної мережі [Текст] / Г.С. Прокудин // Економіка і управління. – К.: ЄУ. – 2006. – №3(4). – С. 54-59.
2. Teodorovic, D. Transportation Systems [Text] / D. Teodorovic, M. Janic // Transportation Engineering. – 2016. – N2. – P. 5-62.
3. Cormen, T. H. Section 26.2: The Ford–Fulkerson method [Text] / T.H. Cormen, C.E. Rivest, R. L. Stein // Introduction to Algorithms (Second ed.). MIT Press and McGraw–Hill. – 2006. – P. 651-664.
4. Knight, H. New algorithm can dramatically streamline solutions to the 'max flow' problem [Text] / H. Knight // MIT News. – 2014. – P. 21-26.
5. Cancela, H. Mathematical programming formulations for transit network design [Text] / H. Cancela, M. Mauttone, E. María // Transportation Research. – Part B: Methodological. –V.77. – 2015. – P. 17-37.
6. Pu C. Information trasport in multiplex networks / C. Pu, S. Li, X. Jian Yang, K. Wang [Text] // Statistical Mechanics and its Applications. – V.477. – 2016. – P. 261-269.
7. Сингх, S. Various Method to Solve the Optimality for the Transportation Problem [Text] / S. Сингх, G. C. Dubey, R. Shrivastava // Statistical Mechanics and its Applications. – V.12. – 2016. – P. 161-169.
8. Wu, J. Topological Effects and Performance Optimization in Transportation Continuous Network Design [Text] / J. Wu, X. Guo, H. Sun, B. Wang // Mathematical Problems in Engineering. – V.2. – 2014. – P. 51-68.
9. Zou, Y. Reachability of higher-order logical control networks via matrix method [Text] / Y. Zou, J. Zhu // Applied Mathematics and Computation. – V.287. – 2016. – P. 50-59.
10. Kavita G. An algorithm for solving a capacitated indefinite quadratic transportation problem with enhanced flow [Text] / G. Kavita // Yugoslav Journal of Operations Research. – V.24. – 2014. – P. 217-236.
11. Прокудін Г.С. Перетворення мережевих моделей процесу вантажних перевезень у матричні моделі [Текст] / Г.С. Прокудін, О.А. Чупайленко, О.С. Дудник, О.Г. Прокудін, Д.М. Омаров // Управління проектами, системний аналіз і логістика. Науковий журнал. Випуск 16. Частина 1. Серія: Технічні науки. – К.: НТУ. – 2016. – С. 125-136.
12. Prokudin G. Improvement of the Methods for Determining Optimal Characteristics of Transportation Networks / G. Prokudin, O. Chupaylenko, O. Dudnik, A. Dudnik, D. Omarov // Eastern-European Journal of Enterprise Technologies. 2016. N. 6/3 (84). P. 54-61. (ISSN 1729-3774, DOI:10.15587/1729-4061.2016.85211).

REFERENCES

1. Prokudin, G. (2006). Optimization of traffic on a road networkin. Economy and management, 3(4), 54 – 59 [in Ukrainian].
2. Teodorovic, D., Janic M. (2016). Transportation Systems. Transportation Engineering, 2, 5–62 [in English].
3. Cormen, T., Rivest, C., Stein, R. (2006). Section 26.2: The Ford–Fulkerson method. Introduction to Algorithms (Second ed.) // MIT Press and McGraw–Hill, 651–664 [in English].
4. Knight, H. (2014). New algorithm can dramatically streamline solutions to the 'max flow' problem. MIT News, 4, 21–26 [in English].

5. Cancela, H., Mauttone, M., Maria, E. (2015). Mathematical programming formulations for transit trasport design. Transportation Research. Methodological, 77, 17–37 [in English].

6. Pu, C., Li, S., Yang, Y., Wang, K. (2016). Information trasport in multiplex networks. Statistical Mechanics and its Applications, 477, 261-269 [in English].

7. Сингх, S., Dubey, G. C., Shrivastava, R. (2016).Various Method to Solve the Optimality for the Transportation Problem. Statistical Mechanics and its Applications, 12, – 2016. – P. 161-169 [in English].

