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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.

4. THE PROBLEM OF GROUPING OF LOADS

4.1. Description and formulation of the problem of grouping of loads

We are given the routes of transporting shipments for every pair $(i,j)\in \mathbf{R}$, i.e. from the locality $i\in \mathbf{I}$ to locality $j\in \mathbf{I}$ where $\mathbf{I}$ is the set of numbers (indices, names) of the localities taken into consideration.

A route is for every pair (i,j) defined by the sequence[1]

$$M_{ij} = (i^0_{ij}, i^1_{ij}, \dots, i^{m(i,j)}_{ij})$$

of the "length" $m(i,j)$. These routes were determined as the solutions to the problem of concentration of shipments and are, as a rule not the shortest ones.

For every route $(i,j)\in \mathbf{R}$ a number Λ_{ij} is given defining the magnitude of cars moved in the unit of time from locality i to locality j.

Then, for the given graph $(\mathbf{I},\mathbf{U})$, describing the road network, where $\mathbf{U}\subseteq \mathbf{I}\times \mathbf{I}$ is the set of pairs ("branches") defining existence of a path from i to j, subsets $\mathbf{R}_{rs}\subseteq \mathbf{R}$ are defined of pairs (i,j) of such localities that the route connecting them passes through the branch (r,s) of the graph, with $(r,s)\in \mathbf{U}$. This is equivalent to saying the $\mathbf{R}_{rs}$ contain such pairs (i,j) that (r,s) is their element of the sequence M_{ij}:

$$\mathbf{R}_{rs} = \{(i,j) : \exists_k \, [i^{k-1}_{ij} = r,\ i^k_{ij} = s],\ k=1,2,\dots,m(i,j)\}$$

The set $\mathbf{R}_{rs}$ is determined on the basis of knowledge of magnitudes M_{ij} for $(i,j)\in \mathbf{R}$.

On the basis of knowledge of $\mathbf{R}_{rs}$ we can determine the value of ρ_{rs} defining the quantity of shipments moved during the time unit on the way from r to s:

$$\rho_{rs} = \sum_{(i,j)\in \mathbf{R}_{rs}} \Lambda_{ij}, \qquad (r,s)\in \mathbf{U}$$

so that, in particular, when $\mathbf{R}_{rs}=\emptyset$ then $\rho_{rs}=0$.

[1] If there are more than one route from i to j then the indexation of vertices should be broadened.

The data thus defined can be imagined in the following manner:

If the pair (i,j) is interpreted as the name of the color of the line connecting vertices i and j in the graph, passing through all the vertices contained in the route M_{ij} and having "thickness" proportional to the value of Λ_{ij}, then the picture of such a graph covered with colored lines represents the image of input data for the problem of grouping of loads.

Let us now describe what should be obtained due to solving of the problem outlined. The result of solving of the problem of grouping of loads should namely be determination of such chains grouping the loads which satisfy certain requirements and whose number is possibly low.

This corresponds to determination of the minimum numbers of:

- train sets in railway transport,
- trailer sets in car transport,
- ships in sea transport, etc.

Consequently, the number of chains is connected with the magnitude of work related with regrouping of loads, this work corresponding to:

* marshalling in railway transport,
* reloading in car and sea transport, and
* ~~sorting in mail.~~

It is obvious that these all types of work should be minimized, which is connected with minimization of the number of grouping chains. Let us denote with N_{uv} the chain which groups loads on the route from u to v, where $u,v \in I$.

This chain is defined by the sequence

$$N_{uv} = (r_{uv}^{0}, r_{uv}^{1}, \ldots, r_{uv}^{n(u,v)}),\ r_{uv}^{i} \in I,\ i=1,2,\ldots,n(u,v),\ r_{uv}^{0}=u,\quad r_{uv}^{n(u,v)} = v$$

which is a subsequence of at least one sequence M_{ij}.

If we denote now by B_{uv} a non-empty set of pairs (i,j) for which routes M_{ij} contain the sequence N_{uv} - that means - the ones for which there exists such $k=1,2,\ldots,m(i,j)-n(u,v)+1$ that

$$i_{ij}^{k} = r_{uv}^{0},\ i_{ij}^{k+1} = r_{uv}^{1},\ \ldots$$

then for every grouping chain we can determine the number

$$\rho_{uv} = \sum_{(i,j)\in B_{uv}} \Lambda_{ij}$$

which represents the intensity of transport of loads in the grouping chain N_{uv}.

Note that for any pair (r,s) such that

$$r = r_{uv}^{l}, \quad s = r_{uv}^{l+1}$$

the condition

$$B_{uv} \subseteq R_{rs}$$

must be satisfied.

The desired feature of the solution sought is to have the numbers ρ_{uv} satisfy the condition of "multiplicity" of capacity of the considered transport means:

$$\rho_{uv} = \nu_{uv} N_{uv}$$

where ν_{uv} is a natural number.

This condition can be written down in a somewhat "softer" form as the inequality

$$(\nu_{uv}-1)\cdot N_{uv} \le \rho_{uv} \le \nu_{uv}\cdot N_{uv} \qquad (1)$$

The above condition should be satisfied for every pair (u,v) belonging to the set

$$B = \{(u,v):\ B_{uv} \neq \emptyset\}$$

Denote now with $D^{rs} \subseteq B$ the set of names (u,v) of those grouping chains N_{uv}, which pass through the branch $(r,s) \in U$, that is – the ones which fulfil the following definition:

$$D^{rs} = \{(u,v) \in B:\ \exists_{l}\ [r_{uv}^{l-1}=r,\ \ r_{uv}^{l}=s],\ l=1,2,\dots,n(u,v)\}$$

If, afterwards, we introduce the following notation:

$D_j = \bigcup_r D^{rj}$, i.e. set theoretical sum sets of inputs D^{rj}

$D^j = \bigcup_s D^{js}$, i.e. the set theoretical sets sum of outputs D^{js}

If we denote by $\|A\|$ cardinality of a finite set A then the value of

$$\|D_j\| - \|D^j\|$$

defines the number of chains regruping with the vertex j.

Work connected with regrouping of loads is proportional to this number.

