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ORGANIZATION OF TRANSPORT OF PARCEL CARGOES

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INTRODUCTION

One of the most difficult problems in organization of transport is the question of transporting of parcel cargoes. In order to explain this question we shall first have to define what we mean by the notion of "parcel cargoes".

In order to do this we first introduce the notion of "one-time cargo". It shall be assumed that this notion denotes a cargo which cannot be divided into smaller parts and which is determined through one and only one couple of names: the name of the sender and the name of the recipient. Such a "one-time cargo" is sometimes called consignment or shipment. It is obvious, for instance, that the notion of one-time cargo cannot be applied to dry loose goods. It can be applied, on the other hand, to commodities transported in packages: parcels, pallets, cases, containers, barrels, sacks etc. One-time cargo has, obviously, its volume, mass, dimensions etc., hence it is defined also by its magnitude, similarly as transport units have their proper carrying capacity, defined by their lifting capacity, draught, volume capacity and so on.

Parcel cargo is the cargo whose magnitude is much smaller than the carrying capacity of a transport unit, which is to carry this cargo. This definition is, however, insufficient. We must, namely, exclude here mass transport of parcel cargoes from the same sender to the same recipient. Thus, for instance, the question of transporting of thousands of parcels between two partners, with the carrying capacity of the transport means of the order of several or tens of parcels shall not be treated as the problem of transport of parcel cargoes, but as the problem of transport of mass cargoes.

The following questions can be treated as the ones contained in the definition of transport of parcel cargoes:

- the problem of mail transport (letters, parcels, sacks etc.) with cars, wagons, airplanes etc.,
- the problem of railway transport of small cargoes (i.e. the ones which take only a small portion of a train),
- the problem of sea transport of small cargoes,
- the problem of sea transport of container cargoes,
- the question of dispatching consumption goods to retail trade

shops,

- the question of collecting of packages, mail etc.

and a number of other problems, similar in their nature.

It is characteristic for the technology of transporting of parcel cargoes to perform the operation of grouping of loads so as to form greater "portions", equal to the capacity of a transport unit. This operation is called differently for various branches of transport.

Thus, for instance, in railway transport, in case of loads which do not fill whole trains the operation of marshalling the train sets (compositions) is performed, consisting in grouping of cars having the same destination direction to form the train compositions. These compositions (train sets) are being changed in marshalling stations, which are special kinds of stations, distinct from loading stations, in which sending and receiving of loads takes place.

In car transport of parcel cargoes the operation of completion of shipments in warehauses and change of loads in special facilities takes place. Analogous problem appears in air transport.

This problem appears much more distinctly in sea transport of small freight. The operation of grouping of loads takes place in the port. In doing this of special importance is the question of adequate spatial location of loads in the hold (the problem of stowing), so that the necessity would not arise of pulling the loads from under the other ones when they have to be unloaded.

A similar problem is "completion" of the load of newspapers for cars dispatching the press to newsstands. Depending upon the choice of these loads the transport of the newspapers (to all newsstands by all cars) will cost less or more.

The attentive Reader shall certainly notice that the latter problem can be reversed, namely: to determine the car routes from which, simultaneously, the principles of load completion shall result.

In transporting of mail we are dealing with the problem of "sorting" of posted mail shipments. This is also the operation of grouping of loads.

It is not difficult to notice that the grouping operation occurs also in an entirely different kind of transport, and namely in the telecommunication systems for transmission of messages. This can best be seen in the case of organization of sending of cables.

We shall be interested in the problem of transporting the parcel cargoes from the point of view of organization of shipment, that is - the manner of putting together and moving of transport units (trains, cars, ships etc.) under given transport needs (demands, for we do not take into account the market side of the problem). In further considerations we shall therefore not be dealing with the details of transport technology, but shall limit ourselves to moving of the given transport means, in such a way as to satisfy the demands put on transport with a possibly low cost. Similarly, we shall not be interested by the road network, assuming that it is given, together with the adequate warehouse infrastructure, loading/unloading capacities and the like.

In order, however, for a Reader to better grasp the essence of the problem of grouping of loads we shall describe it through the example of transporting of parcel cargoes through railway transport.

Assume, therefore, that the railroad network is given. The vertices (nodes) of the network are railway stations (marshalling or loading stations), while edges - railway lines connecting the edges. Every marshalling station has its ascribed "region" - set of "subordinate" loading stations.

Within the "region" or "district" the so called "collect trains" are being organized, which bring down from the loading stations the cars which are loaded or empty to the marshalling stations or bring from the marshalling station to the loading stations loaded or empty cars.

Between the marshalling stations only trains of definite length are moving, composed of, say, several tens of cars.

In the marshalling stations train compositions are being changed. Incoming compositions are divided and new ones are being put together out of car groups.

Such an organization of transport is the result of many years of experience in the practice of solving the following problem:

We are given a definite road network (railway, car, airplane, sea etc.) and definite transport units of predefined capacity. Likewise, we are given periodical transport demand defined for instance for daily periods. These demands, or needs, are defined as the magnitudes of loads which have to be brought from given vertices to other vertices. Load magnitudes are many times smaller than the capacity of transport units.

In such a situation two extreme kinds of solutions to this problem appear.

The first one would consist in putting in every vertex the number of transport units equal to the number of potential addressees of the loads. In the extreme case, when transport needs account for shipments between all pairs of vertices, then there would have to be in every vertex the number of transport units equal to the number of all vertices minus one. Then, transport units (each labeled with its destination) should be left in their vertices of origin until they are filled completely with shipments. Then, these transport units would bring the loads in accordance with their vertex labels, along the shortest routes, of course.

The second extreme solution would consist in sending a shipment from a vertex immediately after this shipment appears in the vertex, irrespective of the fact that the transport units may be dispatched even almost empty.

A Reader will notice with ease that both these extreme solutions are not satisfactory.

In the first case we need an enormous amount of transport means, although we spare a lot in travelling. In the second case we lose a lot out on travelling, forcing transportation of empty units.

Practice, therefore, dictated a compromise solution, such as we observe, for instance, in the described organization of railway transport of small freight. This solution is the result of recognition of the fact that both keeping of a too great number of transport units costs ("frozen assets") and too much travelling of these units costs as well (in fuel and road use).

Still, the compromise solution described has a certain disadvantage. A new, additional operation of load grouping appears, which costs as well, for it is related, generally speaking, with loading, and in the case of the railroad example described - with the marshalling activities (division of the train sets, rolling and coupling). In this case, therefore, the summary translocation of loads in time and space is the result of addition of consecutive stages of translocation, of which every one is caused by moving of another transport unit.

Thus, in transport of parcel cargoes there is a separation of the movements of loads and the movements of transport units. The movement of loads should comply with the requirements set by the transport demands (vertices of sending and receipt), but it results from the movements of transport units. The movement of transport units, together with definition of loading (regrouping, marshalling) locations constitutes the decision variable. This decision variable is constrained by the direct limitations related to capacities of tansport units and to road network, and by the indirect limitations, concerning the load transport requirements.

Summing up, we can say that we are looking for the schedule of movement of transport units together with the schedule of loadings (marshalling - in the case of railway transport), and the criterion of evaluation of the quality of the schedule is the total cost of carrying out the transport task.

It should be emphasized here that in many transport systems two kinds of transport units appear: the active and the passive ones. Passive transport units fulfill the role of freight packaging, their only characteristic is load capacity. These are, for instance, freight cars, trailers, barges, containers etc.

The active transport units are, for instance: locomotives, tractors, tugboats etc.

Consequently, the time and space schedule of the movement of transport units shall be composed in such a case of the schedule for the passive units and the schedule for the active units. The first of these schedules is bound to satisfy the transport requirements, while the second - to provide for satisfaction of the first schedule.

Thus, for instance, for the railway transport of containers we would have the following three schedules:

- of the movement and loading of containers (full and empty),
- of the movement of cars (loaded and empty) and marshalling of the train sets, and
- of the movement of locomotives.

For the complete description of organization of transport one would have yet to include the schedules of work of train teams, engine-drivers and marshalling yard employees.

In further course of the book we shall limit ourselves to the case of determination of the schedules of movement of active and passive units. We shall be analysing this problem further on on the example of railway transport, turning attention especially to the schedules of freight cars and train sets.

For the sake of simplicity of problem consideration we shall be looking for the schedules of regular shipments, i.e. those which provide for satisfaction of cyclically recurring transport needs. Besides this, transport needs may be divided into fixed-time and open-time ones.

Let us explain: the fixed-time shipments are those, for which the instance of sending or the instance of receiving, or both, are precisely determined. In contradistinction, the open-time shipments should take place within a given time period, usually within the period of repetition of transport needs (in regular shipments).

Another simplification shall therefore consist in consideration of uniquely open-time shipments.

3. THE PROBLEM OF CONCENTRATION OF SHIPMENTS

3.1. Formulation of the problem

We are given a graph $\Gamma = (I,R)$ of the marshalling point network, in which I is the set of vertices - marshalling stations, and R is the set of branches (i,j), $i,j \in I$, corresponding to the fact of existence of a railway line connecting vertex i with vertex j. On the network defined by this graph we are given the transport demand for empty and full courses of transport means $A_{ij}>0$ for $(i,j)\in R$. Following functions are defined on the set R:

distances d_{ij} and

capacities μ_{ij}, $(i,j)\in R$,

while on the set I -

$P_i>0$ - the function of work performance capacity of a marshalling station.

It is our task to determine the transport routes in the network which would be possibly short and possibly shipment concentrating.

The route M_{kl} of transport from station k to station l, with $k,l\in I$, is the ~~set of the~~ form

$$M_{kl} = \{(i_1,j_1),(i_2,j_2),\ldots,(i_N,j_N)\}$$

such that:

1. $(i_n,j_n)\in R$ for every $n = 1,2,\ldots,N$

2. $i_1 = k$, $j_N = l$

3. $j_n = i_{n+1}$ for every $n = 1,2,\ldots,N-1$

4. pairs (i_n,j_n) do not form internal loops.