8. Wu, J., Guo, X., Sun, H., Wang, B. (2014). Topological Effects and Performance Optimization in Transportation Continuous Network Design. Mathematical Problems in Engineering, 2, 51-68.

9. Zou, Y., Zhu J. (2016). Reachability of higher-order logical control networks via matrix method. Applied Mathematics and Computation, 287, 50-59 [in English].

10. Kavita G. (2014). An algorithm for solving a capacitated indefinite quadratic transportation problem with enhanced flow. Yugoslav Journal of Operations Research, 24, 217-236 [in English].

11. Prokudin, G., Chupaylenko, A., Dudnik, O., Prokudin, A., Omarov, D. (2016). The conversion process network models of freight transport in the matrix model. Project management, systems analysis and logistics. Science journal, 16 (1), 125 – 136 [in Ukrainian].

12. Prokudin, G., Chupaylenko, A., Dudnik, O., Dudnik, A., Omarov, D. (2016). Improvement of the Methods for Determining Optimal Characteristics of Transportation Networks. Eastern-European Journal of Enterprise Technologies. 6/3 (84), 54-61 [in English].

РЕФЕРАТ

Прокудін Г.С. Методи визначення оптимальних характеристик транспортних мереж / Г.С. Прокудін, О.А. Чупайленко, О.С. Дудник // Вісник Національного транспортного університету. Серія «Технічні науки». Науково-технічний збірник. – К. : НТУ, 2018. – Вип. 1 (40).

Стратегічною метою науково-технічної політики у сфері транспортної системи держави є досягнення світового рівня з точки зору технічних параметрів та якості послуг, які впроваджуються в транспорт. Тому вирішення проблеми створення прогресивних технологій раціональної організації перевезень вантажів є актуальним.

Об'єкт дослідження – характеристики транспортних мереж, на яких здійснюються процеси перевезення вантажів.

Мета роботи – удосконалення методів визначення оптимальних характеристик транспортних мереж, на яких здійснюються процеси перевезення вантажів.

Метод дослідження – аналіз топологічних характеристик графів.

Досліджено процес транспортування вантажів у мережевому представленні з метою удосконалення існуючих методів визначення оптимальних характеристик транспортних мереж. Встановлено вплив показників структури мережі, напряму руху і пропускної здатності транспортних комунікацій на визначення фактичної щільності руху на транспортній мережі в статичному стані. Визначено механізм перетворення мережевих моделей процесу вантажних перевезень у матричні моделі, які задаються у вигляді орієнтованих графів і допускають перевезення вантажу через проміжні транспортні вузли.

Розроблено удосконалений метод підходу до розрахунку максимального потоку, який полягає у використанні метода дерев і можливостей табличних процесорів. Розв'язання можна поширити і на задачу з кількома джерелами і стоками. Це дозволить вирішити задачі для оптимізації транспортних мереж з обмеженням та без обмежень пропускної здатності.

Розроблено удосконалений метод по розрахунку найкоротших шляхів, який вирішено за допомогою використання алгоритмів Мінті і Дейкстри. Розв'язуючи задачу знаходження найкоротшого шляху, одержуємо найкоротший маршрут і перелік вершин, через які він проходить. Маючи показники вантажопотоків від кожної вершини до всіх інших, будуємо дерево найкоротших шляхів. Переходячи від вершини до вершини, одержуємо густоту руху на мережі без обмеження пропускної здатності.

Ключові слова: транспортна мережа, максимальний транспортний потік, найкоротші шляхи, матрична модель.

ABSTRACT

Prokudin G.S., Chupaylenko O.A., Dudnik O.S. Methods for determining optimal characteristics of transportation networks. Visnyk National Transport University. Series «Technical sciences». Scientific and Technical Collection. – Kyiv: National Transport University, 2018. – Issue 1 (40).