If, therefore, quantity C_j defines the regruping possibilities of the vertex j then the grouping chains must satisfy condition

$$\|D_j\| - \|D^j\| \le C_j \qquad (2)$$

for every $j \in I$.

The setting of these conditions determines the necessity of fitting the organization of transports to current reloading capacities existing in vertices of the given network. Note that solutions obtained when neglecting the system of conditions (2) may be used to elaborate the program of modernization of the network - meaning the thruflow capacities in terms of loading and unloading in partcular nodes.

Independently of the above, in case of limited road capacities, just as it is for instance in railway transport, solutions should satisfy an additional system of constraints

$$\sum_{(u,v)\in D^{rs}} \nu_{uv} < \mu_{rs} \tag{3}$$

for $(r,s)\in U$, where μ_{rs} is the capacity of the road segment (rs).

If quantity N_{uv} is interpreted as the line connecting vertex u with vertex v, having color (u,v) and thickness ν_{uv}, then the image of the graph covered with such colored lines makes the solution of the problem come out clearer.

Since the input data were similarly represented, forming colored coverage of a graph corresponding to the network in question, then the algorithm for solving the problem is the one of transforming one coverage into the other.

In this, the resulting coverage should strictly overlay the input coverage.

The transformation mentioned has as its purpose to reduce maximally the number of lines.

This means that if the initial number of lines was defined by the cardinality $\|R\|$ of the set R then the number $\|B\|$ of the resulting lines B should be much smaller. In our problem we are therefore having the criterion of minimization of cardinality of the set B, i.e.

$$\|B\| \to \min$$

If we interprete the pair (u,v) as the name of the color of the line which connects vertex u with vertex v and goes through the vertices defined by the sequence N_{uv} having thickness proportional to the number ν_{uv}, then the pattern of such a graph covered with colored lines illustrates the solution result searched for. In this we want to use as little as possible of colors - pairs (u,v) - and to have the summary thickness of lines representing the result cover entirely the colored lines which represented the input data to the problem. In the solution sought we may of course encounter the case of identity of pairs, i.e.

$$(i,j) = (u,v)$$

where: $(i,j) \in \mathbf{R}$, $(u,v) \in \mathbf{B}$.

Still, grouping of loads should lead to maximization of the difference

$$\|\mathbf{R}\| - \|\mathbf{B}\| \Rightarrow \max$$

which corresponds, for a given **R**, to the objective function of the form

$$\|\mathbf{B}\| \Rightarrow \min \qquad (4)$$

4.2. The solution method

Since, as of now, the problem of optimum grouping of loads has not been formulated mathematically in the literature known to this author, so that the formulation presented in point 1 is the first one, there are of course no algorithms known from existing publications which would solve this problem.

On the other hand, as can easily be verified, none of the existing algorithms from the domain of operations research is suited for solving of this problem, so that in the present point we are showing the method which makes it possible to determine a suboptimal solution.

The method consists in creation of variants of grouping - covering - chains, i.e. the ones which satisfy uniquely the system of conditions (1) and (2), conditions (3) omitted.

The algorithm of creation of covering chains is based on their construction depending upon the parameters of the grouping strategy, which are selected intuitively, without initial consideration of the system of conditions (2).

By adequately controlling the parameters of the strategy we can, by applying the method of consecutive trials, attain the situation in which the solution reached satisfies the system of conditions (2) as well.

The choice of parameters of the grouping strategy can be fully automatized, due to which the method makes easily it possible to automatically find feasible solutions, satisfying conditions (1) and (2). Condition (3), as the least important, shall in such a case be entirely omitted although its fulfilment could be brought about through minimal changes in the algorithm proposed.

The property desired, i.e. the minimum number of grouping chains, can be attained only partly, through better or worse selection of parameters of grouping strategy.

Further on we shall present the simplest algorithm of construction of covering chains for N_{ij}=C=const. Initially we shall define the the strategies of grouping loads into chains.

Strategies of grouping are sequences of elementary strategies. An elementary strategy may take on, in the simplest case here described, just two "values", corresponding to two following principles:

1.The sequences of routes M_{ij} proper at the given time instant for vertex i should be sorted into separate subsets, so that in each of them there would be routes having common vertex $i_{ij}^{k}=v$. In that, k should attain a possibly high value. Additionally, it can be assumed for the groups distinguished as subsets, that the condition on the sum of values of Λ_{ij} in each subset to best approximate a multiplicity of number C holds. Each group forms a chain for which the route

$$N_{iv} = \{i,\ldots,v\}$$

is determined together with the set B'_{iv} containing all these routes M_{ij} whose common part is the route N_{iv}.

2.The sequences of routes M_{ij} proper at the given time instant for the vertex "i" should be sorted in accordance with the second element of the route (assuming that i is the first element), that is - according to the vertex $i_{ij}^{1} = u$, into subsets (groups) of common value of u. Additionally, it can be assumed for the groups distinguished as subsets, that the condition on the sum of values of Λ_{ij} in each subset to best approximate a multiplicity of number C holds.

Each group forms a chain, for which the route

$$N_{iu} = \{i,\ldots,u\}$$

is determined together with the set B'_{iu} containing all these routes (i,j), whose common part is the route N_{iu}.

The first of the above rules shall be denoted further on by the symbol "SE" (sorting according to end), while the second one shall be denoted by the symbol "NC" - no changes.

These two names are connected with the observation that strategy "SE" maximally orders loads in groups according to the longest common path, while strategy "NC" makes it possible to avoid sorting altogether if in the sets B_{is} obtained before the routes M_{ij} have the same second elements. The second strategy consists in transferring the existing compositions to the subsequent vertices without changes - as much as it is possible.

Each vertex in the network is assigned one of the two outlined sorting strategies.

Obviously, if for a given vertex indexed i the cooresponding value P_i - power of regrouping (sorting) - is high, then strategy "SE" should be applied.

Conversely, for low values of P_i vertex i should be assigned strategy "NC".

The above manner of establishing of strategies is the simplest here described version of the algorithm of construction of the sets B_{uv}, N_{uv}. In more advanced algorithms intermediate strategies might be applied (not only according to the second or the most distant element of M_{ij}), or assignment of strategies to elementary vertices could be made dynamically - during execution of the algorithms.

