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Parcels Transport Optimization Problem

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1. Introduction

To describe a parcels transport organization problem, firstly, it is necessary to define the concept of parcel. let us define a parcel to be wrapped freight having specified origin and destination. Its quantity is much smaller than a carrier load capacity, excluding bulk transport from one origin and destination pair.

In transport category the parcels belongs to such examples as: container transport, goods delivering to markets, postal delivering and others. Different transport modes can be engaged in parcels transport, for examples, road, rail, sea and our transportation.

When the carrier load capacity is only equal to several parcels, however, the problem of thousands parcels transport from one origin to one destination is not a parcels transport problem but a bulk transport problem. Operation of parcel—further—freight grouping in "portions" summed to carrier load capacity is a typical operation for parcels transport techniques. For railway transport, there is an operation of marshalling. Coaches having the same destinations are grouped in a freight trainschains. Trains are reassembled at marshalling yards which are special kind of yards compared with loading and unloading yard for road transport. There are operations of parcels grouping at stores and reloading of tracks in special bases. The same is in air transport. In shipping parcels grouping operations are performed at ports and there exist a problem of stevedoring. Notice that grouping operations are typical not only for transportation but for communication systems as well. For better understanding of parcels freight grouping problem it will be described more detailedly for rail transport.

Consider a railway network where nodes represent reloading and marshalling yards and links represent lines connecting yards. Each marshalling yard has its region of loading and unloading yards which are served from the given marshalling yard. Between marshalling yards are moving only trains assembled from dozens of coaches. Such transport organization exits as a result of experiences over many years. We consider parcels transport as a freight movement and a carriers movement. Freight movement should satisfy demands for parcels delivering from given origins to destinations and that movement is caused by carrier movement. It makes carrier movements and reassembling(marshalling) point choices—decisions. Those decisions are constrained by carrier load capacities, line capacities and trans port demands. In carrier movement and their reassembling organization, operation plan which minimize total cost of parcels delivering and while satisfying existing constraints is the objective of our interest.

In many transport system, there are two kinds of transport means: passive transport means (coaches, trailers, barges) for which main characteristic is loading capacity; and active transport means such as locomotives, tugs etc. In such cases operation plan—timetable of transport consist of two plan—timetables for passive and active transport means. Passive transport means movement is determined by parcels delivering demands. Active transport means movement is determined by passive transport means delivering demands. For example: considering a contained railway system, there will be three plans:

- movement and reloading of containers (empty and full up);
- movement of coaches and reassembling of trains;
- locomotives movement.

In the remainder of the paper we will consider passive and active transport means movement in a railway system. For simplification we only consider routing problem.

2. Decomposition of the Parcels Transport Problem

The railway network consists of nodes and links representing rail connections and marshalling yards. Movement of trains—further being understood as assembled number of railway coaches will be the objective of our interest. Each coach has its origin—destination pair. Locomotive routing problem is omitted, for it is the secondary problem. Demands for locomotives are determined by the number of coaches assembled, therefore, we are able to formulate a locomotives routing problem separately.

There are five problems involved in trains movement. First of them is the problem of coach movement to the nearest marshalling yard. The second problem is the determination of regions—set of yards from which coaches are delivered to the given marshalling yard. The third problem is inter-marshalling yards routing problem. Coach movement from the given marshalling yard to destinations yards which are located in the region served from the marshalling yard is the fourth problem. The fifth problem is the problem of determination of region—set of yards to which are delivered coaches from the given marshalling yard. Notice that the second and fifth problems can be thought as a problem of set dividing into subsets. Subset number is equal to marshalling yards number. Those divisions can be different and there can be some of empty subsets. The location problem of marshalling yards is omitted. Assume that regions served by marshalling yards are given, hence, we have three problems to solve. The overall problem formulation was done at work but here we pass further.

Reassuming the parcels transport problem was decomposed into three problems as:

- inter-marshalling yards transport problems;
- problem of delivering coaches from or to marshalling yards inside region.
- inside region transport problem.

Notice that knowing the amount of trains coming to marshalling yards and going out and their structures, we can calculate the amount of marshalling work at each marshalling yard. Then knowing train route, we can calculate transport flow intensity on each link.

In the remainder part of paper there will be presented inter-marshalling yards transport problem —called further interregion transport problem. The problem will be presented in two stages. Interregion transport concentration problem involved in choice of routes on which will be delivered parcels from specified origins to destinations in the first problem. Freight grouping in trainschain and grouping yards choice is the second problem being considered. In terms of routing theory, the problem consists in constructing concentrated flow (first problem) with the minimization of total energy cost of transportation.