The strategic objective of scientific–technical policy in the field of transportation system of the state is achieving the world level in terms of technical parameters and services quality that are implemented in transport. Therefore, solving the problem of creating advanced technologies for the rational organization of cargo transportation is relevant.

Object of the study – the characteristics of the transport networks on which the processes of cargo transportation are carried out.

Purpose of the study – to improve the methods of determining the optimal characteristics of the transport networks in which the processes of cargo transportation are carried out.

Method of the study –analysis of topological characteristics of graphs.

The process of cargo transportation in the network representation was studied with the aim of improving the existing methods of determining the optimal characteristics of transport networks. Influence of indicators of network structure, direction of movement and throughput of transport communications on determination of actual traffic density on the transport network in static state is established. The mechanism of transformation of network models of the cargo transportation process into matrix models, which are specified in the form of oriented graphs and allows the transportation of cargo through intermediate transport nodes, is determined.

An improved approach to calculating the maximum flow is developed, which is to use the tree method and the capabilities of the table processors. The solution can be extended to a task with several sources and flows. This will solve the problems for optimizing transport networks with restrictions and without bandwidth constraints.

An improved method for calculating the shortest path was developed, which was solved using the Minty and Dyckstream algorithms. By solving the problem of finding the shortest path, we get the shortest route and the list of vertices through which it passes. With the traffic flow rates from every vertex to all others, we build the tree of the shortest paths. Moving from top to peak, we get traffic density on the network without limiting bandwidth.

KEYWORDS: TRANSPORT NETWORK, MAXIMUM TRANSPORT FLOW, SHORTEST PATHS, MATRIX MODEL.

РЕФЕРАТ

Прокудин Г.С. Методы определения оптимальных характеристик транспортных сетей / Г.С. Прокудин, А.А. Чупайленко, А.С. Дудник // Вестник Национального транспортного университета. Серия «Технические науки». Научно-технический сборник. – К.: НТУ, 2018. – Вып. 1 (40).

Стратегической целью научно-технической политики в сфере транспортной системы государства является достижение мирового уровня с точки зрения технических параметров и качества услуг, внедряются в транспорт. Поэтому решение проблемы создания прогрессивных технологий рациональной организации перевозок грузов является актуальным.

Объект исследования – характеристики транспортных сетей, на которых осуществляются процессы перевозки грузов.

Цель работы – совершенствование методов определения оптимальных характеристик транспортных сетей, на которых осуществляются процессы перевозки грузов.

Метод исследования – анализ топологических характеристик графов.

Исследован процесс транспортировки грузов в сетевом представлении с целью усовершенствования существующих методов определения оптимальных характеристик транспортных сетей. Установлено влияние показателей структуры сети, направления движения и пропускной способности транспортных коммуникаций на определение фактической плотности движения на транспортной сети в статическом состоянии. Определен механизм преобразования сетевых моделей процесса грузовых перевозок в матричные модели, которые задаются в виде ориентированных графов и допускают перевозку груза через промежуточные транспортные узлы.

Разработан усовершенствованный метод подхода к расчету максимального потока, который заключается в использовании метода деревьев и возможностей табличных процессоров. Решение можно распространить и на задачу с несколькими источниками и стоками. Это позволит решить задачи для оптимизации транспортных сетей с ограничением и без ограничений пропускной способности.

Разработан усовершенствованный метод по расчету найкоротших путей, который решено с помощью использования алгоритмов Минти и Дейкстры. Решая задачу нахождения кратчайшего пути, получаем кратчайший маршрут и перечень вершин, через которые он проходит. Имея

показатели грузопотоков от каждой вершины до всех остальных, строим дерево кратчайших путей. Переходя от вершины к вершине, получаем плотность движения на сети без ограничения пропускной способности.

КЛЮЧЕВЫЕ СЛОВА: ТРАНСПОРТНАЯ СЕТЬ, МАКСИМАЛЬНЫЙ ТРАНСПОРТНЫЙ ПОТОК, КРАТЧАЙШИЕ ПУТИ, МАТРИЧНАЯ МОДЕЛЬ.