Construction of a feasible solution, and not the worst one at that, proceeds therefore in the following manner:

In a given time step instant $t=0$ we select any arbitrary couple $(r,s)\in R^0$ - or the one for which the length of the sequence $M^0_{r,s}$ is the biggest.

Superscript "0" means that the sequence M_{rs} is updated for a given time step instant t, in the present case - $t=0$. For the vertex r we establish the set D_{rv} of pairs (i,j), in which the sequence M^0_{ij} contains the element r. In the case when r is the first element of the sequence M^0_{ij} then the sequence does not undergo changes. When r is the last element of the sequence, then M^0_{ir} does not undergo changes, too. If, however, r is located on an intermediate position in the sequence M^0_{ij}, then we divide this sequence into two subsequences:

$$M^0_{ir} = \{i^0_{ir}=i,\ i^1_{ir},\dots,i^m_{ir}=r\}$$

$$M^0_{rj} = \{i^0_{rj}=r,\ i^1_{rj},\ldots,i^{m'}_{rj}=j\},$$

thereupon wiping out the sequence M^0_{ij} from memory.

All the routes having common initial element r are sorted into groups according to the elementary strategy in force in the vertex r.

Thereby we determine sets B'_{ru}, B'_{rv},... and the sequences N_{ru}, M_{rv},... corresponding to them.

Next, we repeat the whole cycly of the operations mentioned above in the subsequent step, for $t=1$, in the neighbouring vertex, selecting its number from any of the sets M^0_{rj}. Before doing this we update the sets R^0 and M^0_{rj}, in which r is the first element, shortening them by the first element. If we denote by s the element following r in the set M^0_{rj} then we obtain shortened updated sets M^1_{sj}. Other sequences M^0_{ij} are left unchanged.

The set R^0 is being updated in the following manner: We delete from this set all these pairs (i,j) whose sequences M^0_{ij} underwent division into two subsequences: M^0_{ir} and M^0_{rj}. Then we complement the set R^0 with the pairs (i,r) which correspond to sequences M^0_{ir} resulting from division of the sequence M^0_{ij}. Besides this we complement the set R^0 with the pairs (s,j) corresponding to sequences M^1_{sj}. The thus obtained modified set is the set R^1.

The value of A_{ij} corresponding to the sequence M^0_{ij} is assigned to the two sequences M^0_{ir} and M^0_{rj}, resulting from the division previously mentioned, which after updating will have the forms of M^1_{ir} and M^1_{sj}.

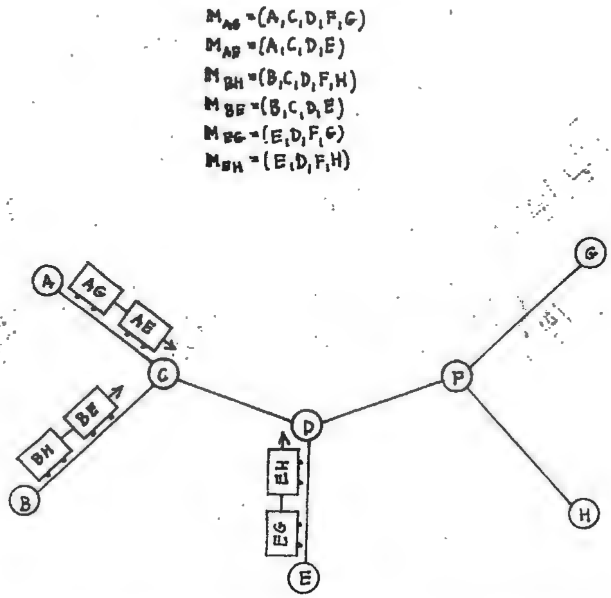

Fig.9. Road network and transport demands (Example 9)

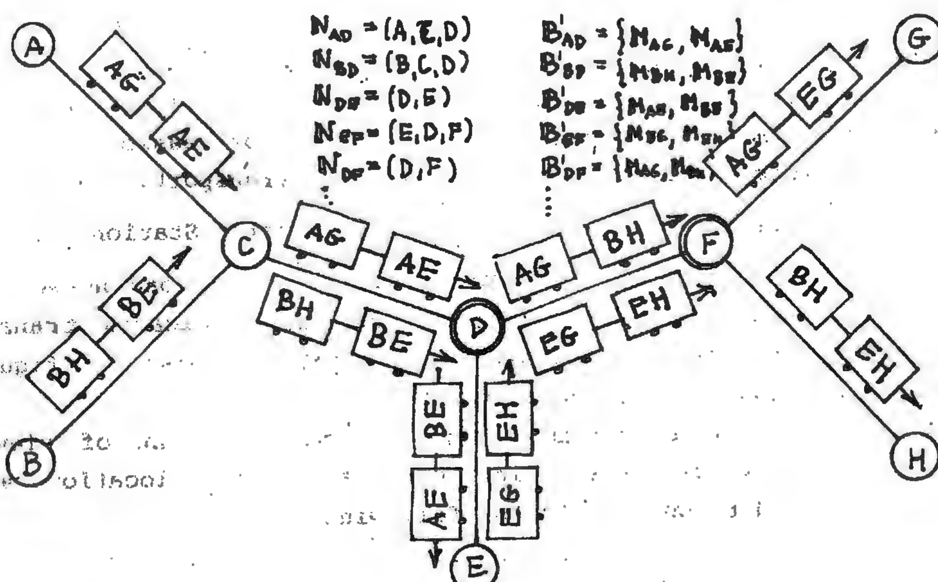

Fig.9a. Process of formation of train compositions according to strategy "NC" (Example 9)

