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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.

5. THE PROBLEM OF SCHEDULING OF TRANSPORTS

5.1. Characterization of the problem

The purpose of unambiguous determination of organization of transport of parcel cargoes can be attained through definition of transport schedule. If the first two problems - of concentration of loads and of grouping of loads concerned translocation of cargoes in physical space - over the road network - then the schedule determines translocation of loads in temporal space.

Problems of scheduling are generally encountered in various production processes, service and supply systems etc. [16]. In transport they are of specific nature although they significantly differ depending upon the nature of transport means. One of the most difficult is certainly the problem of scheduling of railroad transport. This problem differs from the other scheduling problems in that on one railway segment (between two consecutive semaphores) there may only be one train. It can be said that every route in a railroad network is composed of segments of unit capacity, although the time of covering of these segments may be different (there may be different lengths of these segments). Such networks are referred to as capacity networks and their properties are described in more detail in [13].

The problem of scheduling of transport of loads will be shown, for better illustration, on the example of railroad transport, with significant simplifications. Therefrom the names we shall be using. In this case, namely, vertices of the network correspond to junction stations, loads correspond to cars, and transport assemblies correspond to train compositions. All our considerations can of course be extended to other transport means by adopting further simplifications.

In order not to introduce unduly complications caused by insignificant details we shall assume that the lengths of all segments connecting nodes (vertices) is the same (constant over the network). Thereby the description of the network gets much simplified. On the other hand it will be more complex, for every vertex and every segment must be assigned corresponding families of "occupancy sets".

The occupancy set for a given segment or node (vertex) shall be composed of all the time instants belonging to a compact set, during which this entity is inaccessible. A train composition "wishing" to enter such a segment or a node must wait before a semaphore prior to be allowed to enter. Every occupancy set is a closed and compact set and it is defined for a node with a pair of numbers (α_r,β_r) defining the edges of the set $(\alpha_r \le \beta_r)$, and for a segment - by a pair of numbers (γ_s,ξ_s), with, naturally, $\gamma_s < \xi_s$. If we take into account a definite segment indexed "i", then it is characterized with the family of sets

$$O^i = \{(\gamma_1^i,\xi_1^i),(\gamma_2^i,\xi_2^i),\ldots,(\gamma_s^i,\xi_s^i),\ldots\}$$

Similarly, every vertex having index "j" is characterized by the family of sets

$$W^j = \{(\alpha_1^j,\beta_1^j),(\alpha_2^j,\beta_2^j),\ldots,(\alpha_r^j,\beta_r^j),\ldots\}$$

Thus, as we can see, description of the network gets very complicated in spite of the simplifying assumptions we had adopted at the beginning.

If we accept, furthermore, that we consider only problems of scheduling for regular transports then the cardinality of families is limited. In case when the basic cycle of regularity is, for instance, day, which means that schedule is repeated every 24 hours, we can restrain ourselves to determination of the daily schedule for all the stations and segments in the whole network, while the sets O^i and W^i would concern daily periods.

Note, then, that families W^i and O^i have the nature of given initial external constraints.

On the other hand, once we plan a movement of a train composition then during its translocation through consecutive segments and nodes both these kinds of entities through which it passes are occupied by this composition and cannot therefore be used by other compositions whose movements we should also plan. Thus, any decision concerning motion of one of the compositions immediately sets limitations upon the motion capacities of other compositions. It is this interdependence that is the main cause of difficulties in finding of optimal solution. Practically, only Bellman's optimality principle can be applied. And it is on the basis of this principle that all the algorithms described further on meant for elaborating schedules were developed.

The problem of scheduling of transports gets further complicated for independently of determination of schedules we have simultaneously to determine all the occupancy sets for all the nodes and segments, resulting from the schedule adopted, so that we have to update the given initial occupancy sets of the network.

It can also be said that the problem of determination of a schedule reduces to determination of occupancy sets (for segments and vertices) which do not overlap mutually and with the initial sets.