3. Interregion Transport Concentration Problem

The marshalling yards network is represented by a graph $\Gamma = (J, R)$ where is the set of node (marshalling yards) and the set of (i, j) links which define existing railway lines. There are given $\Lambda_{ij} > 0$ transport demands for empty and full up coaches on the set defined by the graph.

$\Lambda_{ij} > 0$ for $(i, j) \in R$

There are defined, on the R set, next functions:

d_{ij}—the distance between i and j node;

U_{ij}—the (i, j) line capacity (trains per time unit).

There is defined $P_i > 0$ the i yard marshalling capacity function. Our task is to calculate the shortest and most concentrated possible transport routes.

Define M_{kl} route, from the K to L yard, K, L $\in$ J, to be a set of node pairs being ordered;

$M_{kl} = \{(i_1, j_1), (i_2, j_2), \ldots, (i_n j_n)\}$

where: 1) $(i_n, j_n) \in R$ is an element of R set; 2) $i_1 = k$, $j_n = l$; 3) $j_n = i_{n+1}$ for each $n = 1, 2, \cdots, n-1$; 4) (i_n, j_n) pair has no loops inside. We introduce a discrete decision variables class:

$$X_{ij}^{kl} = \begin{cases} 1 \text{ if } (ij) \in M_{kl} \\ 0 \text{ otherwise} \end{cases} \quad (1)$$

Freight train routes are well-defined by those variables. M_{kl}^{min} is a route having the shortest length D_{kl}^{min}. But minimum routes are not searching for. In many cases, practically, the better solution is that one for which routes cover each other at least partly, for greater freight flow makes it possible more frequently full up transportation means running possible, which ensures faster parcels delivering, better transport means utilization, and in consequence transportation cost decrease. All it is constrained that a difference between given M_{kl} and M_{kl}^{min} (the chosen route and the shortest route) is inconsiderable. To find a transport concentration solution, there is proposed the next criterion function:

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

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

$$v_{ij} = \sum_{k,l \in A} X_{ij}^{kl}, \quad \Phi(v_{ij}) = \begin{cases} v_{ij} \text{ if } v_{ij} > 1; \\ 0 \text{ otherwise.} \end{cases}$$

The distance and freight product sum, represented by the first function element, prefers total route length minimization. The second function element prefers solutions for which routes cover each other on the most of routes sections.

Notice that Z_{ij}—number of trains per time unit in (ij) relation could be calculated as:

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

where: N_{ij}—the preferable number of rail coaches at a train on (ij) line. Hence, the X_{ij}^{kl} —decision variables have to satisfy line capacity condition:

$$Z_{ij}\leq u_{ij} \qquad (3)$$

The number of reassembled freight trains—marshalling work at the given h yard can be obtained as:

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

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

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

Limited marshalling capacities at yards makes that decision variables should satisfy the next condition:

$$\sum_{i\in J}(Z_{ih}+Z_{hi})\leq P_h \qquad (4)$$

Optimal transport concentration is now obtained by minimization of function (2) under the given constraints.

1) Solution Approach

There is presented a heuristic algorithm that could be used to find a solution in easy way. The algorithm iteratively, for the given (α) task parameter, calculates M_{kl} routes from the k origin to l destination for (k, l) $\in$ A pair.

(1) Main Step

Assume that only one transport demand is given. Then routes satisfy conditions which are selected from all possible routes between the k_1 origin and the l_1 destination. For the chosen (k_1, l_1) routes, a (k_2, l_2) route is selected, which realize second transport demand to minimize criterion function and to satisfy the conditions. The produce is repeated to calculate all routes so as to realize all transport demands. The algorithm was implemented on IBM PC in Turbo language with using graphics procedures. Distance between optional solution and a solution obtained by using the algorithm suggested was omitted.

2) Examples

This section applies the solution method to hypothetical examples. Each example was calculated many times for different task parameter a.

(1) First Example

There is shown a network on the figure 1. All elementary distances are equal 1, d_{ij} = 1 (i, j) $\in$ R. Link capacities are equal 2, μ_{ij} = 2 except (2, 3) and (3, 4) link, P_i—the marshalling yards capacities are enough.