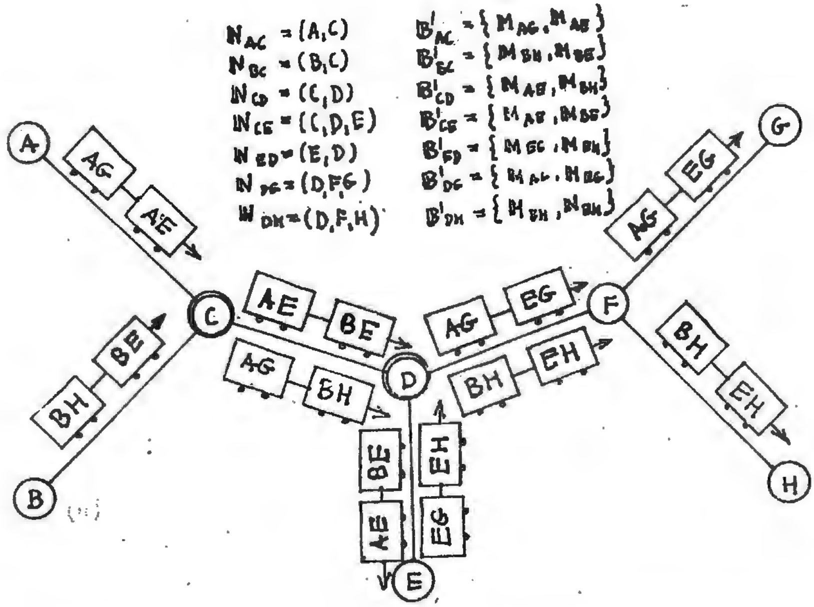

Fig.9b. Process of formation of train compositions according to strategy "SE" (Example 9)

Example 9

In order to illustrate the functioning of the algorithm let us consider the elementary instance of construction of feasible solutions (and not the worst ones) for the case of train transport.

In the example we admit $A_{ij} = 1 \frac{\text{car}}{\text{day}}$, $C = 2$ cars. Station names are designated with letters of alphabet. Figure 9 shows road network and transport demands. A pair of letters on cars indicates transport relations. Car routes are indicated by the sets M_{ij} given in figures. Soultions are shown in Figures 9a and 9b.

By analysing the solutions obtained from the point of view of overall intensity of marshalling work and its allocation among stations C, D and F, we come to the following result:

a) when applying strategy NC we obtain the following marshalling plan (Fig.9a):

* in station C compositions coming from stations A and B, i.e.

(AG,AE), (BH,BE)

are let through without changes to station D;

* in station D compositions coming from station C, i.e.

(AG,AE), (BH,BE)

are being reordered to form

(AG,BH), (AE,BE)

and directed, respectively, to stations F or E;

on the other hand, composition

(EG,EH)

which comes from station E is let through without changes to station F;

* in station F compositions coming from station D, i.e.

(AG,BH), (EG,EH)

are reordered to form

(AG,EG), (BH,EH)

which are directed, respectively, to stations G and H.

Thus, the magnitude of marshalling work is 2×2 compositions, i.e. 2 compositions in stations D and E each.

b) by applying strategy SE we obtain the following marshalling plan (Fig.9b):

* in station C we reorder the compositions coming from stations A and B, i.e.

(AG,AE), (BH,BE)

forming the following new compositions

(AG,BH), (AE,BE)

which are directed to station D;

* in station D compositions which come from stations C and E, i.e.

(AG,BH), (EG,EH)

are reordered to form new compositions

(AG,EG), (BH,EH)

which are directed to station F; the composition coming from station C, i.e.

(AE,BE)

is let through without changes to station E;

* in station F compositions which came from station D, that is

(AG,EG), (BH,EH)

are let through without changes and directed to stations, respectively, G or H.

Thus, the magnitude of marshalling work is 2×2 compositions, 2 compositions at stations C and D each.

Note, that with the change of strategy from NC to SE the magnitude of the marshalling work does not change, although there was a change in its allocation - it was transferred from stations D and F to stations C and D.

4.3. Examples of grouping of loads

Example 10

We are given the required translocation of cars within the given network. The intensity of demands λ is equal one car per day. Composition length $C=2$. Stations are denoted with A,B,C,D,E,F,G,H, while relations (routes) are as follows:

$M_{EA} = \{E,C,B,A\}$

$M_{EF} = \{E,C,B,F\}$

$M_{DA} = \{D,C,B,A\}$

$M_{AH} = \{A,B,D,H\}$

$M_{HG} = \{H,D,F,G\}$

$M_{HE} = \{H,D,C,E\}$

$M_{BD} = \{B,F,D\}$

Figure 10 shows the transport demands described above. For the input information here characterized computer algorithm yielded the following two solutions:

a) By applying strategy NC the following results were obtained:

$B'_{EB} = \{M_{EA},M_{EF}\}$, $B'_{BD} = \{M_{AH},M_{BP}\}$,

$B'_{HD} = \{M_{HG},M_{HE}\}$, $B'_{AF} = \{M_{EF}\}$,

$B'_{DC} = \{M_{DA},M_{HE}\}$, $B'_{DH} = \{M_{AH}\}$,

$B'_{CB} = \{M_{DA}\}$, $B'_{CE} = \{M_{HE}\}$,

$B'_{BA} = \{M_{EA},M_{DA}\}$, $B'_{DG} = \{M_{HG}\}$.

This solution is illustrated with Figure 10a.

b) By applying strategy SE the following results were obtained:

$B'_{EC} = \{M_{EA},M_{EF}\}$, $B'_{CE} = \{M_{HE}\}$,

$B'_{CA} = \{M_{EA}, M_{DA}\}$,
$B'_{CB} = \{M_{EF}\}$,
$B'_{BD} = \{M_{AH}, M_{BD}\}$,
$B'_{AF} = \{M_{EF}\}$,
$B'_{DG} = \{M_{HG}\}$,
$B'_{DH} = \{M_{AH}\}$,
$B'_{HD} = \{M_{HG}, M_{HE}\}$,
$B'_{DC} = \{M_{HE}, M_{DA}\}$.

This second solution is illustrated with Figure 10b.