The routes of train sets are decision quantities, defined by the sequence of variables:

$$x_{ij}^{kl} = \begin{cases} 1, \text{ if } (i,j)\in M_{kl} \\ 0, \text{ in the opposite case} \end{cases} \qquad (1)$$

We denote by M_{kl}^{min} the route of minimum length, D_{kl}^{min}, and call it minimum route.

Still, the minimum routes are not the solution we are looking for.

In many cases we treat as better such a solution for which the routes determined overlap at least partly (have common edges). This results from the fact that greater flows of loads make it possible to ensure more frequent transports of full transport units, which consequently leads to faster delivery of shipments, better utilization of transport units - and therefore lower cost of transport, provided, of course, that the difference between the length of the route M_{kl} determined as the component of the solution and the length of the shortest route connecting vertices k,l is not too big.

In order to force the solutions which concentrate shipments we shall introduce the following criterion function:

$$F = \sum_{(k,l)\in A} \sum_{(i,j)\in R} X_{ij}^{kl}\cdot\Lambda_{kl}\cdot d_{ij} - \alpha\sum_{(i,j)} \Phi(v_{ij})^2\cdot d_{ij} \qquad (2)$$

where:

$$v_{ij} = \sum_{(k,l)\in A} X_{ij}^{kl}$$

$$\Phi(v_{ij}) = \begin{cases} v_{ij}, & \text{if } v_{ij}>1 \\ 0 & \text{in the opposite case} \end{cases}$$

and

$$A = \{(i,j):\ i,j\in I,\ \Lambda_{ij}>0\}$$

The first component of the objective function F represents the sum of products of transport distances and loads, while the second is meant to force the preference of these solutions, for which the routes determined overlap on the possibly the greatest number of segments.

Note, then, that the average number Z_{ij} of compositions of transport units in a time unit over the relation (i,j) is defined by the formula:

$$Z_{ij} = \frac{1}{N_{ij}} \sum_{(k,l)\in A} X_{ij}^{kl}\cdot\Lambda_{kl}$$

where N_{ij} denotes the desired length of the train set on the segment (i,j) of the network. Thus, variables X_{ij}^{kl} have to satisfy the following constraints:

$$\frac{1}{N_{ij}} \sum_{(k,l)\in A} X_{ij}^{kl}\Lambda_{kl} \le \mu_{ij} \qquad (3)$$

which result from the limited capacity of transport routes. Since the number of compositions of transport units which are put together and disassembled at the transport node i is equal

$$\sum_{i\in V_h} \frac{1}{N_{ij}} \cdot \sum_{(k,l)\in A} X_{ij}^{kl}\Lambda_{kl} + \sum_{j\in V^h} \frac{1}{N_{ij}} \cdot \sum_{(k,l)\in A} X_{ij}^{kl}\Lambda_{kl}$$

where

$$V_h = \{i: \sum_{(k,l)\in A} X_{ih}^{kl} > 0\}$$

$$V^h = \{j: \sum_{(k,l)\in A} X_{hj}^{kl} > 0\}$$

then, in view of the limited capacity as to the assembling and disassembling of compositions of transport units at a node, the variables X_{ij}^{kl} have to satisfy also the constraints

$$\sum_{i\in V_h} \frac{1}{N_{ij}} \sum_{(k,l)\in A} X_{ij}^{kl}\Lambda_{kl} + \sum_{j\in V^h} \frac{1}{N_{ij}} \sum_{(k,l)\in A} X_{ij}^{kl}\Lambda_{kl} \le P_i \qquad (4)$$

Thus, solution to the problem (2) taken together with constraints (1), (3) and (4) determines the optimum concentration of shipments.

3.2. Description of the algorithm and the program

The nonlinear objective function of the form (2) causes that when solving the problem we are not able of making use of known methods. In this situation a heuristic algorithm was proposed allowing for a relatively simple finding of the feasible solutions.

In the essential step, for the determined parameter of the problem, the routes M_{kl} are defined for the sending point k and the destination point l, for pairs $(k,l)\in A$.

The scheme of determination of routes is as follows:

From among the possible routes joining the first pair (k_1,l_1), where, as always, k_1 is the starting point and l_1 is the final point, we choose these which are the solutions to the problem (1),(2),(3),(4) assuming that there exists only one piece of demand for transport. Once the route (k_1,l_1) established we select the route (k_2,l_2) which satisfies transport demand $\Lambda_{k_2l_2}$, so as to make the value of the objective function (2), calculated for two demand magnitudes, minimal and to satisfy the constraints (1),(3),(4). This procedure is repeated as long as all the routes which provide for satisfaction of all the demand values Λ_{kl}, $(k,l)\in A$ are not determined.

The above algorithm was implemented in TURBO PASCAL language on an IBM PC compatible equipment. In order to make possible the graphical presentation of program results the software was expanded by graphical procedures allowing for communication of the user with the computer (aiming at changes of variants and parameters) and for provision of graphical interpretations of solutions. The output program KOSMIT makes use of the graphical package TURBO GRAPHIC TOOLBOX version 1.0.

3.3. Examples of solutions to problems of concentration

We shall present here several examples of solutions to problems of shipment concentrations obtained with the computer software outlined before. Every example was solved several times for various values of the parameter α.

Example 1.

The network considered is shown in Fig.1, which also indicates that all the edges are equal 1. Capacities of network segments are equal 2 excepting segments (2,3) and (3,4). This node capacities are sufficiently big.

Transport demand appear on the lines (1,4), (1,5) and (2,3) and the appropriate values are all equal 1.

Fig.1a shows solution for α=0. In this case there exist the following shortest routes: 1-2-8-4, 1-7-6-5 or 1-2-6-5 and 2-3. For α=0.1 the algorithm selects three following routes: 1-2-8-4, 1-2-8-5 and 2-3. For α=0.3 the algorithm selects routes 1-2-8-4, 1-2-8-4-5 and 2-3. These cases were illustrated in Fig.1a, 1b, 1c.

This example shows increasing concentration of shipments over just a few segments of the network, even at a cost of lengthening of the route, as was observed for transport over the relation (1,5), for which the shortest route 1-2-8-5 is given up at the advantage of the longer route 1-2-8-4-5 which, though, overlaps on three segments with the transport route on the relation (1,4).

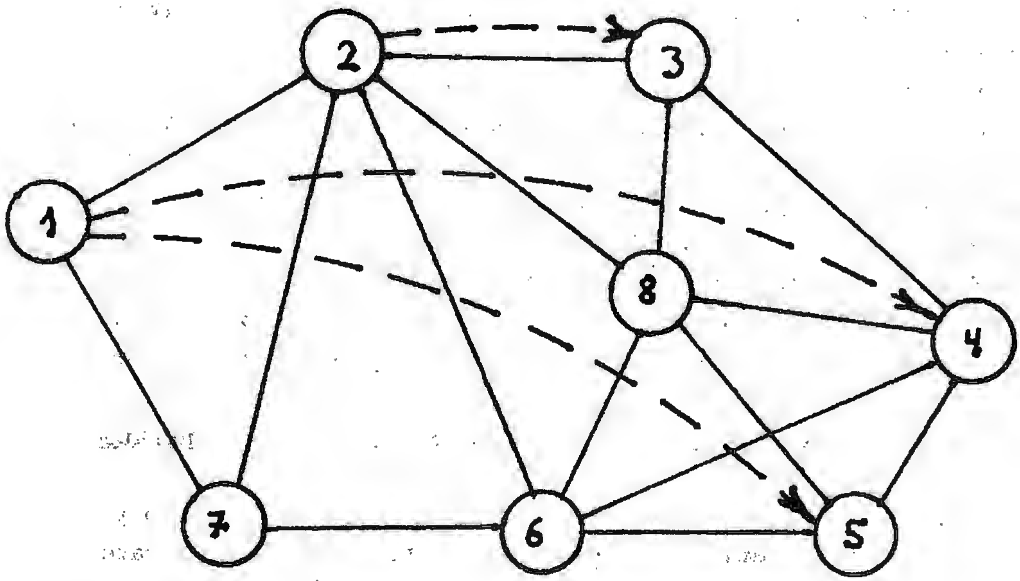

Fig.1.Road network (Example 1) and transport demand.

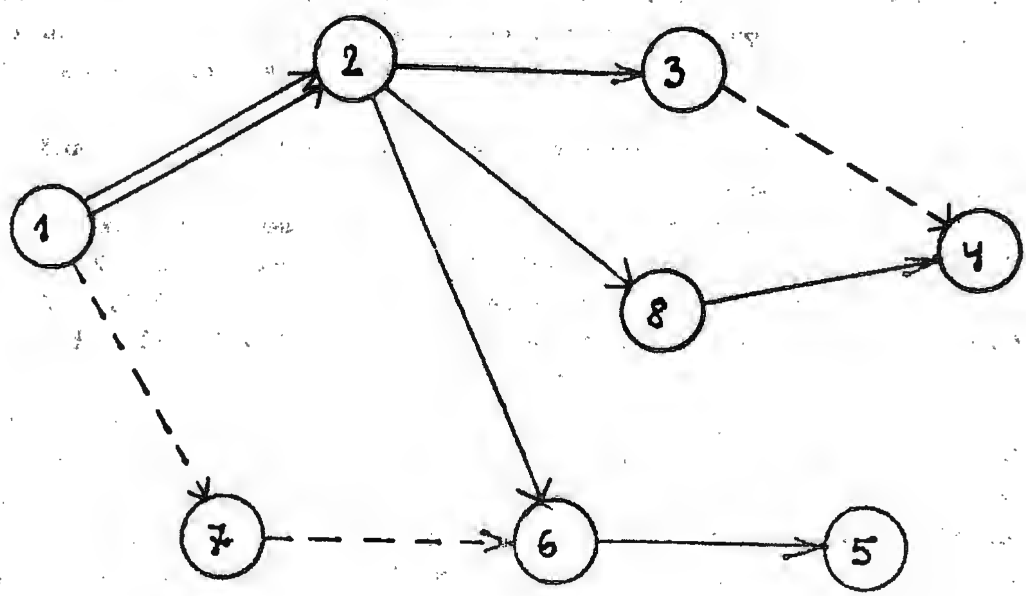

Fig.1a. Transport routes for α=0.