Note that if a composition reaches a segment (or a node) in the instant when this element of the network is occupied then the composition has to wait until occupancy ends. If the composition reaches an element of the network in the instant when it is free, then one should verify whether it can fit time-wise into the time period before the instant when the next occupance period begins. In order to state this one should determine the time which is necessary to cover the distance in question (in our present considerations, due to assumptions of equality of segments the time mentioned is a unit time), and then compare it with the time we dispose of until the time of subsequent occupancy. If our composition fits in time-wise then such a movement is (in our case) acceptable. In reality, when segments considered do not connect nodes but are only segments along a line between two stations then we have one more condition, namely, our composition must not only cover the segment considered in the time period available, but it has also to leave this segment, that is - enter the subsequent one which has to be open (unoccupied). Since in our case every segment ends with a junction station the condition mentioned is insignificant, for it applies therefore to stations which have, according to the assumptions adopted, unlimited possibilities as to "keeping" of the trains.

Thus, in the simplified case here considered all the train stops occur uniquely in the vertices. The time of passage through a vertex may be "short" (passage with a possibility of change of locomotive), or "long" (passage connected with the necessity of marshalling work over the composition - disconnecting or connecting of cars).

Consequently, the time during which a composition is in a station can result from:

- the necessity of waiting until a segment is no longer occupied, with the time of waiting defined by the transport situation in the network;
- the time necessary for changing the locomotives ("short stay");
- the time necessary for rearranging the composition (and the change of the locomotive) - the "long stay".

It was assumed in the numerical examples that the "short stay" is equal quarter of a time unit, while the "long stay" is equal half of a time unit. To compare, recall that the time of passage over a segment equals one unit. A certain disbalance of temporal proportions in relation to the real ones existing in railroad transport was introduced purposefully in order to make the role of vertices come out more distinctly. The algorithms of solving of the scheduling problems do not depend, of course, upon the proportions mentioned.

It is assumed, as well, that in a given time instant only one train composition can be subject to marshalling - while it is possible that other compositions and cars wait until the system of the marshalling yard is freed and can be used.

In order to simplify calculations very short train compositions (car sets) are considered only, containing at most two cars (loads, cargoes) or two car groups.

Recall that the initial data are the routes of all the loads (cars) together with determination of all the vertices over which marshalling of the compositions (car sets) shall take place.

One more remark. Persons dealing with railway transport shall be probably surprised that the schedules of movements of compositions are being determined as if we forgot that compositions do not ride "by themselves" but are always pulled by a locomotive thereby forming a "train".

Such an approach was taken purposefully. Namely, in the first stage the movements of compositions are determined as if they really moved by themselves. Then, on the basis of the schedule of translocations of these compositions the needs for locomotive work are established. The thus determined needs for locomotive work serve as the basis for elaboration of the schedule of employment of locomotives. The latter schedule, together with the previously determined schedule of movements of compositions, makes up the train schedule, which in turn serves as the basis for establishing the schedules of train team work, marshalling work etc. Thus, the spatial schedule of movements of cars (loads) and train compositions (car sets) determines the whole organization of transport of cargo loads (that is, movements of cars, locomotives and trains as well as utilization degrees of segments and stations) [23].

5.2. Description of the solution method

In order to present the main ideas of the proposed algorithm we shall consider a number of fundamental cases which might appear during the search for solution of the problem. Simultaneously, we shall introduce certain nominal notions of actions undertaken, which on the one hand shall be helpful in the formalized notation of the algorithm and on the other hand remain in close relation with the names used in the test program.

Case 1A

The load (car), whose schedule is determined, travels the whole way alone.

This case is identical with the situation which was commented upon in the previous point, concerning the general problem of scheduling - with the difference (mentioned already before) that the route of cargo is predetermined. It was decided to take up the variant which is conform with the general formulation of the problem consisting in the fact that the time for the cargo to reach the final node on its route is given. Determination of time segments, i.e. of the schedule, is performed starting with the final node of the route. Consecutive - earlier - times of arrivals at departures from preceding nodes are determined on the basis of knowledge of passage times for particular segments and junctions on the route, accounting for determination of the periods of waiting for a segement or a node to be accessible ("short stays") which might bring about a lengthening of the time of travel as compared to the minimum time necessary for covering the distance over the route.

