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MODELING OF TRANSPORT SYSTEMS. STREAMS IN AD NETWORKS

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Annotation
One of the main applications of networks is modeling transport systems that people, cars, ships move through, transport cargo, liquid products, etc. In these models, points where the flow of transported items changes – localities, stations, branch points, or mergers – are marked with vertexes.

Keywords
transport system; models; general algorithms; network models ; algorithm; mechanical losses.

Introduction. Those parts of the system where the actual spatial movement of

objects takes place (sections of pipelines, power lines, roads, channels) are represented by weighted oriented edges (arcs). Weight means the maximum capacity of a given section of the system.

Graph models of transport systems usually consider two poles: source v_{and}(input

vertex that has no incoming arcs, but only outgoing ones) anddrain v_c(output vertex that has only incoming arcs). All other vertexes areinternal. Both incoming and outgoing arcs are incident to them. We denote the set of incoming arcs of an internal vertexv$i_i$by$D^+(Vi_i)$, and the set of outgoing arcs by$D^+(Vi_i)$.

A graph model of a transport system can be represented as a weighted oriented two-pole network R =({$v_и$ i, v_c}, V, X, D), in which the weights of arcs are given by a matrix of weightsD. Figure 1.15 shows a graph network model of the simplest transport network. Weights are placed directly on the arcs of the network.

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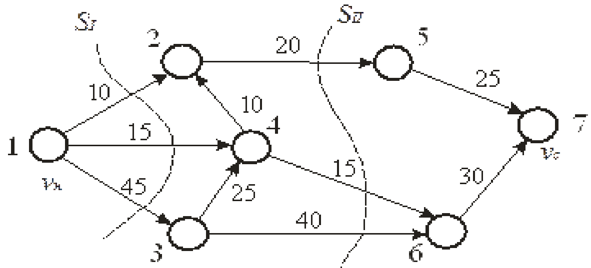

Fig. 1. 15. Network model of the transport system

For network models of transport systems, special concepts are introduced that characterize their capacity.

Relevance of the topic. A non-negative map j defined on the set of arcs of the network is calleda flowif it satisfies two conditions:

1) for each arc of the networkx= (VVi, Vj,vj):j(x)=j $_{ij}$=j$_{ij}$=j (VVi, Vj) £,vj) £$_{dij}$,

2) for each internal vertexof the network$_{vi}$:

$$\sum_{x \in D^{+}(V_i)} \varphi(x) = \sum_{x \in D^{-}(V_i)} \varphi(x),$$

3) for source v$_{and}$ and network drainv$_{with..}$:

$$\sum_{x \in D^{-}(v_u)} \varphi(x) = \sum_{x \in D^{+}(v_c)} \varphi(x) = A,$$

whereAis the amount of product supplied through the source to the network and coming

out of its drain, calledthe total flow to the setand(flow in the network). Its maximum possible value is abbreviated asthe maximum flow in the network [1,2,3].

Physically, flow usually means the amount of product transferred over a dedicated section of the transport system per unit time. The first condition expresses the limited capacity of the considered section. The second is the continuity of the flow in the internal vertices, the transmitted product does not appear or disappear in them. The third means that there are no losses and additives of the product when it is transmitted over the network as a whole as soon as the product enters the source, the same amount is removed from the drain.

Definition. If for the network arcx= (V_i, V_j)if the condition$_{ij}$=j$_{ij}$is satisfied, then this arc is calledsaturated. Ifthe condition$_{dij}$>$_{ij}$jij is met, then the arc is calledunsaturated, andthe value ($_{dij}$-$_{jij}$) iscalled the residual capacity of the arc.

To estimate the flow in the network, the concept of a section is used.