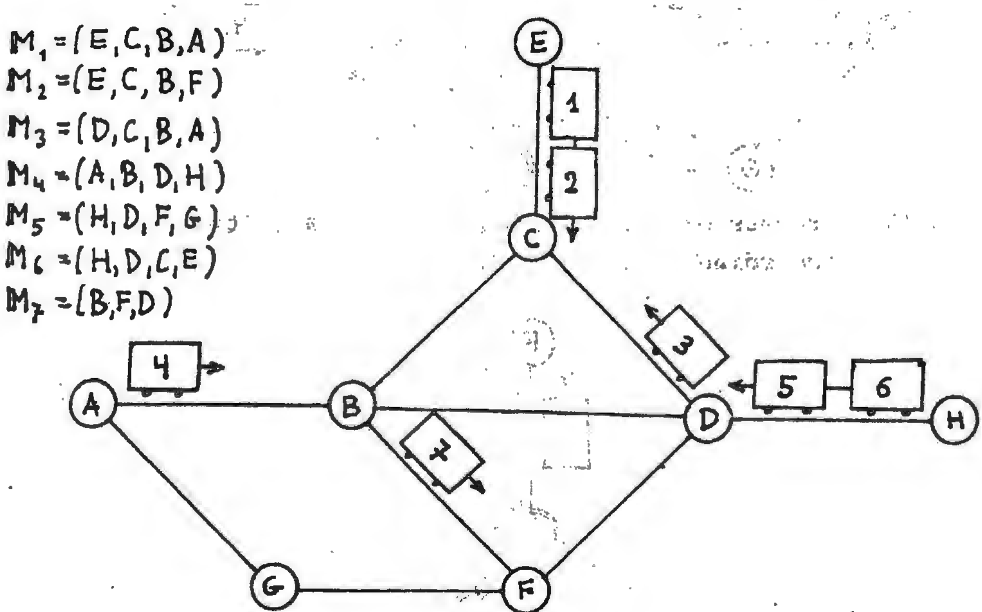

Fig.10. Road network and transport demands (Example 10)

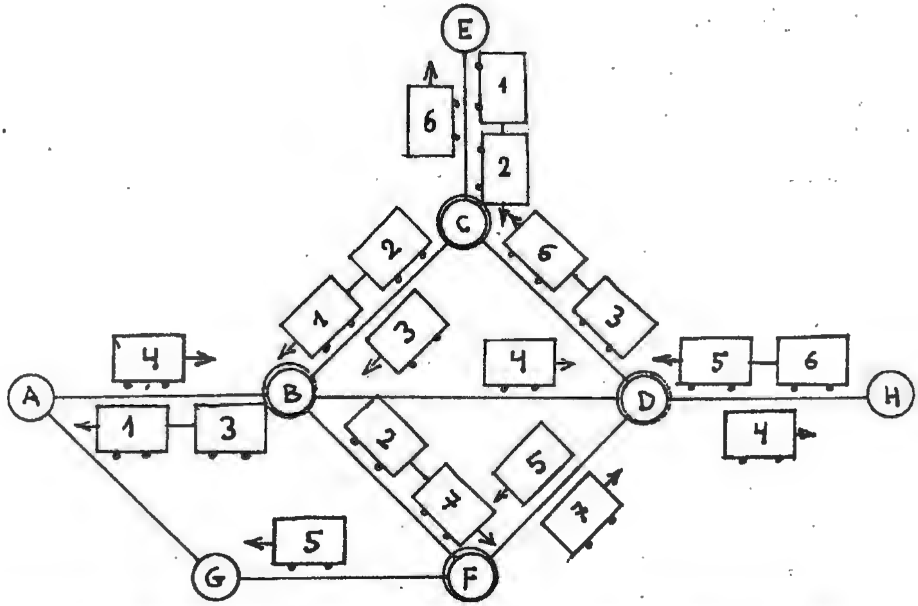

Fig.10a. Process of establishment of train compositions according to strategy NC (Example 10)

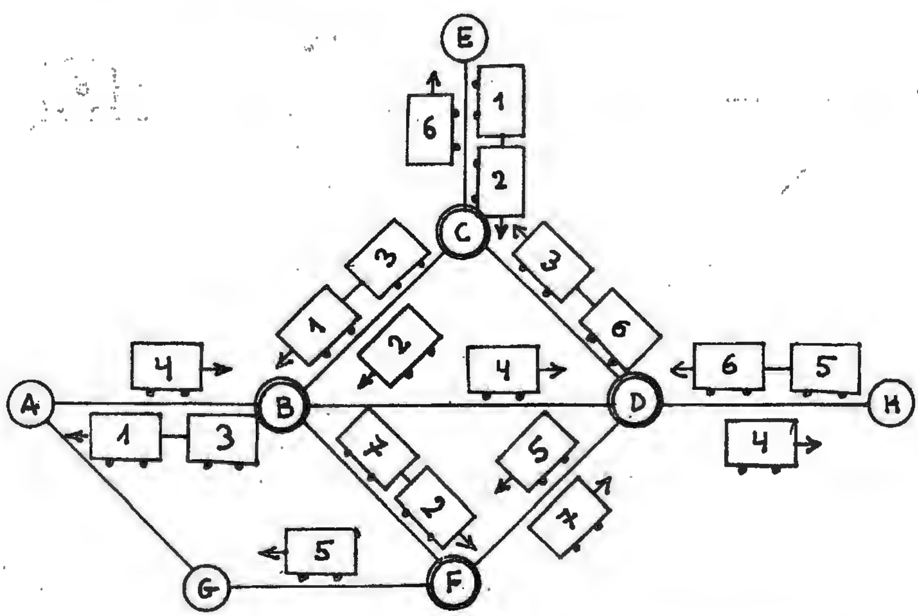

Fig.10b. Process of establishment of train compositions according to strategy SE (Example 10)

If we compare the above two solutions then we can conclude that from the point of view of minimization of the amount of marshalling work second solution, that is - the one obtained with application of SE strategy - is better.

In this case, namely, marshalling is performed only in stations C and D. In the station C two train compositions, (DA,HE) and (EA,EF) are rearranged to composition (EA,DA) and two separate cars EF and HE. In station D composition (HE,HG) is rearranged and composition (DA,HE) is formed. In the first case, on the other hand (i.e. for strategy NC) marshalling in station D is identical, while in station C composition (DA,HE) is broken down into separate cars.

Besides this, in station B the coming composition (EA,EF) and cars DA, AH and BD are rearranged to form compositions (AH,BD) and (EA,DA) and a separate car EF.

As we see, therefore, marshalling work is greater in the first case by at least the magnitude of work done in station C, if we assume that the magnitude of work in stations B and D in the first case is equal the magnitude of work in stations C and D in the second case.