These activities shall be referred to as backward scheduling. This name is meant to underline the fact that the time of arrival at the final node of the route is given.

Case 1B

The case of a load (car) communicating with loads of lower priority.

Since car-loads are considered in accordance with the sequence corresponding to their importance, then in the case of a joint load composition the schedule determined for the load of lower index - that is, of higher priority - defines the schedule for the load which is sent jointly with it over certain segments of the route. Thus, if the load currently considered is over certain segments of the route "communicated" (sent commonly) only with loads of lower priority then the main load can be treated in the same way as the load described in case 1A. The only difference is that in marshalling stations, i. e. - in these nodes where train compositions have to be grouped or split - time should be allotted to execution of just these functions, summing up to the "long stay" - and such a time interval should be added to the occupancy sets of corresponding sets. On the other hand, in this case as well, scheduling shall proceed in the backward manner, that is, starting with the final node of the route, depending upon the predefined time of arrival in this final node.

In our further considerations we shall not distinguish cases 1A and 1B, denoting them together as case 1.

Case 2

Initial segments of a route are covered by the load considered together with another load of higher priority, while on other segments of the route situation is the same as the one described in case 1.

As mentioned already, in case of existence of segments covered jointly by two loads, the schedule for the load having higher priority is in force also for the load which is connected ("in communication") with it. Thus, the schedule previously established is the same for the load currently considered - and the activity resulting from this conclusion is called "rewriting". On the other hand time instances for particular nodes of the route are determined as in Case 1, the only difference being that it is not the time of reaching the final node of the route that is given, but the time of entering the first segment of the route not overlapping with the already determined schedule. The starting time is the same as the previously determined time of leaving the node, in which separation of loads occurred, by the "communicated" load of higher priority. This type of scheduling, with given starting time, shall be called *forward scheduling*.

Case 3

At the terminal segments of its route the load is communicated with a load for which schedule was already established.

Situation at the terminal segments of the route is analogous to the one presented for Case 2 - the schedule already defined will be over these segments in force also for the current load - rewriting takes place. On the other hand schedule for initial segments of the route is being put together in the manner described in Case 1, with given time of reaching of the node in which connection of appropriate loads into a composition will occur. This will therefore be the activity defined before as backward scheduling.

Case 4

Combination of Cases 1,2 and 3.

The "middle" segments of the route (see figure) are ascribed times with the method of forward scheduling, where the time instant of reaching the node in which regrouping is to occur is given. There is, obviously, a risk of inconsistencies resulting from earlier definition of periods of staying in some nodes of the route. It is proposed at the present stage to give up in such a situation joining of the load considered into a composition and to shcedule it separately, according to the method described for case 1.

5.3. Determination of occupancy of nodes and segments

Both when carrying out activities connected with forward scheduling and when performing backward scheduling, in ascribing time instances of entering into particular segments (equal to times of leaving of preceding nodes) and time instances of entering nodes, one should take into account the fact that for certain time periods segments and nodes can be occupied.

The task of determination of occupancy can be formulated as follows: For a given node or segment, having definite current set W_i or O_i of times of occupancy and having - resulting form a concrete situation - time of entering a node or segment, a1, and the time period of staying there, determined by the time interval (a1,a2), to place this interval in the respective set W_i or O_i and to make use of it in the scheduling procedure.

As can be concluded from considerations accompanying Case 2 there are two possible situations:

First, when the time of waiting for a node or a segment to be free is zero (see Case 2) - temporal interval (a1,a2) can be added to the set W_1 or O_1 without any modifications, and, consequently, upon entering a node or segment considered there will be no additional stopping to wait for the network element to be free.