All transport demands for relations (1, 4), (1, 5) and (2, 3) are equal 1. There are shown of figure:
1a—the solution for α = 0;
1b—the solution for α = 0.1; 0.2;
1c—the solution for α = 0.3, we observe concentration of transport,

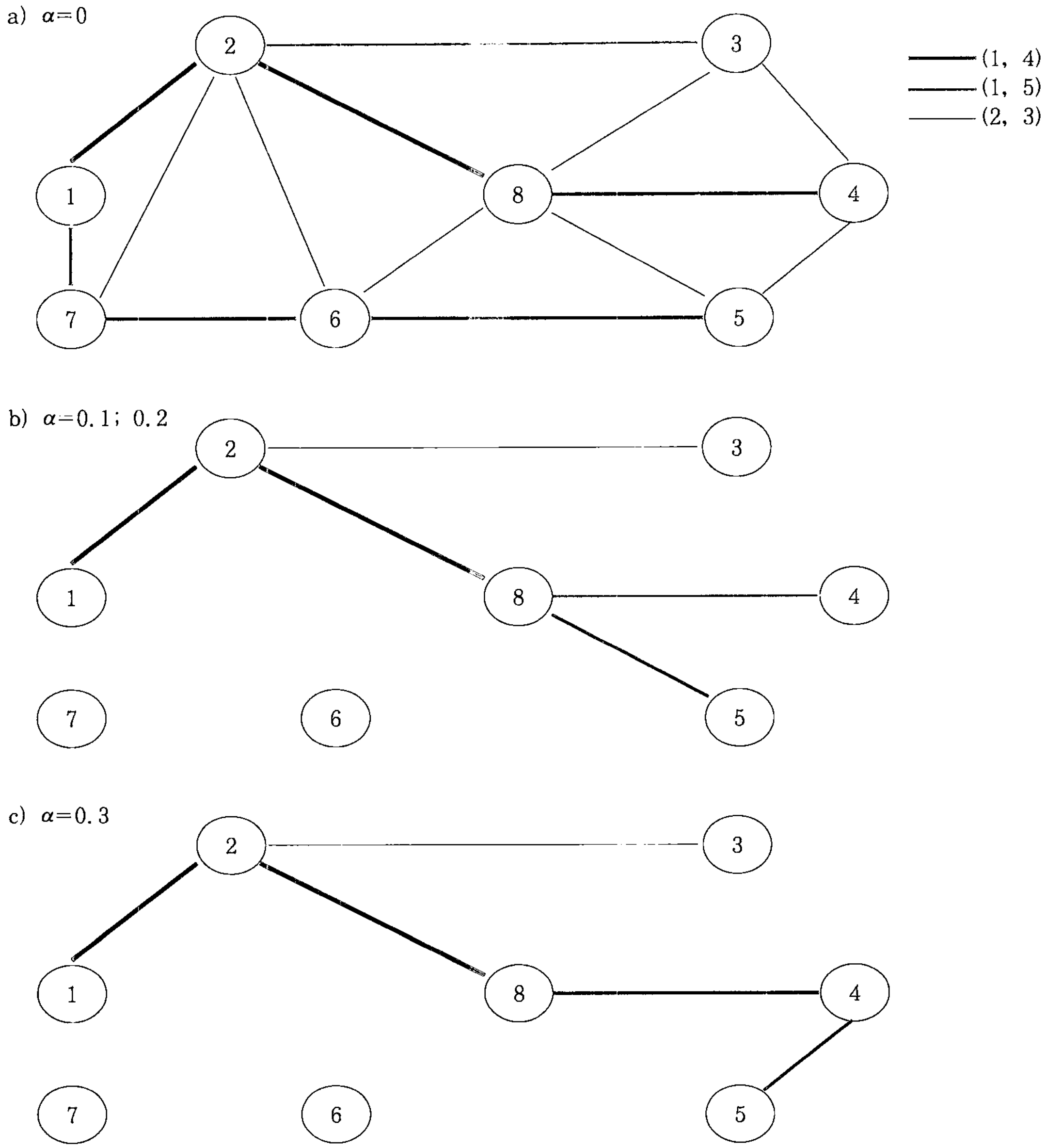


Figure 1

in the example, increase with the increase of parameter α.

(2) Second Example

There is given a network, on the figure 2. The distance are put on links, link capacities and node capacities are enough. Transport demands are as presented. For α = 0; 0.5 and 0.7 we have got the same result. For α = 0.8 and 1.0 we have more concentrated routes. Shown examples illustrate the transport concentration problem and the imperfection of the proposed algorithm. For α = 0 always are