Example 11

Road network is shown in Figure 11. Similarly as in the first case, $\lambda = 1$ car per day over the route:

$$M_{AE} = \{A,B,C,D,E\}$$
$$M_{FG} = \{F,B,C,D,G\}$$
$$M_{CG} = \{C,D,G\}$$

with the lengths of compositions not exceeding the value of C=2. Figure 11a shows the solution obtained for strategy NC, while Figure 11b shows the solution obtained for strategy SE (the latter only for the portion of the network for which results obtained with the help of the two strategies differ).

As can be seen from the figures, in the second case, when strategy SE is applied, marshalling work devoted to transformation of composition (AE,FG) into composition (CG,FG) takes place in station C, while in case of strategy NC it takes place in station D. Thus, in this example only allocation of the marshalling work changes, while its overall magnitude does not.

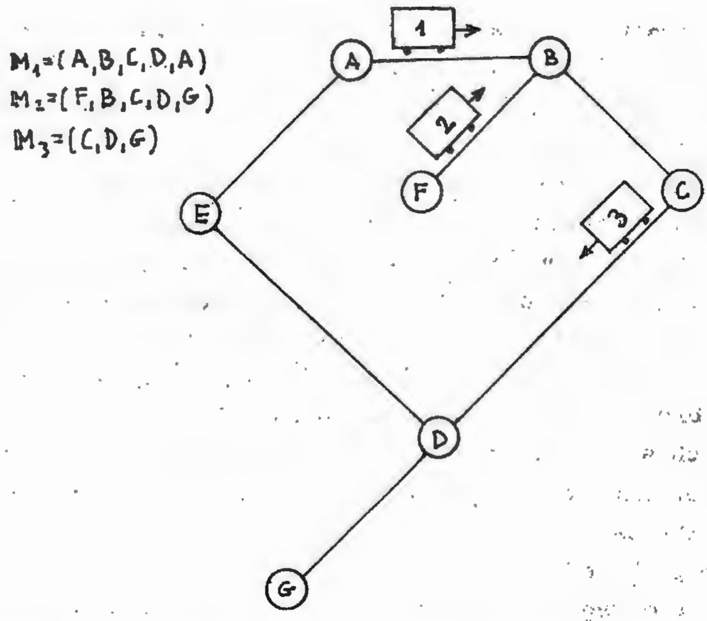

Fig.11. Road network and transport demands (Example 11)

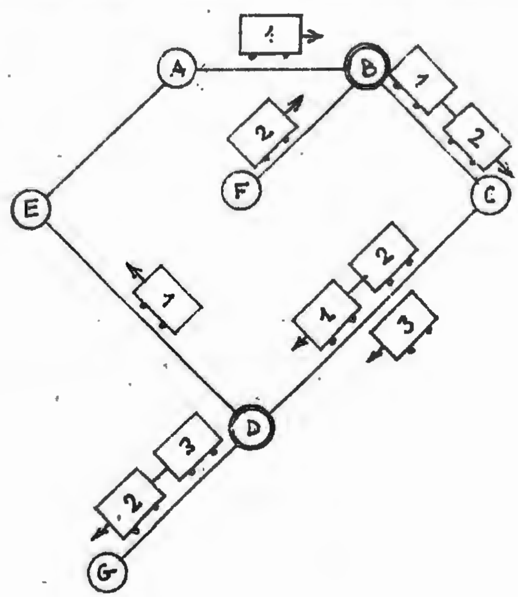

Fig.11a. Process of creation of train compositions according to strategy NC (Example 11)

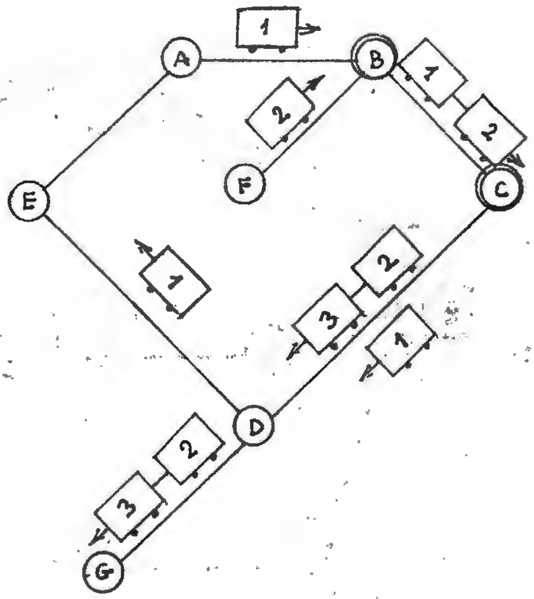

Fig.11b. Process of creation of train compositions according to strategy SE (Example 11)

Example 12

Road network is in this case constituted by the "line" along which stations A,B,C,D,E are located (see Figure 12). Similarly as before we shall assume that λ = 1 car per day, and the lengths of compositions cannot exceed C=2.

Relations corresponding to transport demands are as follows:

M_{AE} = {A,B,C,D,E}

M_{BD} = {B,C,D}

M_{EB} = {E,D,C,B}

M_{EA} = {E,D,C,B,A}.

We obtain for two strategies considered, i.e. NC and SE, two identical solutions to this problem. The solution obtained is shown in Figure 12a.

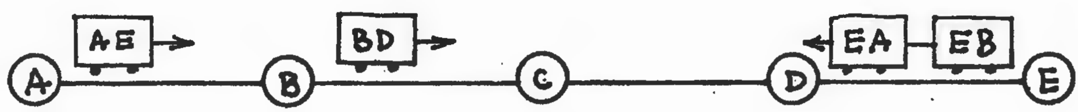

Fig.12. Road network and transport demands (Example 12)

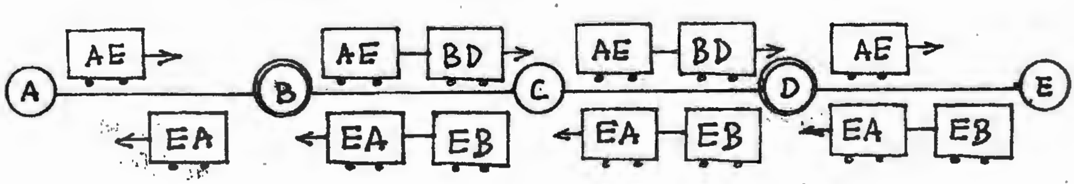

Fig.12a. Process of establishment of train compositions according to both strategies NC and SE (Example 12)

In the third example, separate cars appear over relations A,B; B,A; D,E. So, while over the route N_{EB} = {E,D,C,B} composition (EA,EB) is translocated every day, over the route N_{BA} composition (EA,EA) is moved every seond day. Similarly, over the routes N_{AB} and N_{DE} compositions (AE,AE) and (DE,DE), respectively, are being translocated every second day.