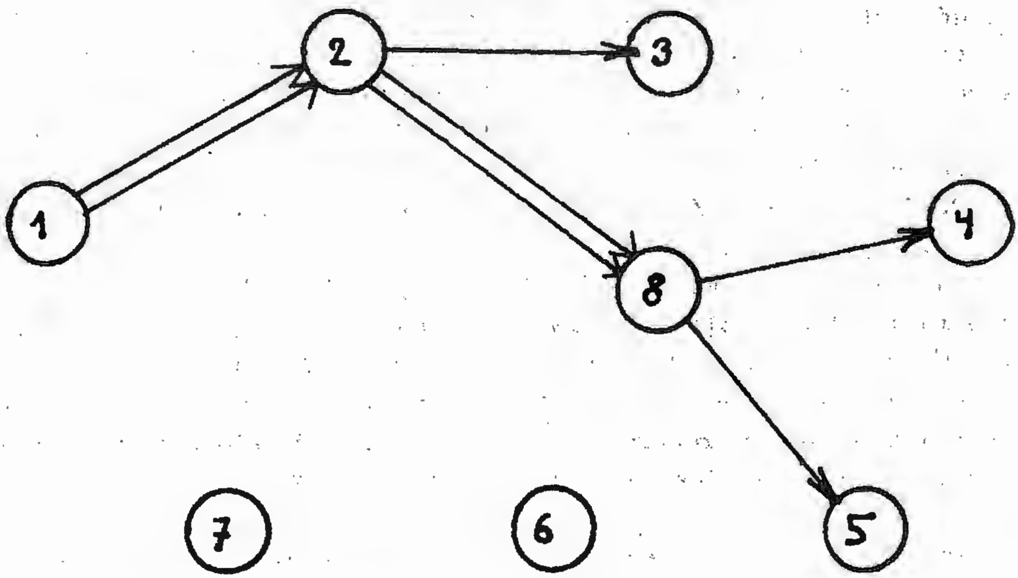

Fig.1b. Transport routes for α=0.1, 0.2.

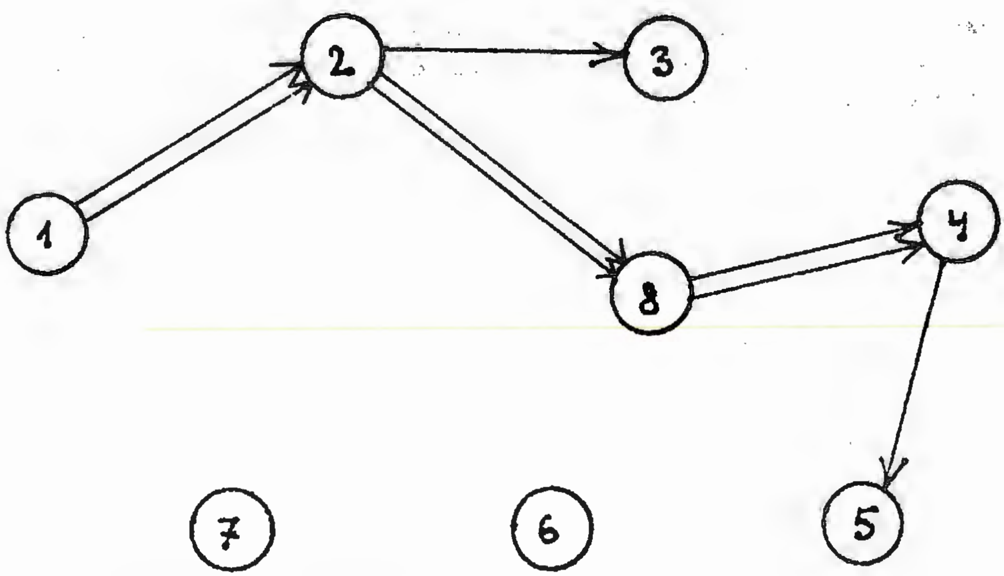

Fig.1c. Transport routes for α=0.3.

Example 2.

We are given the road network as in Fig.2, which shows that the lengths of all the segments are equal 1, and the capacities are equal 2, excepting segments (2,3), (3,4), (6,2), over which the capacity is equal 1. Node capacities are sufficiently big, excepting node no.7, for which capacity is equal 0 (this node is momentarily inactive due to reconstruction).

Transport needs are equal 1 for the following relations: (6,3), (5,3), (1,5), (4,8).

In this case we obtain for α=0, 0.2 and 0.4 the solution encompassing the following transport routes: 6-8-3, 5-8-3, 1-2-6-5 and 4-5-8. For α=0.8, on the other hand, we obtain the following routes: 6-8-3, 5-6-8-3, 1-2-3-4-5, 4-5-8. We can easily see the cases of lengthening of two routes for two transport relations in exchange for a better concentration, as can be seen in Fig.2b.

Example 3.

We are given the road network as in Fig.3, with lengths of all segments equal 1. Segment and node capacities are sufficiently big. Transport demands are equal one over the following relations: (1,4), (1,5), (6,4), (3,7), (8,2), (2,3).

For α=0 the following shortest routes were obtained: 1-2-3-4 or 1-2-8-4, 1-2-6-5 or 1-2-8-5, 6-5-4 or 6-8-4, 3-2-7, 8-2 and 2-3.

The shortest routes obtained for α=0.2 were: 1-2-3-4, 1-2-3-4-5, 6-2-3-4, 3-2-7, 8-2 and 2-3.

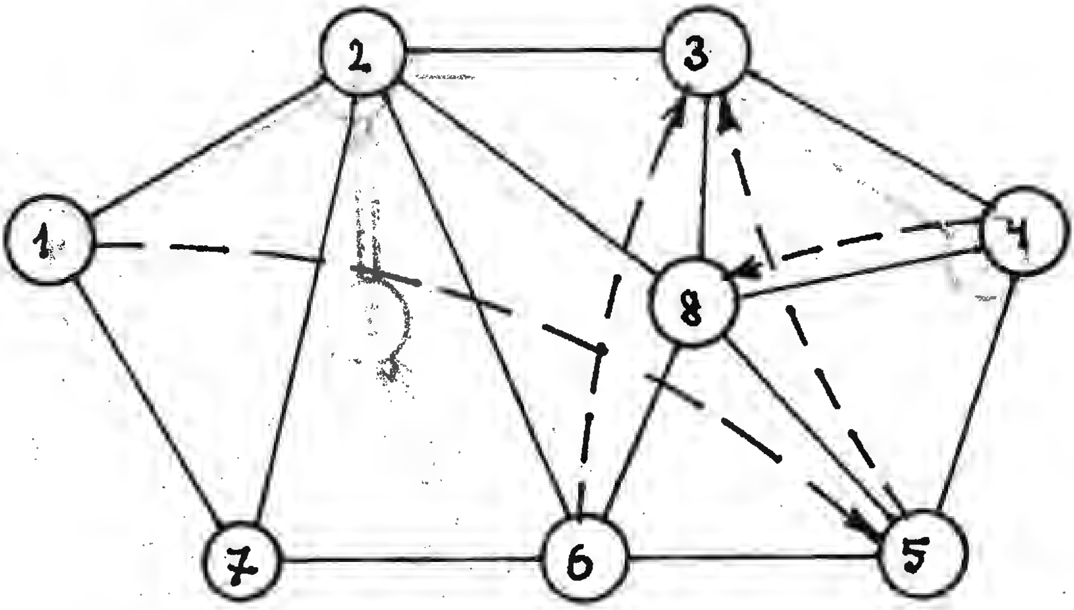

Fig.2. Road network (Example 2) and transport demand.

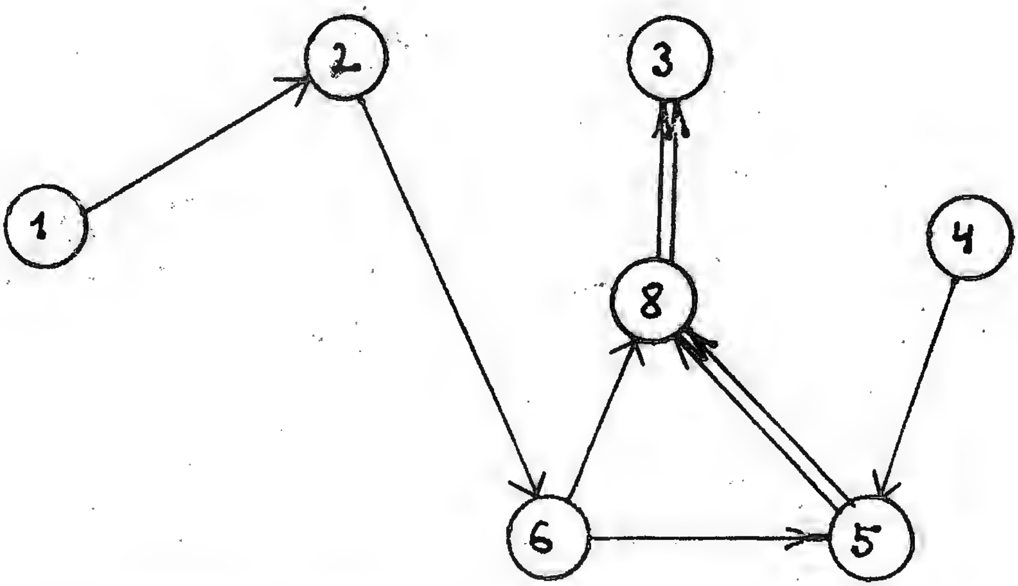

Fig 2a. Transport routes for $\alpha=0.2$ and $\alpha=0.4$.