Definition. The set of arcs of a network whose removal breaks all the chains in it in such a way that the beginnings of all arcs lie in one part of the network, and the ends – in another, is calleda cut [4,5]. You can specify a section by listing the arcs {($_i$ViV$_j$, vj)} that form it. Denote the section byS{($_i$ViV$_j$, vj)}.Bandwidth P(S{(V$_i$, V$_j$)})of a section S{($_i$ViV$_j$, VJ)} is called the sum of the throughput capacities of the arcs{($_i$ViV$_j$, VJ)} forming it:

$$P(S\{(V_i, V_j)\}) = \sum_{x \in D^{+}(V_i)} d(x).$$

A section with minimal throughput is called minimal.

In the network model of the transport system, Fig. 1. 15. shows the sections marked$S_I$andS_{II}. As the picture shows,

PPS(Si) =P({(V_{V1},$_{V2}$);(V_{V1},$_{V3}$);(V_{V1},$_{V4}$)}) = 10 +15 + 45 = 70,

P(S_{II}) =P({(V_2, V_5);(V_3, V_6);(V_4, V_6)}) = 20 + 40 +15 = 75.

Connection of the maximum flow in the network with cross sections sets

Ford – Fulkerson theorem 1.2.. In any weighted oriented two-pole network, R =({$v_и$ i, v_c}, V, X, D), the maximum flow in the network is equal to the capacity of its minimum section.

Let's consider the properties of flows in networks that are used when constructing general algorithms for determining the maximum flow in a network. LetMbe an arbitrary route in the network from the source to the sink, consisting of vertices ($v_и$i , V_{i1}, V_{i2},..., V_{ik}, $v_c$vc). Obviously, its throughput is equal to the minimum of the weights of arcs that make up the route:

A(M)= min{$d_{иi, i1}$, $d_{i1, i2}$,..., $d_{ik,c}$}.

If you subtract this limit flowA(M) from the total network capacity, then all arcs (V_i, V_j)

entering the routeMwill have a residual capacity (d_{ij}-A(M)). In this case, arcs with zero residual bandwidth (d_{ij}-A(M)=0)can be excluded from the network, since their bandwidth is fully used[6,7,8].

Example 1. Find the maximum flowA(M1$_1$) inthe route$_{M1}$=($v_и$v and=V1,$_1$, V_{V2},$_5$,v_c=$V_{V5,\ vc=V7}$) of the network in Fig.1.15 and determine the residual throughputof arcs$_{M1}$after subtractingA(M_{M1}).

Decision. The maximum throughputof $M_1$is equal to:

A(M_1) = min {d_{12}, d_{25}, d_{57}}= min {10, 20, 25}=10.

If we take into account the flow ofA(M_{M1})=10 over the network as a whole, the arcs included inM_{M1}must be assigned new (residual) throughput:

d_{12}¢= d_{12} - 10 = 0, d_{25}¢= d_{25} - 10 = 10, d_{57}¢= d_{57} - 10 = 15.

In this case, the arc (V_{V1},$_{V2}$) with zero residual bandwidth can be excluded from the general network.

Answer: A(M_{M1})=10.d_{12}¢=0, d_{25}¢=10, d_{57}¢=15.

This property is the basis of all algorithms for calculating the maximum flow. Consider its simplest version.

STEP 1. Initial assignments. Current valueAnd$_t$of the maximum flow in the network is set to 0.STEP 2. Select independent routes in the network and define flows in them. From the entire set of possible routes in the network from source to drain, we choose independent routesM_{m1},...,$M_k$mk that have no common vertices, except for the initial (sourcev_{and}) and final (drainv_{with}) [13,14,15]. For each selected routeM_i(1£i£k), we determine the maximum flowA(M_i). STEP 3. Correction of the current value of the maximum flow in the network. We addШАГе 2the values of the maximum flows found in step 2 in the independent routesM_{M1},...,M_{mk} $_{to}$the current total maximum flow in the network: A_t:= A_t+ A(M1$_1$)+ A(M_{M2})+...+ A(M_kMk).STEP 4. Network correction. Найденные на ШАГе 2The maximum flowsA(($_{M1}$), ... ,and A(Mk) found in step 2($M_k$are subtracted from the throughput of the corresponding network arcs. Arcs with zero residual throughput are removed.WAG 5. Checking that the algorithm is finished. If, after correction, there are no routes left in the network from the source$v_{and}$to the drainv_c, then the maximum flow in the network is equal to the currentA found:= A_t, the algorithm terminates its work, since all network bandwidth is exhausted. If the corrected network has routes from sourcev_{and}drainv_{with}, then go toSTEP 2and continue running the algorithm[9].