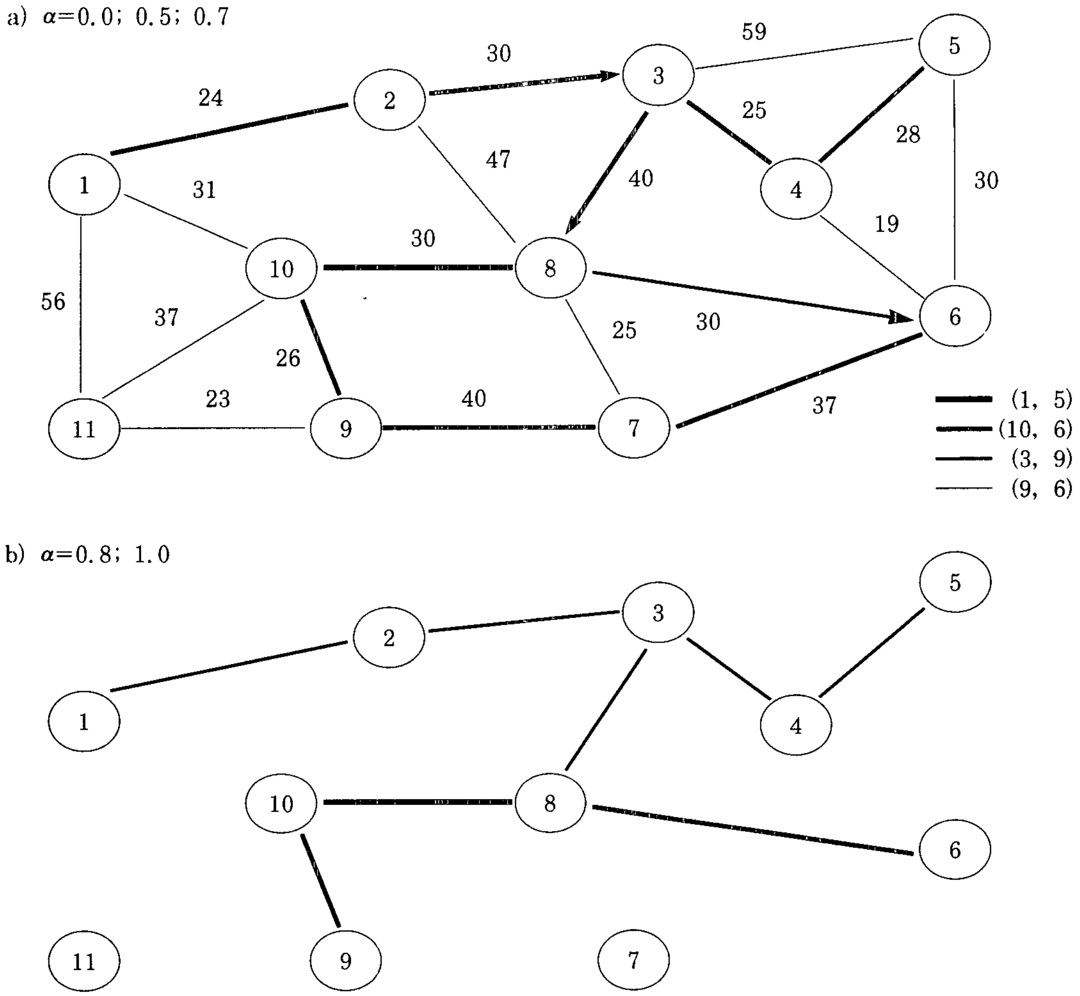


Figure 2

chosen the shortest routes. Increasing the α task parameter causes increasing transport concentration and lengths of routes.

4. Freight Train Grouping Problem

At previous section, there were obtained the routes for each origin—destination pairs, $(ij) \in R$, as a solution of transport concentration problem. The route for the given origin—destination pairs is now defined as a sequence of nodes:

$$M_{ij}=(i_{ij}^{0}, i_{ij}^{1}, \cdots, i_{ij}^{m(ij)}),$$

Each route $(ij) \in R$ has its Λ_{ij} transport demand function which is describing a freight demand per time unit. The railway network is represented by a graph $G(J, U)$, where J is the set of nodes and $U \in J \times J$ the set of links. Let $R_{rs} \subset R$ to be a subset of those (ij) pairs for which M_{ij} route pass the (r, s) link, $(r, s) \in U$.

$$R_{rs}=\{(i,j): \exists_{k}(i_{ij}^{k-1}=r,\ i_{ij}^{k}=s)\},$$

$k=1, 2, \cdots, m(i, j)\}; (i, j)\in R.$

Hence, the freight flow intensity on the (r, s) link is obtained as a sum of transport demands:

$$\rho_{rs}=\sum_{(ij)\in R_{rs}} \Lambda_{ij} \quad (r, s)\in U$$

Particularly, it $R_{rs} = 0$ then $\rho_{rs} = 0$. Such defined data could be imagined in the next way. if a (ij) pair is interpreted as a color and the M_{ij} route is covered by the color line having 'thickness' proportioned to Λ_{ij} transport demand, then an illus- trations of the graph covered by color lines represents as input data for the problem of freight grouping. Generation of freight groups—trains which satisfy the conditions and their number minimization will be obtained by solving the freight grouping problem. It is obvious that works connected with reassembling of freight trains should be minim- ized.