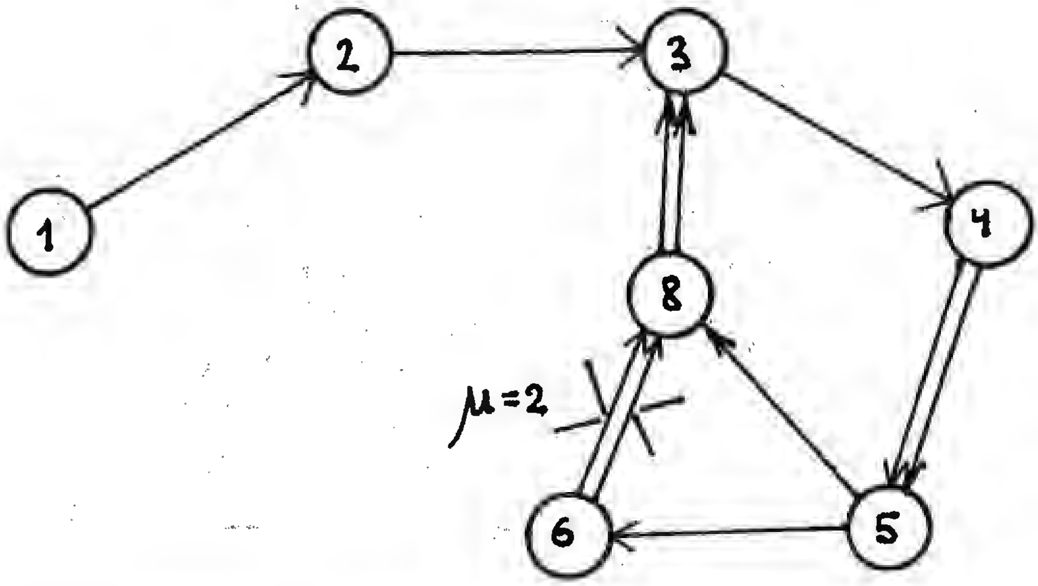

Fig.2b. Transport routes for α=0.8.

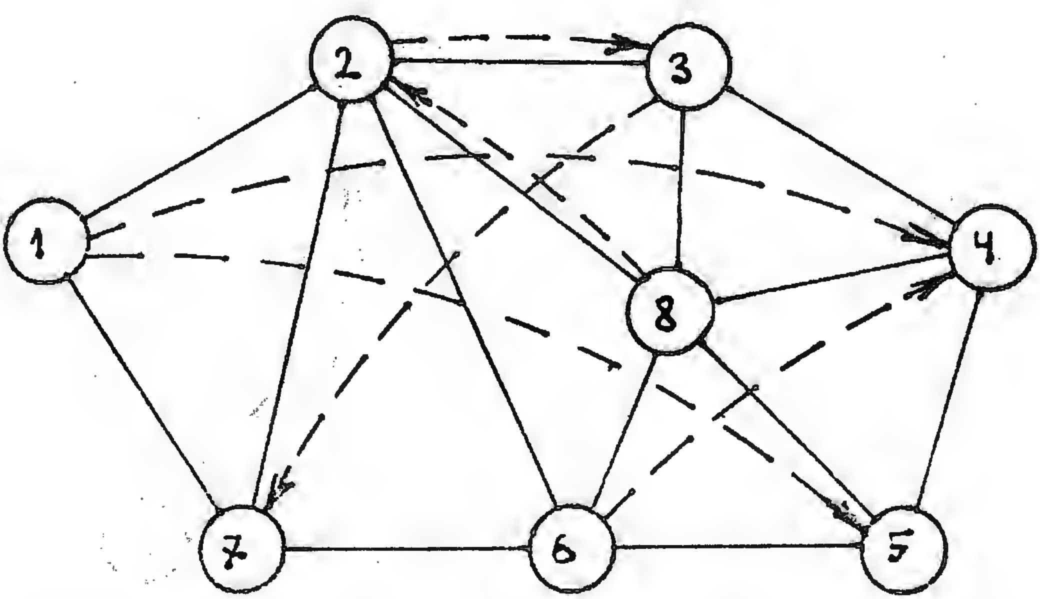

Fig.3. Road network (Example 3) and transport demand.

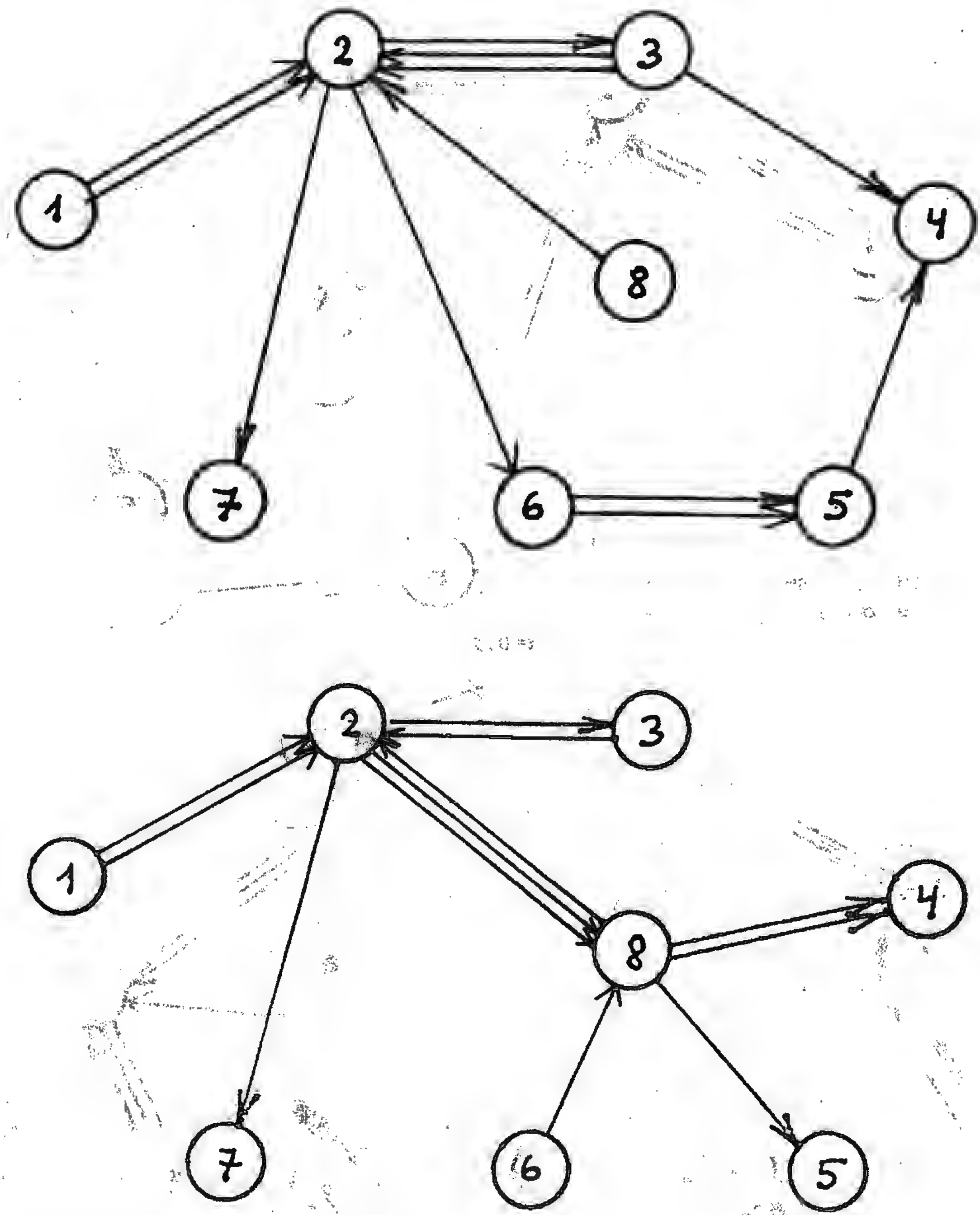

Fig.3a. Transport routes for $\alpha=0$ and 0.1.

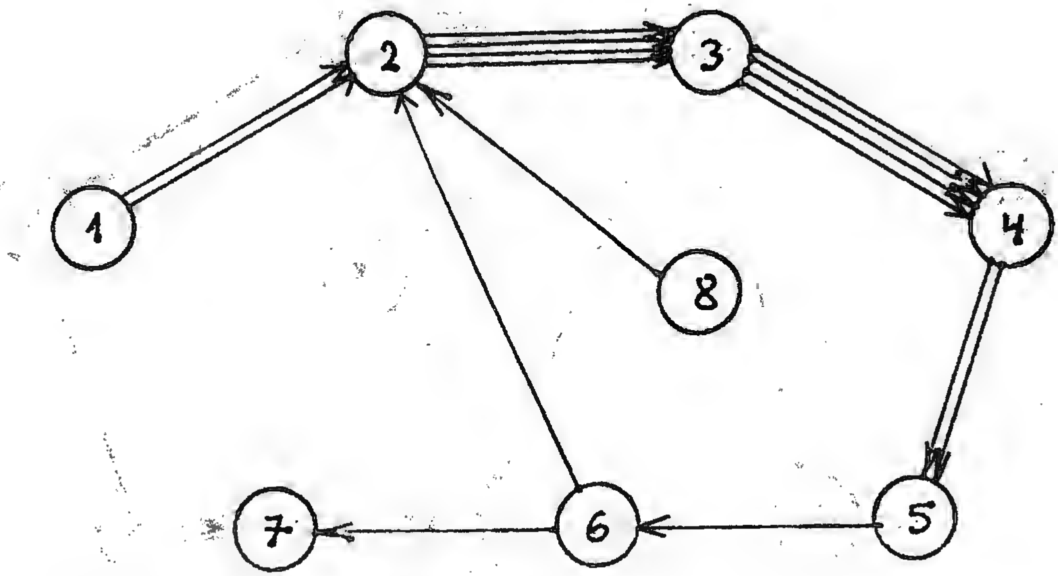

Fig.3b. Transport routes for $\alpha=0.2$.