Example 2. Find the maximum network flow in Fig.1.15 using this algorithm. Decision.WAG 1. Initial assignments. And$_t$: = 0.

I iteration. step 2. Select independent routes in the network and define flows in

them. AsM1$_1$, let's take the route ($v_и$=V_1, V_2i=V1, V2, V_5, $v_{vc=V}$=V_7) considered in Example 1. For it, A(M_{M1}) = 10.

It is also easy to selectM_1 маршрут the route$_{M2}$= ($v_и$v and=$_{V1,V3,V6}$,vc=V7) independent of

M1$_c$=V_7. Let's calculate the maximum throughput for it and adjust the throughput of arcs: A(M_{M2})= min{d_{13}, d_{36}, d_{67}}= min{45, 40, 30}=30.d_{13}¢= d_{13-30}= 15, d_{36}¢= d_{36} 36-30 = 10, d_{67}¢= d_{67} 67-30 = 0.

STEP 3. Correction of the current value of the maximum flow in the network. A_t:= A_t+ A(M_1)+ A(M_2)=0 + 10+ 30 = 40.STEP 4. Network correction. Найденные на ШАГе 2The maximum flowsA(M_1)andA(M_2) found in step 2in the routesM_{M1},$M_{M2}$are subtracted from the throughput of their arcs. Arcs with zero residual throughput are removed. The result is shown in Fig.1.16 a.

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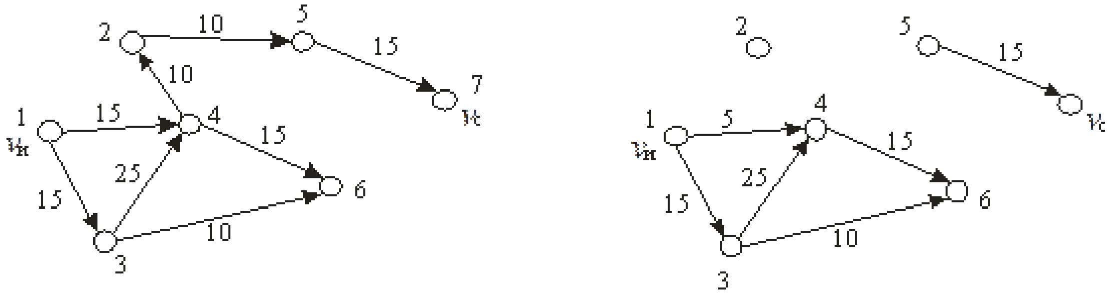

a) b)

Fig. 1. 16. Result of network correction after iterationsIandIISTEP

Checking that the algorithm is finished. In the corrected network (Fig.1.16 a), there are routes from the source$v_{and}$to the drainv_cv with, for example,$_{M3}$= (v_v $_{and}$=V1,$_1$, V$_{V4}$,$_{V2}$,$_5$, v_c=V$_{V5,\ vc=V7}$). Continuation of the algorithm execution[10,11,12].

Iteration II. step 2. As the only independent route, we take$_{M3}$= ($v_и$v and=$_{V1}$,$_{V4}$,$_{V2}$,$_{V5}$, v_c=V$_{vc=V7}$). For him:

A(M_{M3})= min{d_{14}, d_{42}, d_{25}, d_{57}}= min{15, 10, 10, 15}=10.

d_{14}¢= d_{14} - 10 = 5, d_{42}¢= d_{42} - 10 = 0, d_{25}¢= d_{25} - 10 = 0, d_{57}¢= d_{57} - 10 = 5.