Define N_{uv} to be the freight group route between u and v node, where $u, v \in J$,

$$N_{uv}=(r_{uv}^{0}, r_{uv}^{1}, \cdots, r_{uv}^{n(uv)}), \quad r_{uv}^{l}\in J$$

and N_{uv} is a subsequence at least one M_{ij} route.

Define B_{uv} to be unempty set of (ij) origin—destination pairs for which M_{ij} routes enclose the N_{uv} subsequence. There is $K = 1, 2, \cdots, m(i, j) - n(u, v) + 1$ such that

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

Hence, the freight flow intensity on the N_{uv} subsequence is calculated as the sum of Λ_{ij} transport demands:

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

Notice that for any (r, s) pair of nodes such that

$$r=r_{uv}^{l} \text{ and } s=r_{uv}^{l+1}$$

B_{uv} is a subset of R_{rs}

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

For each (u, v) pair belongs to the B set, where:

$B = \{(u, v): B_{uv} \neq 0\}$

the freight flow intensity ρ_{uv} should satisfy a product of train load capacity, if possible,

$\rho_{uv} = \upsilon_{uv} \cdot N_{uv}$

where: υ_{uv} – a natural number;

or $[(\upsilon_{uv} - 1) + q] \cdot N_{uv} \leq \rho_{uv} \leq \upsilon_{uv} \cdot N_{uv}$ (1)

where: q – a coefficient, $q < 1$

Define $D^{rs} \subset B$ to be a set of those (u, v) pairs for which N_{uv} sequence is pressing by the (r, s) link.

$$D^{rs}=\{(u,v)\in B: \exists_{t}(r_{uv}^{l-1}=r, \ r_{uv}^{l}=s\};$$
$$l=1, 2, \cdots, n(uv)\}; \ (r, s)\in U$$

Next, unions are defined:

$$D_j=\bigcup_{r} D^{rj}; \ D^j=\bigcup_{s} D^{js}$$

Intersection of those sets determines which grouping chains are started of ended at the J node. The P_j marshalling yard capacities constraints number of passing by the J yard. hence, a condition

$$[D_j \backslash D^j] \leq P_j \text{ for each } j \in J \qquad (2)$$

where: $[D_j \backslash D^j]$—the cardinality.

That condition forces a transport organization fit to marshalling yard capacities. Notice that problem solution without taking into account the second condition can be used for modernization of railway network.

Also, a solution should satisfy a condition on line capacity.

$$\sum_{(uv)\in D^{rs}} \upsilon_{uv} < u_{rs} \text{ for } (r, s)\in U \qquad (3)$$

where: u_{rs}—the line capacities.

Then, a solution of the freight grouping problem can be presented in the next way. If a N_{uv} sequence is interpreted as a color line connected u and v node and having thickness proportioned the number cf trains passing by uv then the illustration of the graph covered by color lines represents the freight grouping problem solution. Notice that input data were interpreted in the same way. Then, the problem solution algorithm will be an algorithm of transportation of input cover to output cover. The aim of that transportation is freight grouping so that it minimizes marshalling works, which implies minimization of a freight group subroutes number.

The minimization of number of lines defined by the B set is the criterion function.

$$\| B \| \rightarrow \min \qquad (4)$$

1) Solution Approach

The freight grouping problem presented here has substantial new formulation and there has been no algorithms in a bibliography of the problem. No one of the exiting algorithms could be adopted to solve the problem. Therefore a method of suboptimal solution calculation is proposed. The method consists in generation of freight grouping routes which satisfy the first and second condition. Freight grouping routes are constructed dependently on chosen strategy parameters, firstly, without taking into account the second condition. A solution which satisfy the second condition can be obtained by steering grouping strategy parameters. Strategy parameters choice can be fully automated.