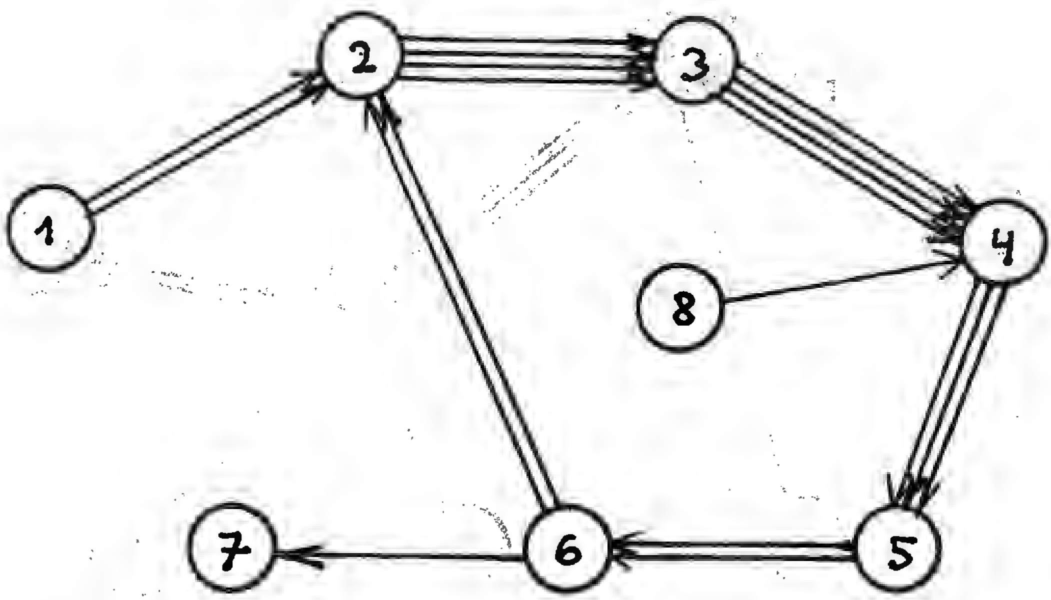

Fig.3c Transport routes for $\alpha=0.5$ and 1.0.

Assuming α=0.5 and α=1.0 we obtain routes: 1-2-3-4, 1-2-3-4-5, 6-2-3-4, 3-4-5-6-7, 8-4-5-6-2 and 2-3.

Figures 3a, 3b and 3c show these three cases with increasing concentration of shipments. Note that with the increasing concentration of shipments (compare the cases of α=0.2 and α=0.5) in place of the shortest route 8-2 for the relation (8,2) we obtained a roundabout route of 8-4-5-6-2 in which segments 4-5, 5-6, 6-2 overlap with the routes of transport on the relations (1,5), (6,4) and (3,7). In this case we obtained a nuising - artificial - concentration of shipments over the segments 4-5, 5-6, 6-2 at the expense of fourfold increase of transport distance for relation (8,2).

As we can observe, therefore, the algorithm tends to attainment of the possibly the greatest number of shipments on the smallest number of segments as the value of α increases, even when this does not make sense.

Consequently we cannot give any method of choosing the value of α. One should gradually change this value selecting these solutions which provide the desired concentration without forcing of the "artificial" density of shipments within the network.

Example 4.

We are given the network as in Fig.4, in which lengths of all segments are equal 1. Capacities of segments and nodes are sufficiently big.

Transport demands equal 1 are given for the following relations: (1,4), (1,5), (6,4).

The following shortest routes were obtained for α=0: 1-2-3-4 or 1-2-8-4, 1-2-6-5 or 1-2-8-5 or 1-7-6-5, 6-5-4 or 6-8-4.

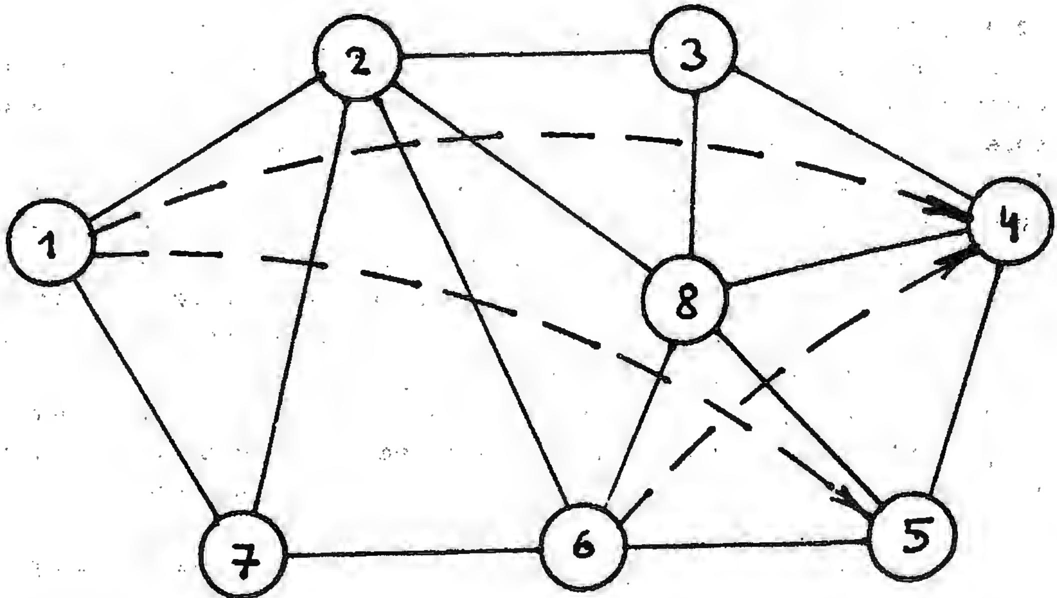

Fig.4. Road network (Example 4) and transport demand.

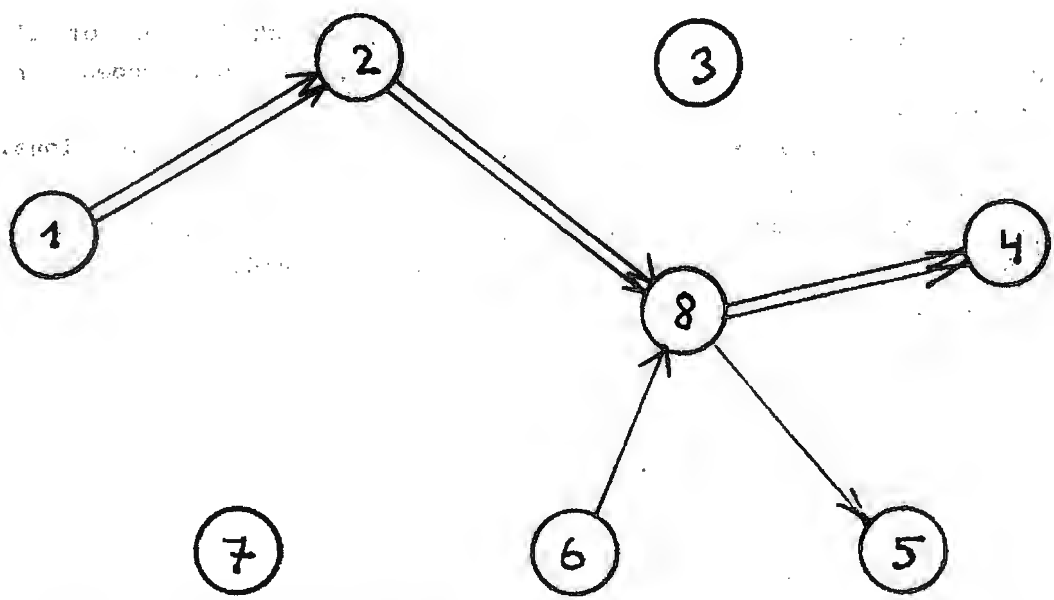

Fig.4a. Transport routes for α=0.1 and 0.2.

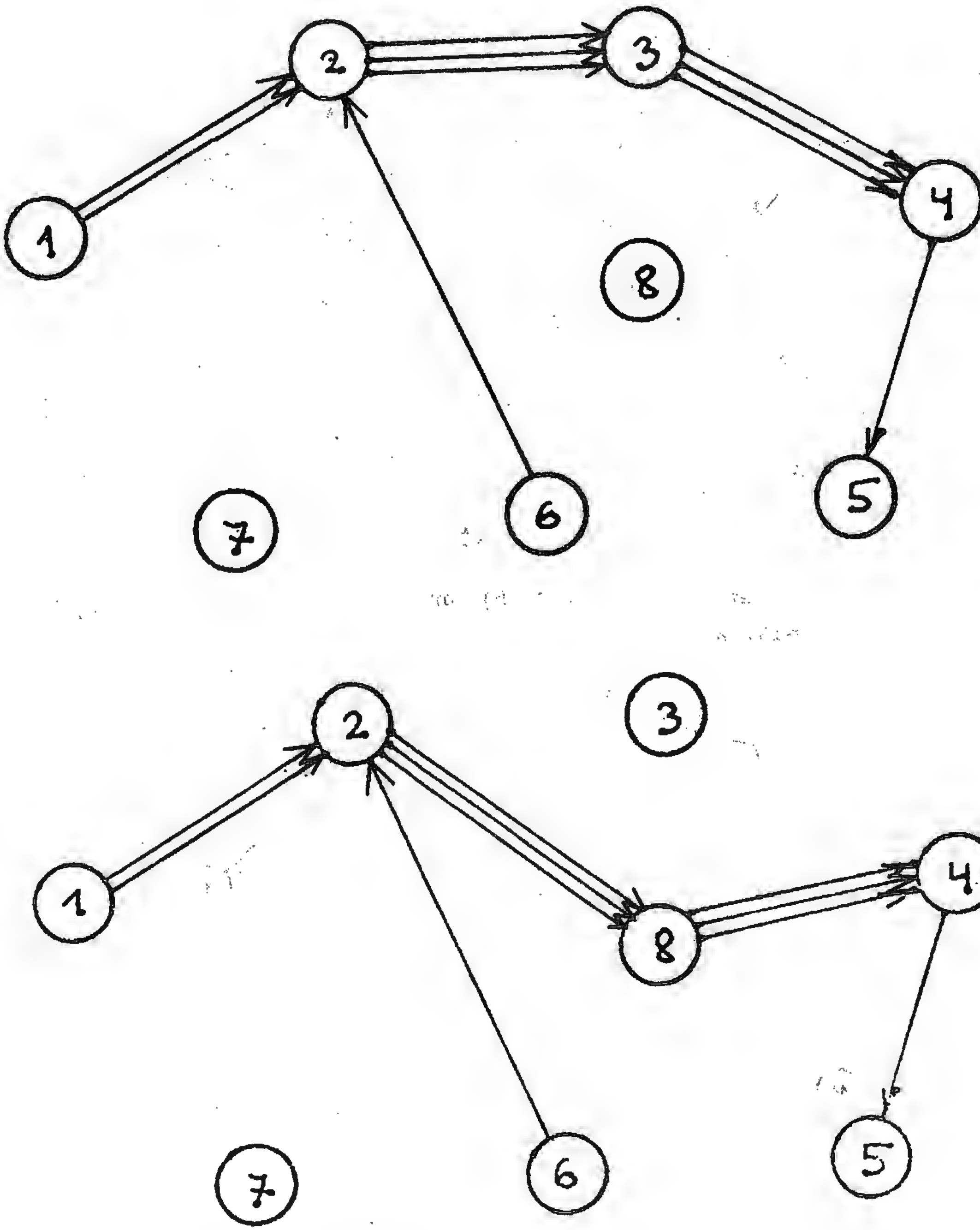

Fig.4b. Transport routes for α=0.5.