Second, when the waiting time is nonzero (see Case 1). In this situation it is necessary to modify the interval (a1,a2) so as to make it possible to join it to the set W_i or O_i. Procedure taken differs depending upon the nature of scheduling algorithm performed (forward or backward). In case of forward scheduling, with given starting time, the nearest - in time - break in occupancy of a node or a segment, which would be sufficient for containing the interval (a1,a2), with the resulting modified value of a1 being bigger (later) than the input value. Modification of a1 entails, of course, modification of a2.

In case of backward scheduling, with given time of arrival at the definite node or segment, procedure is similar, with the difference that the modified value of a2 is smaller (earlier) than the input value.

In both situations the difference between the input value of a1 and the modified value of a1 is defined as the waiting time for a node or a segment to be free (available).

5.4. Description of "HARMO" computer program

Computer program called "Harmo" carries out the algorithm presented in previous section. It is implementable on PC-like XT/AT computers working under MS-DOS. Source program was written in Pascal, and the output code was obtained with TURBO-PASCAL compiler. Since the purpose of the program is merely assistance in the analysis of functioning of the algorithm proposed, a user is not provided with facilitating devices such as a program organizing data definition, data correctness testing or graphical presentation.

As mentioned before, the HARMO program is an experimental construct, both in view of numerous facilitating assumptions and its purpose, namely - verification of correctness of the algorithm elaborated for various sets of data and preparation of fundamentals for inclusion of further improvements.

Let us recall that one of the simplifying assumptions was that time of passing through each and all of the route segments was the same and equal one hour. In a real network such an assumption is rarely satisfied. In a general case one would have to enlarge the data set, adding to it either information on times of travel through each of the segments of the network or assuming certain lengths of these segments and velocity, with which they can be covered.

The second essential limitation on generality of the program implemented is the consequence of certain simplification adopted at the preceding stage, concerning namely the maximum number of loads which could form one composition. Since the algorithm of grouping of loads into transport compositions was firmly based upon the assumption that compositions could be made out of at most two loads combined, this assumption was kept to in setting up the schedules.

Both these assumptions have a "technical" nature. In case of need respective fragments of the program could be replaced by more general procedures.

5.5. Numerical examples of scheduling

In order to illustrate the functioning of the algorithm computer calculations were performed for examples described in the previous chapter. They concerned the method of determination of car grouping in nodes having previously determined transport routes, accounting for the necessity of their concentration. The examples provided illustrate the final result of computer-based organization of transport of cargo loads in the form of a schedule.

Example 15

Routes of transport of loads are given, as resulting from solution to concentration of load transport from Example no. 10. Similarly, stations (nodes) are given, at which marshalling is to be performed (these are the results of the problem of load grouping from Example no. 10). Let us remind the corresponding data:

Transport routes (consecutive numbers of stations on the routes):

1st car: E-C-B-A
2nd car: E-C-B-F
3rd car: D-C-B-A
4th car: A-B-D-H
5th car: H-D-F-G
6th car: H-D-C-E
7th car: B-F-D

Routes of car compositions:

I. Cars 1 and 2: route E-C-B
II. Cars 5 and 6: route H-D
III. Cars 3 and 6: route D-C
IV. Cars 2 and 7: route B-F
V. Cars 1 and 3: route B-A
VI: Car 6: route C-E
VII: Car 4: route A-B-D-H
VIII: Car 5: route D-E-G
IX: Car 7: route F-D

As can be seen five two-car and four one-car compositions were formed. If we add locomotives to these compositions we obtain:

- five two-car trains, numbered I,II,III,IV and V, and

- four one-car trains.

As can be concluded from the above data, according to the No Change (NC) strategy, adopted in the Example 10, there is the need of marshalling two-car compositions in the following nodes (stations):

* in node A composition of train V (cars 1 and 3) is disassembled,
* in node B composition of train I (cars 1 and 2) is disassembled, while train IV is assembled (of cars 2 and 7) and train train V is assembled (of cars 1 and 3),
* in node C composition of train III (cars 3 and 6) is disassembled,
* in node D composition of train II (cars 5 and 6) is disassembled, while train III is assembled (of cars 3 and 6),
* in node E train I is assembled (of cars 1 and 2),
* in node F composition of train IV (cars 2 and 7) is disassembled, and
* in node H train II is assembled (of cars 5 and 6).