STEP 3. A_t:= A_t+ A(M_{M3}) = 40 + 10=50.

STEP 4. Network correction. The maximum flowA(M_{M3}) is subtracted from the arcs of the routeM_{13}. The result is shown in Fig.1.16 b.

STEP 5. There are no routes left in the corrected network from sourcesav runoff. A:= A_t:=50, algorithm shutdown.Abouttvet: The maximum network flow is shown in Fig.1.15 equals 50 [16,17,18].

If the network has severalsources, it is completed by introducing a new common source, which is connected to the original sources by arcs that have unlimited bandwidth. Then the problem is solved using the usual algorithm. The required flows through the source sources will be flows along the newly added arcs that are included in them from the new common source. They do the same if there are several drains in the network.

Conclusion.

Network planning Any task of designing or constructing a rather complex object (project) can be divided into a number of smaller component steps. The timing of the entire project depends on the correct sequence of these steps.

The entire set of actions for project implementation is presented as a setof eventsandworks. Events are defined as individual project stages. Works are the process of performing them[19]. The whole complex of events and works required for the project implementation can be represented as a two-pole networkR =({$v_{и}$ i , v_{z}}, V, X), in which:

a) alleventsare indicated by a set of verticesV.Among them, theinitial event $v_{и}$i (start of work) andthe final event v_{h}(completion of the entire project) are highlighted. Internal network vertices defineintermediate events— stages that need to be completed in the project implementation process.

b) allworksare indicated by arcs connecting pairs of vertex events.

A graphical representation of a given network is calleda network graph. To indicate the sequence of actions, fictitious work is also introduced into the network schedulwhich is not related to the performance of any actions. The corresponding works are marked with dashed arcs [20].

As an example, consider the organization of a certain production. The project requires performing the following tasks:

I) marketing research, II) pre-project research on equipment, III) organization of a sales network, IV) conducting an advertising campaign, V) development of technical specifications for production equipment, VI) development of technical documentation for production facilities and communications, VII) purchase of standard equipment, VIII) design and manufacture of non-standard equipment, IX)construction of production facilities and installation of communications, X) installation of standard equipment, XI) installation of non-standard equipment, XII)commissioning.

We will denote these works in the network graph by arcs with corresponding numbers.

Events in this project will include the following:

- start of work (initial event),
- completion of marketing research,
- completion of pre-project research,
- organization of a sales network,
- organization of an advertising campaign,
- preparation of a technical task for production equipment,
- completion of the development of technical documentation for production facilities and communications,
- completion of the purchase of standard equipment,
- completion of design and manufacture of non-standard equipment,
- completion of construction of production facilities and installation of communications,
- completion of equipment installation and commissioning,

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➢ project completion (final event).

We map vertexes to events with corresponding numbers. The network schedule for the project is shown in Figure 1.17:

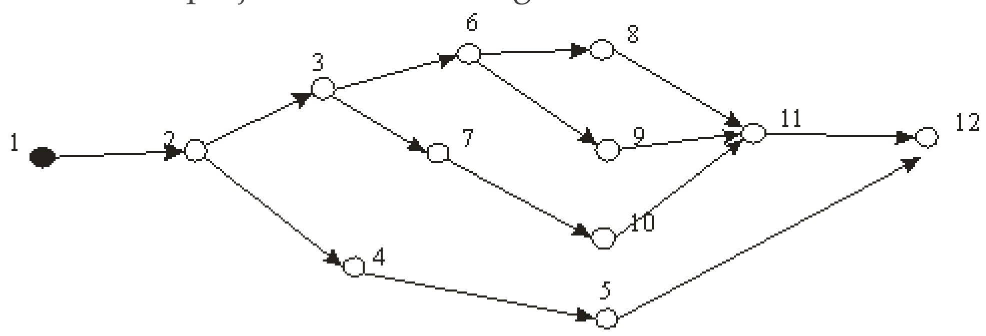

Figure 1. 17. Network schedule of project execution

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