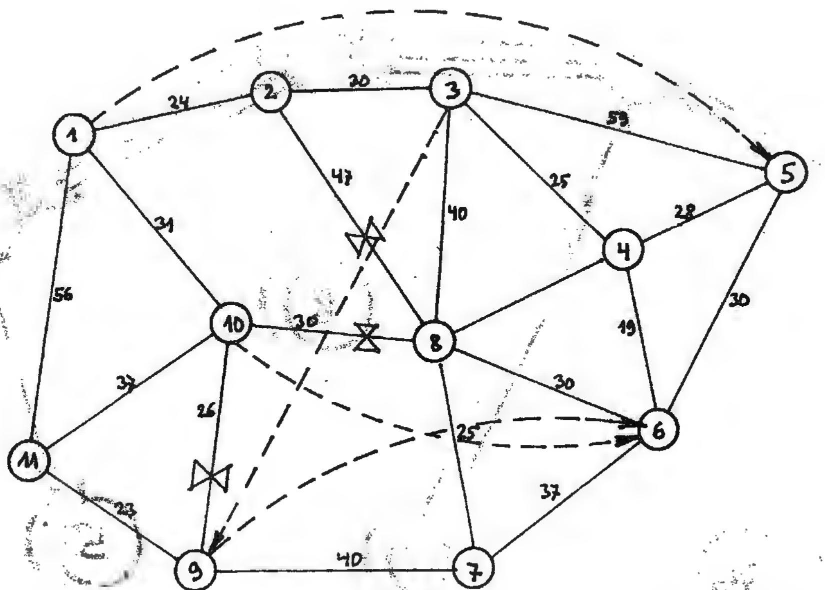

Fig.5. Road network (Example 5) and transport demand. $\lambda_{1,5}=20$, $\lambda_{10,5}=20$, $\lambda_{3,9}=10$, $\lambda_{9,6}=20$.

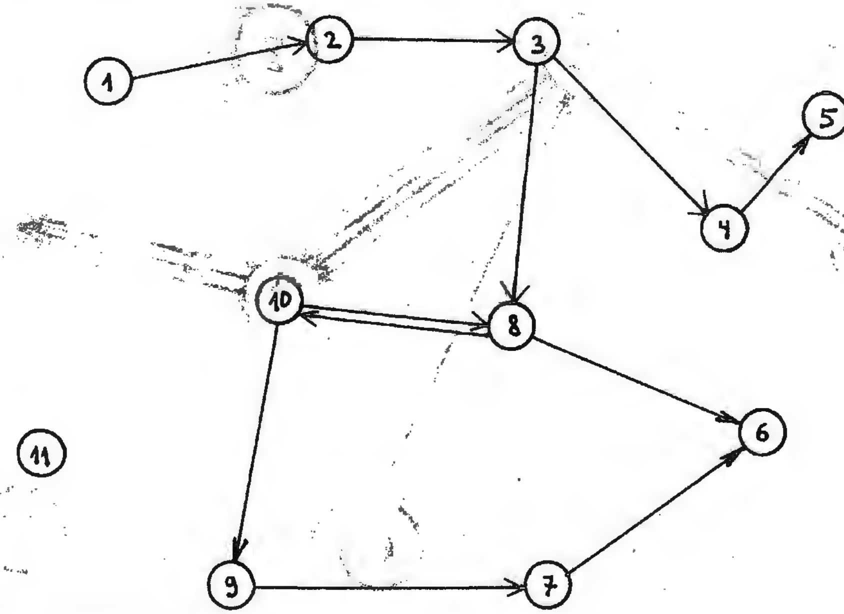

Fig.5a. Transport routes for $\alpha=0$, 0.5, 0.7.

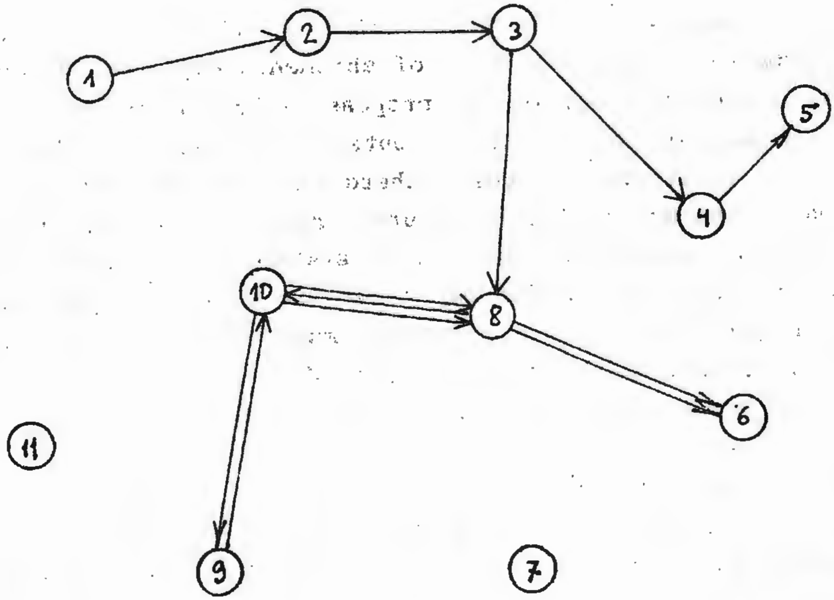

Fig.5b. Transport routes for α=0.8, 1.0.

For α=0.1 and 0.2 we obtain yet the following shortest routes: 1-2-8-4, 1-2-8-5 and 6-8-4.

For α=0.5 the following - not the shortest ones anymore - routes were obtained: 1-2-3-4, 1-2-3-4-5, 6-2-3-4 or 1-2-8-4, 1-2-8-4-5, 6-2-8-4. The solutions obtained are shown in Figs. 4a, 4b.

Example 5.

We are given the road network as in Fig.5, in which lengths of road segments are given. Capacities of road segments and nodes are sufficiently big. Transport demand is given for the relations: (1,5), (10,6), (3,9), (9,6).

For α=0 one obtains the following shortest routes: 1-2-3-4-5, 10-8-6, 3-8-10-9 and 9-7-6.

Then for the subsequent values α=0.5 and 0.7 the solutions obtained were identical as for α=0. It is only at the values of α=0.8 and 1.0 that the following routes: 1-2-3-4-5, 10-8-6, 3-8-10-9 and 9-10-8-6, were obtained. These solutions are shown in Figs.5a, 5b.

* * *

The above examples, which have uniquely illustrative nature, explain the problem of concentration of shipments over the network as well as certain imperfectness of the proposed solution method.

For $\alpha=0$, in example, the shortest routes are always selected. When the value of α increases then there ensues an increase of concentration at the expense of the route lengths. At an appropriately big value of the parameter the route system stabilizes. Further increase of the parameter value may cause an overly lengthening of routes, within the tendency of forced maximum overlapping of certain segments which causes a decrease of the objective function value, "encourage" the algorithm to further irrational lengthening of routes (see Example 1c and 3c).

By analysing the results of Examples one can notice yet another property of the influence exerted by the values of the parameter α. In some examples there existed many shortest routes (for $\alpha=0$). Assignment of even a small value of α different from 0 (for instance - $\alpha=0.1$) ensures selection of such a combination of the shortest routes which leads to the greatest concentration of shipments, yet with preservation of the shortest routes. This can be very well seen in the example 4.

In order to avoid the irrational lengthening of the routes appearing for high values of α an additional constraint was introduced for maximum feasible lengthening of the routes in order to obtain better concentration. This constraint is obtained through specification of the value of a coefficient $\beta\geq1$, defining the number of times that the feasible route can at most be longer than the shortest one, determined for $\alpha=0$.

The results of the influence exerted by the values of β on the solutions obtained are shown in Examples 6, 7 and 8. Example 7 shows, one should note, application of the algorithm and program developed to the problem of dispatching.

Examples 6 and 7.

We are given a "rectangular" network as shown in Fig.6a, whose edges are of unit length. Capacities of roads and nodes are sufficiently big.

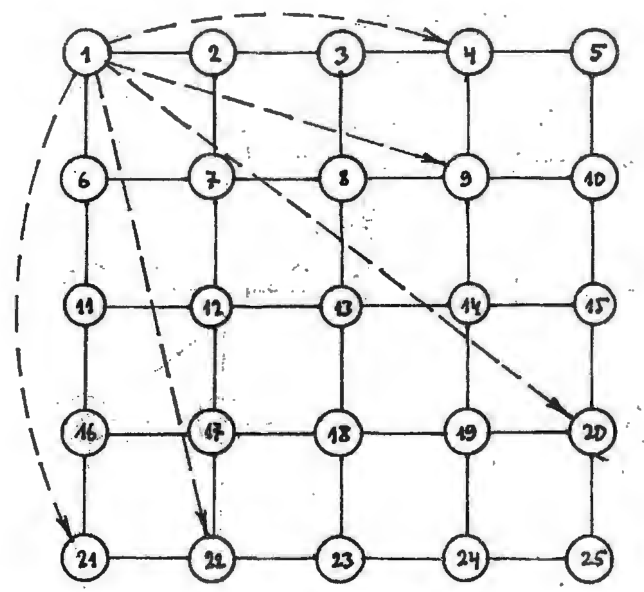

Fig.6. Road network (Example 6) and transport demands.