Hence, if the two-car composition (AE,AE) reaches station B from station A every second day, then one of cars is immediately attached to car BD, while the second one waits one day in station B for attachment of the second car BD. Consequently, every second day there will be one car waiting in station B.

Thus, even if it were possible to synchronize ideally in time the instant of loading of the car BD with the one of coming of composition (AE,AE) from station A, we would be witnessing the phenomenon of waiting of one car of relation AE every second day in station B.

Such a phenomenon is known in railroad transport and referred to as accumulation of cars in marshalling stations. In the case considered there is, on the average, a "half" car waiting in station B.

The set of examples presented before shall now be complemented with the results of grouping for two examples concerning concentration. Namely, the result of load concentration of Example 4 (for α=0.5) shall be complemented with the results of the computer program of grouping described in Example 14.

Thereby the results of Examples 13 and 14 shall present the ultimate solutions to transport problems described in, respectively, Examples 4 and 8. Transport demands are shown in Figures 4 and 8, and the resulting solutions are presented in Figures 13 and 14.

Example 13

For transport routes as in Example 4, for α=0.5 (see Fig. 4b) we must determine translocations of containers under the assumption that the capacity of road train is C=2. Intensity of demand for transport (see Fig.4) is equal λ=1 container per day.

Transport routes are as follows:

$M_{1,4}$ = {1,2,3,4}
$M_{1,5}$ = {1,2,3,4,5}
$M_{6,4}$ = {6,2,3,4}

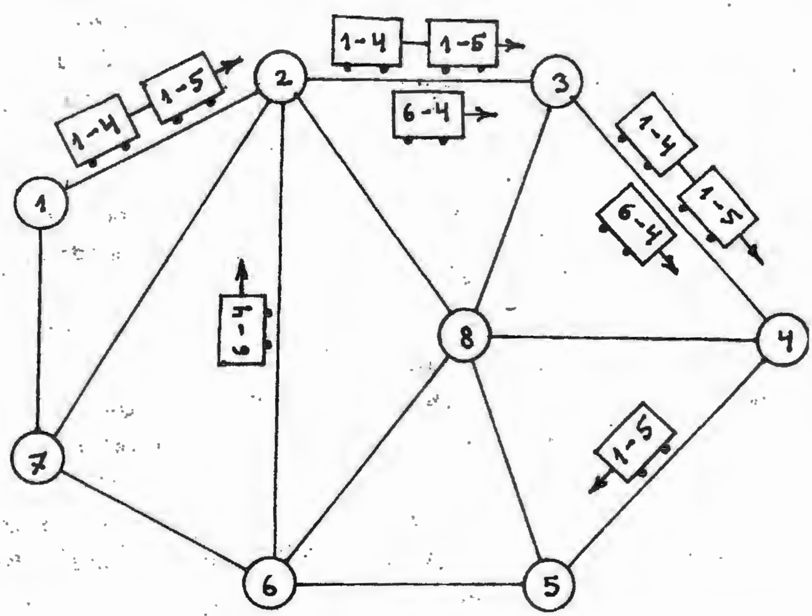

Fig.13a. Process of establishment of compositions according to strategy NC (Example 13)

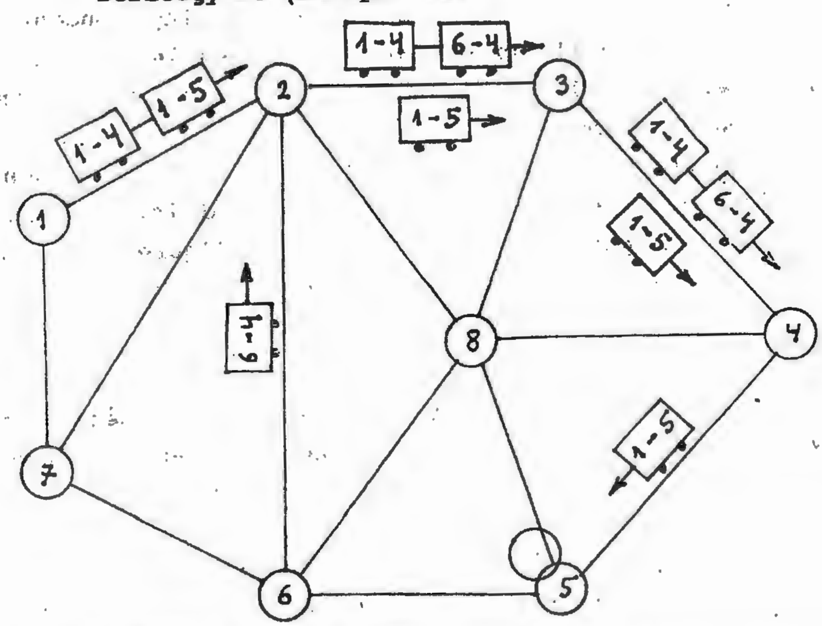

Fig.13b. Process of establishment of compositions according to strategy SE (Example 13)

Results obtained from the algorithm are shown in Figures 13a (for strategy NC) and 13b (for strategy SE).

Example 14

For transport routes as in Example 8, with $\alpha=0.75$ (see Fig.8c) we must determine translocations of containers, assuming that the capacity of the road train is $C=2$.

Intensity of transport demands (see Fig.8) equals $\lambda=1$ containers per day. Transport routes are as follows:

$M_{1,2} = \{1,2\}$
$M_{1,3} = \{1,2,3\}$
$M_{1,4} = \{1,4\}$
$M_{1,5} = \{1,4,5\}$
$M_{1,6} = \{1,6\}$
$M_{1,7} = \{1,6,7\}$

Results produced by the algorithm for this problem are shown in Fig.14.