For the data given above transport schedules were determined for particular cars using HARMO program running on an IBM PC computer.

Tables below present the schedules of particular cars, with entries denoting arrival and departure times of cars from particular stations.

Recall again that the necessary technological stops at stations (nodes) are of two kinds:

- "short" stop (15 minutes) for exchange of locomotives, and
- "long" stop (30 minutes) for marshalling and locomotive exchange.

CAR SCHEDULES

CAR NO.1

Station	Arr.	Dep.
E	-	16:15
C	17:15	17:30
B	18:30	19:00
A	20:00	-

CAR NO.2

Station	Arr.	Dep.
E	-	16:15
C	17:15	17:30
B	18:30	19:00
F	20:00	-

CAR NO.3

Station	Arr.	Dep.
D	-	16:00
C	17:00	17:30
B	18:30	19:00
A	20:00	-

CAR NO.4

Station	Arr.	Dep.
A	-	14:30
B	15:30	15:45
D	16:45	17:00
H	18:00	-

CAR NO.5

Station	Arr.	Dep.
H	-	15:15
D	16:15	16:45
F	17:45	18:00
G	19:00	-

CAR NO.6

Station	Arr.	Dep.
H	-	15:15
D	16:15	16:00
C	17:00	17:30
E	18:30	-

CAR NO.7

Station	Arr.	Dep.
B	-	19:00
F	20:00	0:00
D	1:00	-

In the example used here for illustration there are no other stops at the stations but the technological ones - no train waits for an element of the network (a segment or a marshalling yard) to be free. It is easy to read out of the car (load) schedules presented the schedules of the trains. And thus, for instance, train no.I (cars 1 and 2) leaves station 5 at 16:15, arrives at station 3 at 17:00, leaves this station, after the locomotive has been changed, at 17:30, and arrives at station 2 at 18:30 to terminate its course and be disassembled.

Similarly we can read out the schedules of other one- and two-car trains.

On the other hand we can determine the demand for work of locomotives.

So, at 14:15, i.e. 15 minutes before the one-car train (car no.4) leaves, a locomotive is needed at station 1, then at 15:00, i.e. 15 minutes before assembling the two-car train II, composed of cars 5 and 6 a locomotive is needed at station 8, then at 15:45, i.e. 15 minutes before assembling the tw-car train III, composed of cars 3 and 6, a locomotive is needed in station 4, etc.

Simultaneously, we can read out from the schedules given above the time instants when locomotives are set free at particular stations. For example, in station no.2, the locomotive of the one-car train (car no.4) is set free at 15:45, exactly 15 minutes after the train has arrived. This locomotive can be sent back to station no.1 or stopped to wait in station no.2 until 18:45 when it will be needed for the two-car train no.IV formed in this station.

This, however, is an entirely different problem - the problem of putting together schedules for locomotives.

Example 16

This example shall be described shortly, for notation used is the same as in the previous example. Data for the example are taken from the Example 11 for grouping of loads. From the example quoted one could read out both the routes of particular cars and the marshalling problems of particular stations. Recall that the routes of transports are as follows:

1st car: A-B-C-D-E
2nd car: F-B-C-D-G
3rd car: C-D-G

Resulting from computations we obtain the following car schedules:

CAR SCHEDULES

CAR NO.1

Station	Arr.	Dep.
A	-	7:30
B	8:30	9:00
C	10:00	10:30
D	11:30	11:45
E	12:45	13:00

CAR NO.2

Station	Arr.	Dep.
F	-	7:30
B	8:30	9:00
C	10:00	11:30
D	12:30	12:45
G	13:45	-

CAR NO.3

Station	Arr.	Dep.
C	-	11:30
D	12:30	12:45
G	13:45	-

It can be concluded from the schedules of cars that car no.2 shall be waiting 1 hour in node C for car no.3 to be dealt with, for these two cars form the two-car train for the route C-D-G.