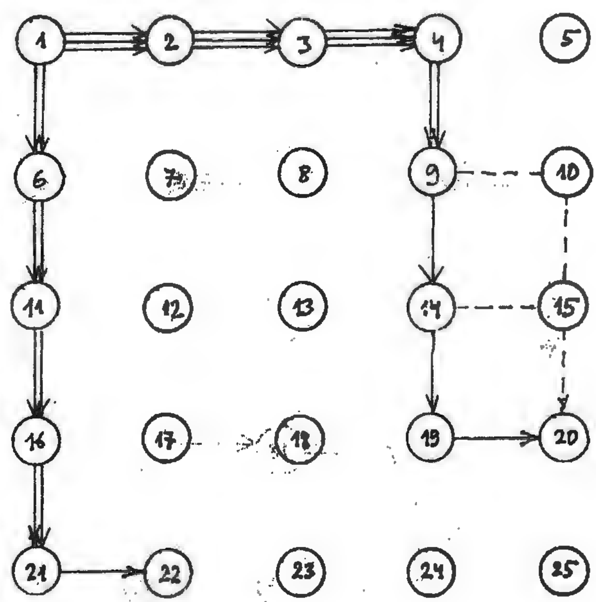

Fig.6a. Transport routes for α=0.1 and 1.0 with β=1.0.

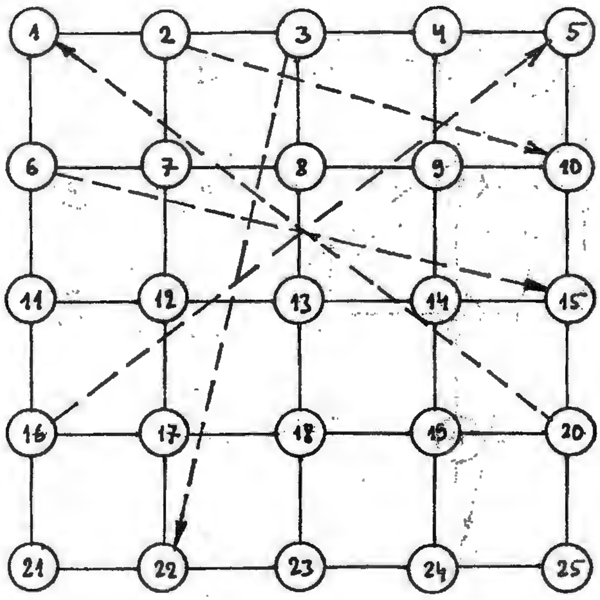

Fig.7. Road network (Example 7) and transport demand.

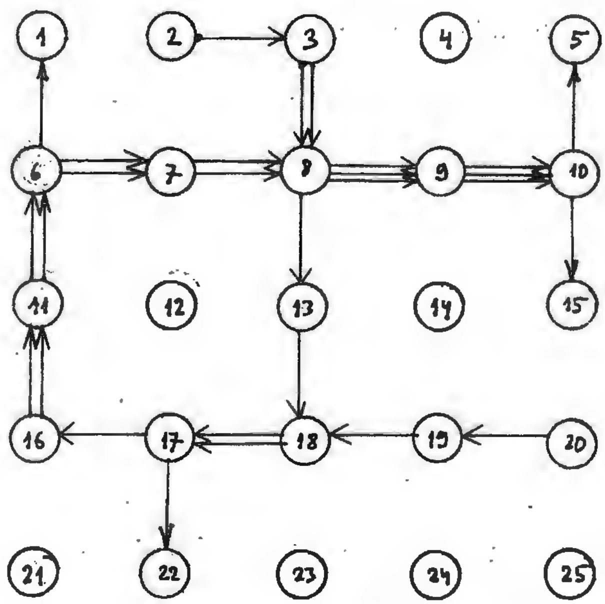

Fig.7a. Transport routes for α=0.1 and 10.0 with β=1.0.

Unit transport demand appears on relations (1,4), (1,9), (1,20), (1,21) and (1,22). The value adopted for β was 1.0 (only the shortest routes were allowed). The identical result obtained for α=0.1 and α=1.0 is shown in Fig.6a, where broken lines denote the alternative routes.

For the same network, having, though, another distribution of unit demands, namely on relations (6,12), (16,5), (3,22), (20,1) and (2,10), shown in Fig.7, identical solutions were obtained for α=0.1, α=1.0 and α=10.0. Their form is presented in Fig.7a.

The above two examples show the effectiveness of the constraint connected with the adopted value of β.

Example 8.

We are given the network of "circular" type, shown in Fig.8, with the lengths of edges along the circumference equal 10 and the lengths of radial edges equal 14. Capacities of roads and nodes are sufficiently big. Unit transport demands appear on relations (1,2), (1,3), (1,4), (1,5), (1,6) and (1,7), so that this one is a problem of dispatching of loads from the node no. 1 to six nodes numbered 2 to 7, lying along the circumference. The value of β=5 was adopted for this example, allowing thereby for the maximum concentration of shipments.

Fig.8a shows the identical solutions for values of α=0.4 and α=0.75 (as well as α=0.8). Then, Fig.8b shows solutions obtained for α=0.85 and α=1.2. As can be seen from the last figure we obtain for α=1.2 just one dispatching route for all the seven units of load.

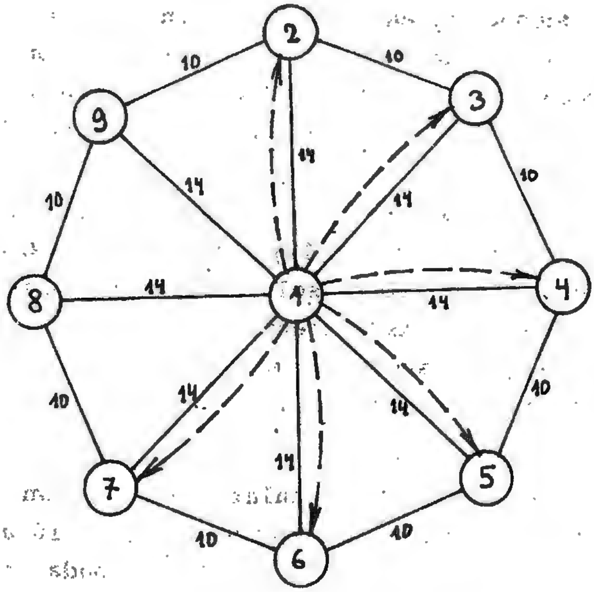

Fig.8. Road network (Example 8) and transport demands. Transport routes for α=0.0 and α=0.3 according to arrows of demands.

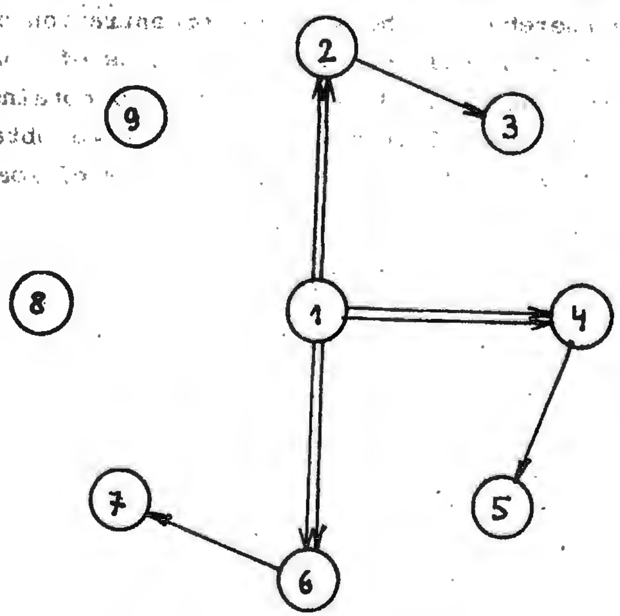

Fig.8a. Transport routes for α=0.4 and α=0.75.

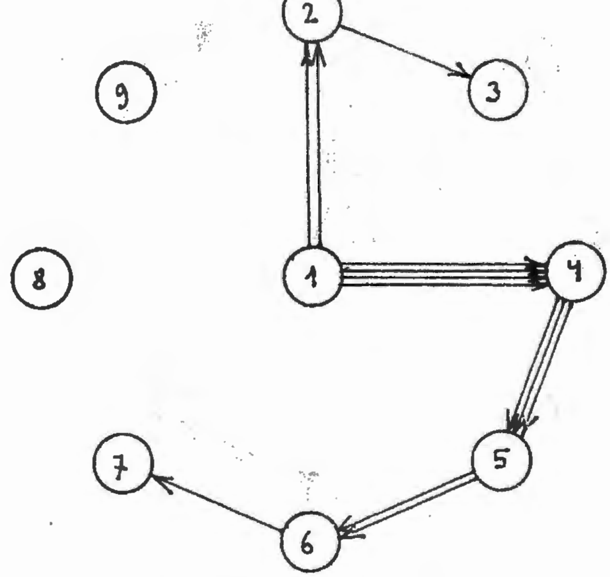

Fig.8b. Transport routes for α=0.6.