АВТОРИ:

Прокудін Гергій Семенович, доктор технічних наук, професор, Національний транспортний університет, завідувач кафедри міжнародних перевезень та митного контролю, e-mail: p_g_s@ukr.net, тел. +380633270243, Україна, 01010, м. Київ, вул. М. Омеляновича-Павленка, 1, к. 430-А, orcid.org/0000-0001-9701-8511.

Чупайленко Олексій Андрійович, кандидат технічних наук, доцент, Національний транспортний університет, доцент кафедри міжнародних перевезень та митного контролю, e-mail: snegirevskyalexey@gmail.com, тел. +380975052559, Україна, 01010, м. Київ, вул. М. Омеляновича-Павленка, 1, к. 437, orcid.org/0000-0002-2004-0355.

Дудник Олексій Сергійович, кандидат технічних наук, Національний транспортний університет, Київ, Україна, доцент кафедри міжнародних перевезень та митного контролю, e-mail: alex_ds@ukr.net, тел. +380674662533, Україна, 01010, м. Київ, вул. М. Омеляновича-Павленка, 1, к. 437, orcid.org/0000-0002-1980-7168.

AUTHOR:

Prokudin Georgii S., doctor of technical sciences, professor, National Transport University, head of department international transportation and customs control, e-mail: p_g_s@ukr.net, tel. +380633270243, Ukraine, 01010, Kyiv, M. Omelyanovicha-Pavlenko str. 1, of. 430-A, orcid.org/0000-0001-9701-8511.

Chupaylenko Olexii A., PhD, associate professor, National Transport University, associate professor department international transportation and customs control, e-mail: snegirevskyalexey@gmail.com, tel. +380975052559, Ukraine, 01010, Kyiv, M. Omelyanovicha-Pavlenko str. 1, of. 437, orcid.org/0000-0002-2004-0355.

Dudnik Olexii S., PhD, National Transport University, associate professor department international transportation and customs control, e-mail: alex_ds@ukr.net, tel. +380674662533, Ukraine, 01010, Kyiv, M. Omelyanovicha-Pavlenko str. 1, of. 437, orcid.org/0000-0002-1980-7168.

АВТОРЫ:

Прокудин Георгий Семенович, доктор технических наук, профессор, Национальный транспортный университет, заведующий кафедрой международных перевозок и таможенного контроля, e-mail: p_g_s@ukr.net, тел. +380633270243, Украина, 01010, г.. Киев, ул. М. Емельяновича-Павленко, 1, к. 430-А, orcid.org/0000-0001-9701-8511.

Чупайленко Алексей Андреевич, кандидат технических наук, доцент, Национальный транспортный университет, доцент кафедры международных перевозок и таможенного контроля, e-mail: snegirevskyalexey@gmail.com, тел. +380975052559, Украина, 01010, г.. Киев, ул. М. Емельяновича-Павленко, 1, к. 437, orcid.org/0000-0002-2004-0355.

Дудник Алексей Сергеевич, кандидат технических наук, Национальный транспортный университет, Киев, Украина, доцент кафедры международных перевозок и таможенного контроля, e-mail: alex_ds@ukr.net, тел. +380674662533, Украина, 01010, г.. Киев, ул. М. Емельяновича-Павленко, 1, к. 437, orcid.org/0000-0002-1980-7168.

РЕЦЕНЗЕНТИ:

Поліщук В.П., доктор технічних наук, професор, Національний транспортний університет, завідувач кафедри транспортних систем та безпеки дорожнього руху, Київ, Україна.

Стасюк О.І., доктор технічних наук, професор, Державний економіко-технологічний університет транспорту, завідувач кафедри автоматизації та комп'ютерно-інтегрованих технологій транспорту, Київ, Україна.

REVIEWER:

Polishchuk V.P., doctor of technical sciences, professor, National Transport University, Head of the Department of Transport Systems and Road Safety, Kyiv, Ukraine.

Stasyuk O.I., doctor of technical sciences, professor, State Economics and Technology University of Transport, Head of the Department of Automation and Computer Integrated Transport Technologies, Kyiv, Ukraine.