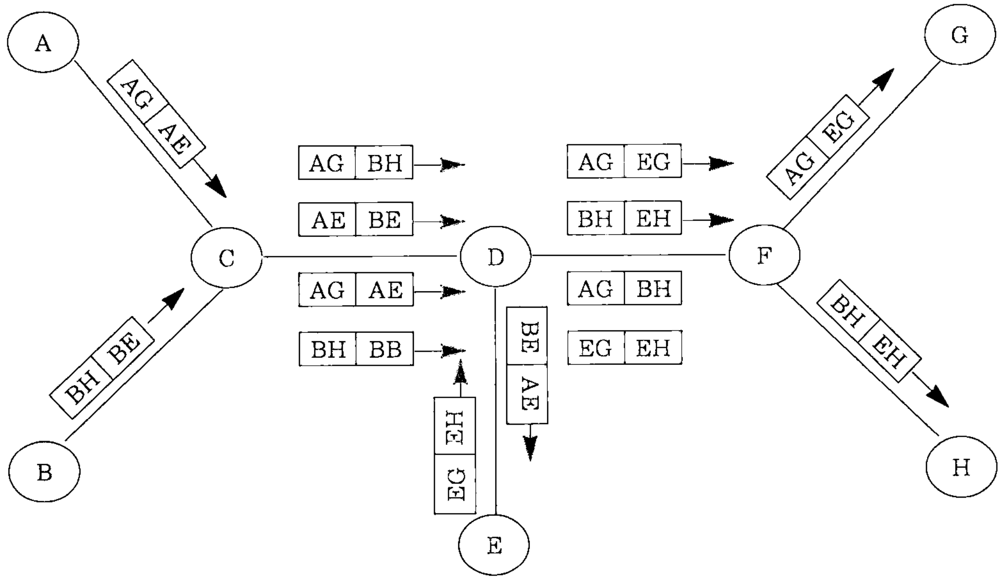
The minimization of number of lines-routes can be obtained by the freight grouping strategy parameters choice. Below, there is presented the freight grouping algorithm. Assume that $N_{ij} = C =$ const.—the preferable coaches number at a train for each route is the same.

Define grouping strategies chain to be elementary strategies sequences. There are defined two elementary strategies:

1. SK—the "sorting on end" strategy. The strategy consist in sorting of M_{ij} route sequences being currently at the given "i" node for separate grouping subsets which include route sequences having a join most distant node $i_{ij}^{u} = V$ where k should be possible large number. Additionally the first condition is taken into account. As a result, the $N_{iv} = \{i, \cdots, v\}$ grouping sequences and suitable B_{iv} set consisting (ij) routes having common N_{iv} part are constructed.

2. BZ—the "without change strategy consist in sorting M_{ij} route sequences being currently at the given "i" node on the some second element $(i_{ij}^{1} = u)$. Additionally the first condition is taken into account. As a result, the $N_{iu} = \{i, u\}$ one element routes and suitable B_{iu} set consisting of (ij) routes having common (iu) element. The SK strategy groups freight in order with the longest common route. The BZ strategy enable not to sort M_{ij} routes having the same second element.

The second strategy consist in sending freight groups to next node without change (reassembling), if it is possible. For each node sets aresorting in accordance with a one of strategy presented. Strategy choice can be involved with marshalling yard capacities. For the



$A_{ij} = 1$; $C = 2$
$R = \{AG, AE, BH, BE, FG, EH\}$
$M_{AG} = (A, C, D, F, G)$; $M_{AE} = (A, C, D, E)$; $M_{BH} = (B, C, D, F, H)$;
$M_{BE} = (B, C, D, E)$; $M_{EG} = (E, D, F, G)$; $M_{EH} = (E, D, F, H)$;

The strategy BZ, BZ ···.

The strategy SK, SK ···.

SOLUTION:

$B = \{AD, BD, DE, EF, DF, FG, FH\}$;
$N_{AD} = (A, C, D)$; $B_{AD} = \{M_{AG}, M_{AE}\}$;
$N_{AB} = (B, C, D)$; $B_{BD} = \{M_{BH}, M_{BE}\}$;
$N_{DE} = (D, E)$; $B_{DE} = \{M_{AE}, M_{BE}\}$;
$N_{EF} = (E, D, F)$; $B_{EF} = \{M_{EG}, M_{EH}\}$;
$N_{DF} = (D, F)$; $B_{DF} = \{M_{AG}, M_{BH}\}$;
$N_{FG} = (F, G)$; $B_{FG} = \{M_{EG}, M_{AG}\}$;
$N_{FH} = (FH)$; $B_{FH} = \{M_{EH}, M_{BH}\}$;
Marshalling: $D - 2 \times 2$, $F - 2 \times 2$