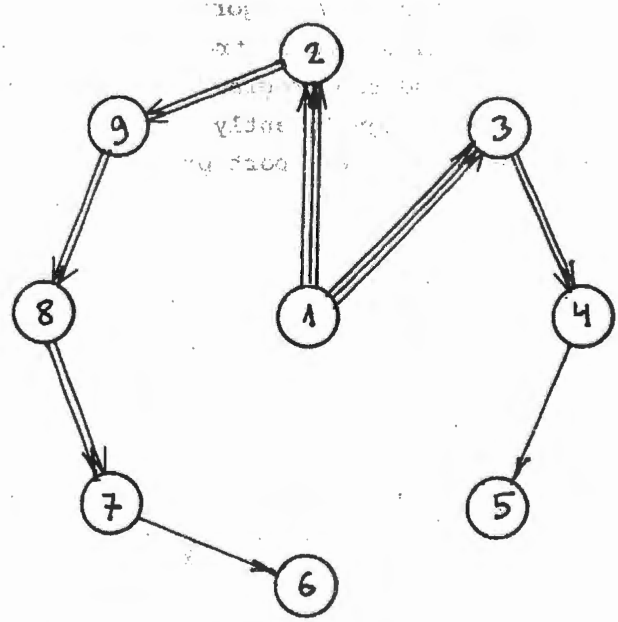

Fig.8c. Transport routes for α=0.85.

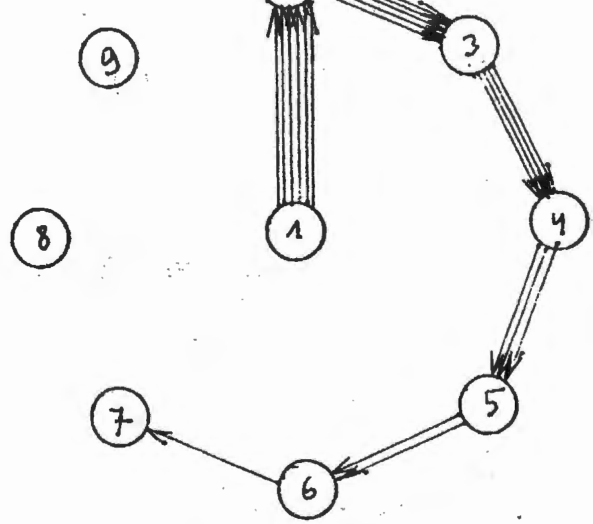

Fig.8d. Transport routes for α=1.2.

It is therefore visible that the algorithm and
solving the tasks concerning concentration of
simultaneously the algorithm and the program for solvi
dispatching problems, which significantly simplifi
problem domain of optimization of transport processes.

6. CONCLUDING REMARKS

The present publication contains the first integrated formulation of problems of organization of parcel cargo transport. This problem area encompasses all the questions of regular transport, with application both to cargoes and to information as well. Depending upon the nature of technical means of transport the whole problem takes on one of a variety of forms and particular cases, although the essence of the main questions remains the same. In view of limited volume of the present publication the variety mentioned could not be described systematically in full detail. This concerns especially these cases which are connected with transmission of information in telecommunication networks, in which the time needed for transmission on the way connecting nodes can be neglected, while the whole essence of the problem is concentrated in the nodes having limited capacity and effectiveness.

As stated, the subject of this publication is limited to regular transport (of cargoes and information).

Regular transport assumes cyclical repetitiveness of motion situations and, first of all, of transport demands. In such a case, by making use of knowledge of future transport needs, we can prepare earlier the whole transport plan. How to put together such a plan - was the subject of this publication.

It remains to explain relations between regular and irregular transport from the point of view of transport organization.

In irregular transport we are dealing with transport demands appearing in an irregular manner, difficult or simply impossible to predict.

Consequently, in irregular transport we are typically dealing with the situation in which a definite load should be moved immediately from one node of the network to another - given definite knowledge of transport situation in a given time instance. If this knowledge is complete, then this problem consists in determination of the schedule of transporting one shipment under conditions of given occupancy of roads and nodes and known movements of all compositions. Thus, an additional composition is to be constructed or the shipment is to be linked with the existing compositions.

In order to solve this problem we can make use of the algorithms described in this publication, proper for regular transport, with the difference that in this case the algorithms would concern singular load (and not the complete set of shipments appearing in the whole cycle of scheduling).

Certainly, in large transport systems assumption of complete knowledge of transport situation in the whole network is not realistic.

An example for that is provided by the computer network of information transmission or by the international telecommunication network.

Let us consider in a bit more detail this latter case of irregular "transport" of data in the telecommunication network.

Thus, namely, in case of appearance in a node of shipment meant to be sent to some other node, the first problem which appears is to decide to which neighbouring node the shipment should be sent (assuming that none of the neighbouring nodes, i.e. directly connected with the initial one, is the ultimate one).

It must therefore be established in the initial node what should be the priciples of proceeding with the shipments - defining the "direction" of sending for various shipments.

Besides this, if these shipments are parcel cargoes then priciples must be determined as to the time during which cargoes shall be gathered for a given direction to be then sent as a package - e.g. "data package".

For the thus organized work in the node no information on the motion situation in the network is necessary. A further improvement of organization of motion in the network would consist in additional dependence of choice of direction of shipment upon the current intensity of traffic in given direction. If, for instance, shipment meant for a given addressee would normally be directed to a definite node, then, in the situation of heavy traffic on the direction towards this node, the shipment would have to wait a very long time in the line until it is sent. In such a situation it may be better to have the shipment sent to some other neighbouring node, a less charged one. In just such a manner the "roundabout" connections (shipment routes) are being put together.

These, or very similar, are the methods of organizing "shipments" not only in telecommunication networks, but also in transport, whose classical example is provided by railroad transport in its part concerning irregular shipments.

At a first glance it would seem that organization of irregular transport in conditions of incomplete information on traffic situation has nothing to do with the methods of organization of regular transport, and in particular with the methods of construction of transport schedules.

Nothing more erroneous. Let us namely apply these procedures of organization of irregular transport to the case of shipments entirely predictable for a given period of time.

In order to do this, in accordance with the predicted transport demand, we hand over the shipments in the chronological order of their appearance to our system of organization of irregular transport.

Our system of organization of irregular transport - in accordance with the priciples of proceeding accepted for the system - shall determine the manner of sending of particular shipments. If we note down, independently, the directions and time instances of sending of the shipments, as well as the structure of compositions into which they will be included, then we shall obtain, as the ultimate result, the contents of the realized schedule for all the shipments. Thus, in regular transport we had been forming schedules through application of appropriate algorithms <u>before</u> the actual transport took place, while in irregular transport, through application of appropriate principles, we obtain schedules <u>after</u> the actual transport has occurred. This is the only difference. Note, that insofar as we have two schedules - one formed before realization and the second written down after transport took place, we are able of comparing their quality.

This is not difficult, since in regular transport schedules are put together considering mutual dependence of transport of all the shipments, while in irregular transport we do take care only of having the currently considered shipment transported optimally. This results from the fact that we do not have current information as to what shall be the subsequent shipments.

We have demonstrated thereby that the schedule of shipments in irregular transport cannot be better than that in regular transport, so that with probability one the effectiveness of functioning of irregular transport is better than in regular transport.

This is an obvious conclusion resulting directly from assumption that in regular transport we know future transport demand and that we make use of this information.

There is, however, certain similarity of methods of transport organization in regular and irregular transport.

Note, namely, that methods of organization of irregular transport could serve to construct the schedules of regular transport before their realization, just as it was presented in the example with noting down of the course of future transport. The thus prepared schedule (with a simulation method) could then be made use of for controlling future transports in a network.

What is therefore the difference between the principles of controlling transports in irregular transport and the principles of elaboration of schedules in regular transport?

The answer could be that there is no essential difference as to the fundamental principles, for the principles of control define *implicite* certain algorithm, and conversely, within the algorithm of determination of schedules one can identify definite priciples of elaboration of schedules. The main difference resides in the fact that the principles in the case of putting together a schedule could be better due to consideration of future situations (e.g. - the information that in the next period heavy traffic is expected to occur over a given direction). On the other hand, algorithms of control of individual shipments can take into account only current situation.

Thus, it can be stated that the algorithms elaborated for regular transport may also have application, once they are adequately simplified, in regular transport. Besides that it can also be stated that construction of algorithms for regular transport is much more difficult than construction of principles of control in irregular transport.

Concluding, I would like to emphasize that the present publication is meant mainly to attract attention to the whole range of interesting problems from the domain of theory of organization of transport.

Algorithms described, computer programs and examples are just an illustration of the real problems and their significance is primarily experimental.

One of the goals which were to be attained through publication of this work was demonstration of the possibility of application of mathematical methods and computerized algorithms in solving of problems traditionally held to be not solvable with the help of computers, and for which adequate mathematical formulations were nonexistent.

I think that I have attained the goal of demonstrating the potential capacities of modern methods of applied mathematics and the available computer software in solving of all the most difficult problems of transport organization.

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STANISŁAW PIASECKI

ORGANIZATION OF TRANSPORT OF PARCEL CARGOES

Procesy przemieszczania zarówno ładunków jak i wiadomości mają coraz większe znaczenie w gospodarce światowej. Wynika to z rosnącej, międzynarodowej kooperacji przemysłowej i wymiany handlowej.

Jednocześnie pojawienie się nowych technologii transportu (kontenerowego, ro-ro itp.) oraz przesyłania wiadomości (sieci komputerowe, łączność satelitarna itp.) wymagają nowego, ogólnego spojrzenia na organizację przemieszczania ładunków i informacji w sieciach. Książka jest próbą takiego spojrzenia, chociaż jej treścią jest teoria optymalizacji – procesu przemieszczania ładunków drobnych – „transportu cząstkowego".

Tak jak drobne ładunki muszą być grupowane w większe „zestawy" dopasowane do ładowności środka transportu, tak wiadomości są grupowane w większe „pakiety" zmniejszające zajętość sieci.

Ze względów dydaktycznych, zagadnienia optymalizacji są omawiane w większości na przykładach transportu kolejowego.

Podane metody rozwiązywania zadań optymalizacyjnych mogą być wykorzystane do optymalizacji działalności przedsiębiorstw transportowych, chociaż, niestety, pracochłonne obliczenia wymagają zastosowania techniki komputerowej.

Książka, w zasadzie przeznaczona jest dla pracowników naukowych, szczególnie wyższych uczelni.

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