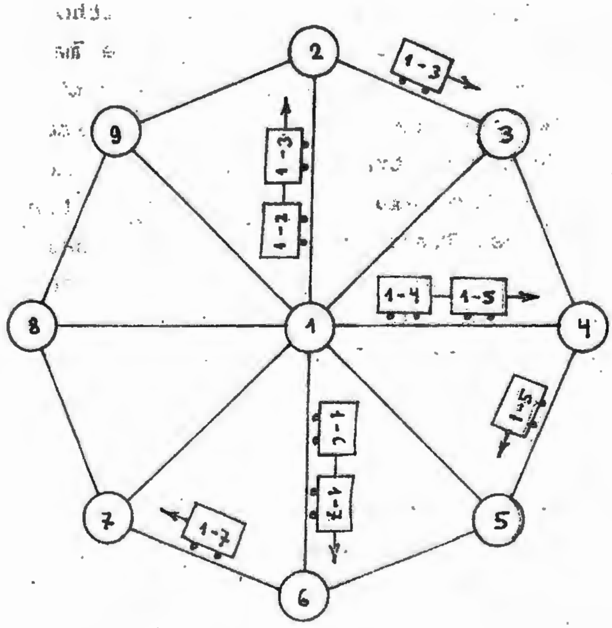

Fig.14. Process of establishment of compositions (Example 14)

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.

7. REFERENCES

1. Bartlett, T.E.: An algorithm for the minimum number of transport units to maintain a fixed schedule. *Naval Res.Logist.Quart.*, 4, pp.139-149.

2. Dantzig, G.B., Fulkerson, D.R.: Minimizing the number of tankers to meet a fixed schedule. *Naval Res.Logist.Quart.*, 1, pp.217-222.

3. Garfinkel, R.S., Nemhauser, G.L.: Integer Programming (Polish translation), WNT, Warszawa.

4. Lenstra, K.J., Rinnooy Kan, A.H.G.: Complexity of vehicle routing and scheduling problem. *Networks*, 11, no.2/1981.

5. Malarski, M., et al.: Wybrane zagadnienia analizy i rozwoju systemów sterowania ruchem i procesami transportowymi w transporcie lotniczym (Selected problems of analysis and development of control systems for traffic and transport processes in air transport; in Polish). Opracowanie IT PW, Warszawa, 1987.

6. Marsten, R.E., Muller M., Killion, C.: Crew planning at Flying Tiger: a successful application of integer programming. *Manag.Infor.Syst.Dept.* No.533/1978.

7. Marsten, R.E., Shephardson, F.: Exact solutions of crew scheduling problemsusing the set partitioning model: recent successful algorithm. *Networks*, 11, No.2, 1981.

8. Mażbic-Kulma, B., et al.: A computer system of flight management. *Modelling, Simulation and Control*, 3, No.3, pp.1-8, 1982.

9. Orlin, J.B.: Minimizing the number of vehicles to meet a fixed periodic schedule. *Oper.Res.*, 30, No.4, 1982, pp.760-775.

10. Rydel, J.: Harmonogram przewozów lotniczych (Schedules of air transport; in Polish). *Zeszyty Naukowe Politechniki Śląskiej, s. Automatyka*, issue 95, 198[illegible].

11. Wahlner, R.D.: An airiline schedule tail routing algorithm. *ORSA/TIMS Conference in Colorado Springs*, 1980.

12. Szczegółowe przepisy ruchu lotniczego cywilnych statków powietrznych. Zasady ruchu lotniczego (PL 2) (Detailed rules of air traffic of civil aviation. Principles of aircraft traffic (PL 2); in Polish). Ministerstwo Komunikacji, Warszawa, 1980.

13. Chojnacki, A.: Przepływy w sieciach pojemnościowych (Flows in capacity networks; in Polish). WAT, Warszawa, 1980.

14. Chojnacki, A.:Metoda wyznaczania rozkładów pociągów pasażerskich (A method for determination of time schedules for passenger trains; in Polish). In: Wyznaczanie rozkładów jazdy dla pociągów pasażerskich i towarowych. Etap III (Determination of schedules for passenger and cargo trains. Stage III; in Polish). Unpublished report from work for COBiRTK WAT, Warszawa, 1980.

15. Chojnacki, A.: Opis problemu wyznaczania rozkładu jazdy dla pociągów pasażerskich (Description of the problem of determination of schedules for passenger trains; in Polish). In: Wyznaczania rozkładów jazdy dla pociągów pasażerskich i towarowych. Etap III (Determination of schedules for passenger and cargo trains. Stage III; in Polish). Unpublished report from work for COBiRTK WAT, Warszawa, 1980.

16. Coffman, E.G., jr. (ed.): Computer and Job-shop Scheduling Theory. John Wiley & Sons, Inc. New York, 1976 (Polish translation: WNT, Warszawa, 1980).

17. Evans, J.R., Jarvis, J.J.: Network Topology and Integral Multicommodity Flow Problems. *Networks*, 8, 1978.

18. Gajda, B.: Technika ruchu kolejowego (Railroad traffic technology; in Polish). WKŁ, Warszawa, 1959.

19. Glover, F., Klingman, D.: Network Applications in Government and Industry. *AIIE Transactions*, 9 (4), 1977.

20. Grabowski, J.: Algorytmy optymalizacji i sterowania w dyskretnych systemach produkcyjnych (Optimization and control algorithms for discrete production systems; in Polish). Praca Naukowa ICT PWr, no.42, Wrocław, 1977.

21. Janocha, M., Michalak-Kowalski, Z., Smolarz, W.: Zagadnienia przeoustowości linii kolejowych (The problem of capacity of railroad lines; in Polish). WKŁ, Warszawa, 1967.

22. Korzan, B.: Elementy teorii grafów i sieci. Metody i zastosowania (Elements of graph and network theory. Methods and applications; in Polish). WNT, Warszawa, 1978.

23. Piasecki, S.: Optymalizacja systemów przewozowych (Optimization of transport systems; in Polish). WKŁ, Warszawa, 1973.

24. Wyrzykowski, W.: Ruch kolejowy (Railroad traffic; in Polish). WK, Warszawa, 1954.

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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