$B = \{AC, BC, CD, CE, DG, DH\}$
$N_{AC} = (A, C)$; $B_{AC} = \{M_{AG}, M_{AE}\}$
$N_{BC} = (B, C)$; $B_{BC} = \{M_{BH}, M_{BE}\}$
$N_{CD} = (C, D)$; $B_{CD} = \{M_{AE}, M_{BH}\}$
$N_{ED} = (E, D)$; $B_{ED} = \{M_{EG}, M_{EH}\}$
$N_{DG} = (D, F, G)$; $B_{DG} = \{M_{AG}, M_{EG}\}$
$N_{DH} = (D, F, H)$; $B_{DH} = \{M_{BH}, M_{EH}\}$
Marshalling: $C - 2 \times 2$, $D - 2 \times 2$

Figure 3

given i node which has a large marshalling capacities—the first strategy should be chosen. Otherwise the second one. More advanced algorithms could use other strategies or change of choice strategies dynamically during the algorithm realization.

2) Examples

To help understand the algorithm, there are presented examples of such construction for a railway network. At the examples for simplification, we assume that: transport demands for each origin—destination pair is the same and equal 1 coach per day. Trains are assembled from two coaches ($C = 2$). There are written origin—destination pairs on each coach at figures.

B_{uv} sets and suitable N_{uv} sequences are also put down at figures. Two variants of solution