Example 17

Data for this example were taken from the Example 12 of load grouping. Recall that the routes of car transport are as follows:

1st car: A-B-C-D-E
2nd car: B-C-D
3rd car: E-D-C-B

4th car: E-D-C-B-A

Resulting from computations we obtained the following schedules of transport of particular cars:

CAR SCHEDULES

CAR NO.1

Station	Arr.	Dep.
A	-	9:45
B	10:45	11:15
C	12:15	12:30
D	13:30	14:00
E	15:00	-

CAR NO.2

Station	Arr.	Dep.
B	-	11:15
C	12:15	12:30
D	13:30	-

CAR NO.3

Station	Arr.	Dep.
E	-	11:30
D	12:30	12:45
C	13:45	14:00
B	15:00	-

CAR NO.4

Station	Arr.	Dep.
E	-	11:30
D	12:30	12:45
C	13:45	14:00
B	15:00	15:30
A	16:30	-

In this example there were no losses of time due to additional waiting.

Example 18

Data for this example were taken from the Example 4 (α=0.5) of load grouping.

Recall that the car transport routes are as follows:

1st car: 1-2-3-4
2nd car: 1-2-3-4-5
3rd car: 6-2-3-4

Car schedules obtained from computations are as follows:

CAR SCHEDULES

CAR NO.1

Station	Arr.	Dep.
1	-	16:15
2	17:15	17:45
3	18:45	19:00
4	20:00	-

CAR NO.2

Station	Arr.	Dep.
1	-	16:15
2	17:15	18:45
3	19:45	20:00
4	21:00	21:15
5	22:15	-

CAR NO.3

Station	Arr.	Dep.
6	-	16:15
2	17:15	17:45
3	18:45	19:00
4	20:00	-

In this example car 2 waited in station 2 one hour for the network segment from station 2 to station 8 to be free, this segment being previously occupied by the two-car (1 and 3) train composition, which left - after being assembled - station 2 at 17:45.

Example 19

Data for this example were taken from Example 8 ($\alpha=1.2$) concerning load grouping.

Recall that the routes of car transport are as follows:

1st car: 1-2
2nd car: 1-2-3
3rd car: 1-2-3-4
4th car: 1-2-3-4-5
5th car: 1-2-3-4-5-6
6th car: 1-2-3-4-5-6-7

Computations yielded the following car schedules:

CAR SCHEDULES

CAR NO.1

Station	Arr.	Dep.
1	-	15:00
2	16:00	-

CAR NO.2

Station	Arr.	Dep.
1	-	15:00
2	16:00	11:15
3	12:15	-

CAR NO.3

Station	Arr.	Dep.
1	-	12:30
2	13:30	13:45
3	14:45	15:50
4	16:00	-

CAR NO.4

Station	Arr.	Dep.
1		12:30
2	13:30	13:45
3	14:45	15:00
4	16:00	11:30
5	12:30	-

CAR NO.5

Station	Arr.	Dep.
1	-	10:00
2	11:00	11:15
3	12:15	12:30
4	13:30	13:45
5	14:45	15:00
6	16:00	-

CAR NO.6

Station	Arr.	Dep.
1	-	10:00
2	11:00	11:15
3	12:15	12:30
4	13:30	13:45
5	14:45	15:00
6	16:00	0:00
7	1:00	-

In this example there are no losses of time due to additional waiting.

It should be emphasized that the problem of scheduling of transport of loads is a very important problem from the point of view of organization of transport, especially of railroad transport in which the necessity of accounting for occupancy of segments of railroad network adds to the complexity.

In reality, capacities of platforms and sidings within the railroad network are also limited, this limitation being omitted in our analysis. In other kinds of transport, like in sea transport a special, essential factor is constituted by the capacity of port wharfs, as opposed to sea routes, which can be assumed to have infinite capacity.

In some cases schedules of transport may be unimportant, suffice to solve the first two problems: concentration of routes and grouping of loads. Such a case applies in communication networks, especially for purposes of data transmission in computer networks. In this situation the schedule of transmission of packages of data results from decisions of local control centers in nodes of the network.

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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