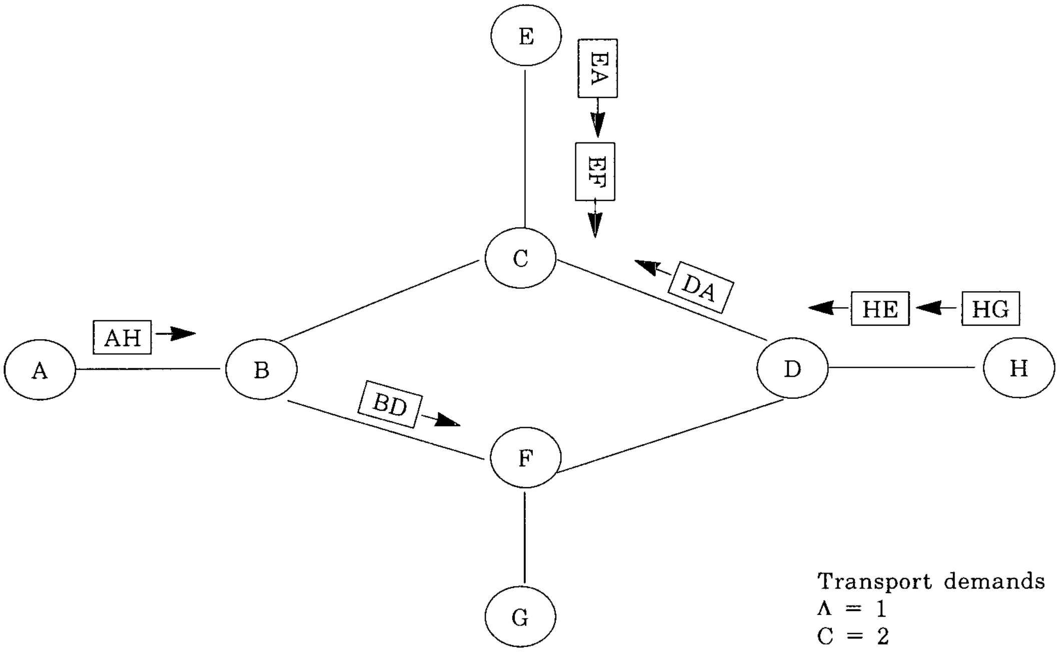


Figure 4

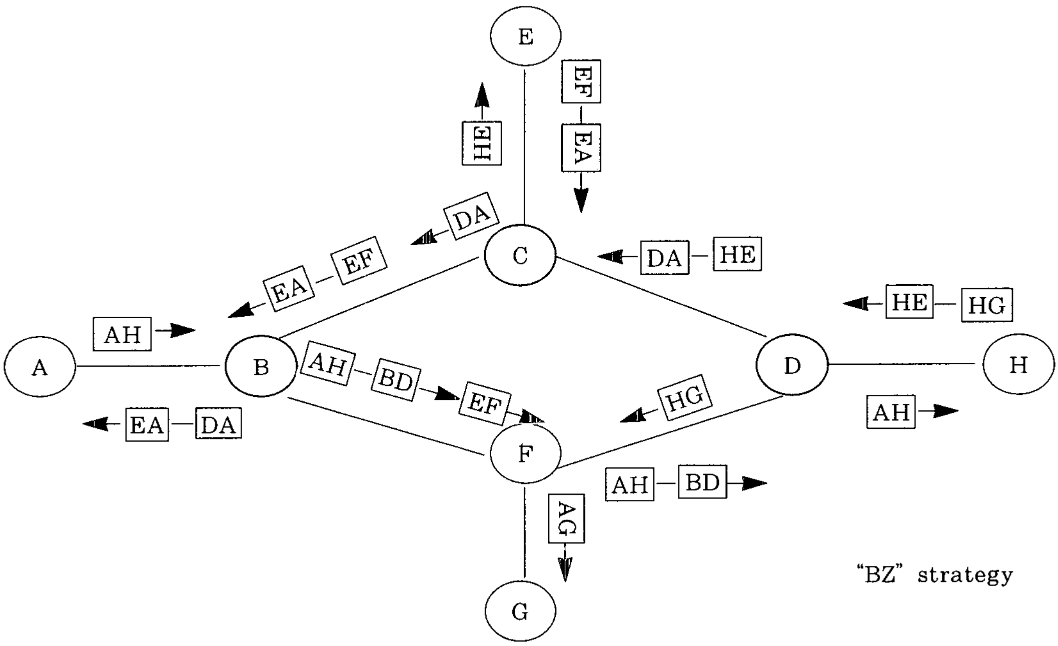


Figure 5

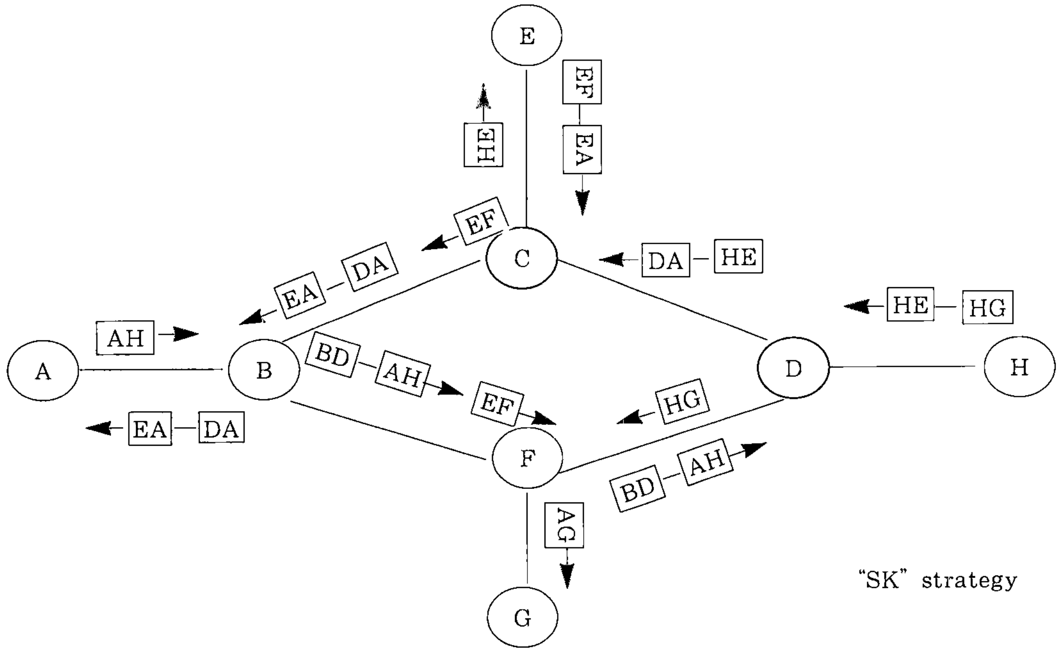


Figure 6

were tested. The first variant is one with "without change" strategy for all nodes and the second variant with "sorting on end" strategy for all nodes. The algorithm was implemented on IBM PC in Turbo Pascal Language with using of graphics procedures. The first example is presented on the third figure. Analyzing the solutions obtained it can be stated the marshalling works for both solutions are the same. The second example is presented on the figure 4, 5, and 6. Compared to two solutions for the point of marshalling works, the better solution is the second one obtained by using the "sort on end" strategy.

5. Conclusions

There were presented only several problems connected with the parcels transport problem for which were new formulation proposed in the paper. The parcels transport problem was presented and was decomposed as the example of railway system. Solution of the problem consists in solving of two subproblems separately. Solution of the interregion transport concentration problem gives the routes concentrating transport on some lines. Solution of the freight grouping problem gives final solution which minimize marshalling works giving trains compositions. The formulations and methods presented here may need improvements and modifications. The problem of distance between optimal solution and solutions obtained by using the method proposed was omitted.

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