SCIENTIFIC PAPERS
OF THE UNIVERSITY OF PARDUBICE
Series B
The Jan Perner Transport Faculty
13 (2007)

INTERMODAL TRANSPORT: CREATION OF SYSTEMATIC TIME TABLES

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1. Introduction

European transport system is nowadays insufficient for whole transport requirements. That situation is striking in cargo transport. That leads to congestions, accidents and air pollutions. Therefore is European transport policy oriented on finding new environmentally more acceptable means of transport. Solution of that situation is in put of intermodal transport systems into praxis. For effective functioning of intermodal transport systems, network of centres for reloading, combine shipments and transportation into other centres must be built. Visions of European transport policy are in White Paper and they support intermodal transport systems (Zavadil, 2001).

Prerequisite for functioning of intermodal system in Europe is system of shuttle or multiple-section trains regularly operating between intermodal terminals or ports oriented on technologies Night Jump (Nachtdprung in German) and Just in Time (with guaranteed term of delivery).

2. Systematic time table

Systematic time table is one of the possibilities for time table's construction. Its principle is in periodically repeated structure of passenger and goods trains so that during the day same groups of trains are repeated. According to distance between those groups we have lag timetable or pulse timetable.

In railroad transport we have household word – lag timetable. Its characteristic is a constant time period between trains. Than we can find one-hour, two-hour, three-hour or eventually four-hour pulse. (Ferchland, 1997).

On higher quality level is integrated lag timetable (further only ILT). It systematically coordinates lag timetables between more train paths or other means of transport. More basic information about ITL can be found in Lichtenegger (1990).

Most important requirements for ITL are (Bär, 1998):

- Offer of lag transport offer in all days during the week,
- Service of each train path in basic pulse (passenger trains one or two hours, intermodal trains – 4, 6, 12 or 24 hours),
- Ensure transport offer in passenger transport from 5am to 10pm, in intermodal transport continuous operation,
- Ensure connection in node stations between systematic trains and other types of trains,
- Increase standard of quality for passengers and customers in cargo transport,
- Ensure maximum accuracy of trains (following the time table).

Different train paths with different pulses may meet themselves in reloading stations or on common stages. It is necessary to define a repeating period for the time table. That period is called a pulse elementary period by Dirmeier (1997) ("Taktperiode" in German).

Another important note of lag time table is time (or axis) of symmetry. It's an instant of time when trains on the same train route are crossing (on the single track line) or meeting (on double track line). Important requirement for ILT is the same symmetry time for all train routes (Hesse et al., 2005). If we observe that principle it leads to the enantiomorph time table. So that for each train in direction A-B we have a train in direction B-A with the same lag time, similar reloading time and block speed. In standard practice is often used so-called zero symmetry. It means that one symmetry time is right in the beginning of an hour. For example, if one train arrives to station in 54th minute (60 – 6), than the train on the same train route in opposite direction will arrive in 6th minute (60 + 6).

3. Intermodal trans

The intermodal trains are taken as a system of fast train connections of intermodal transport (hereinafter as IMT) that ensures connection between individual IMT terminals in requested quality and sufficient volume of transported goods. Systems of through trains and mixed trains are used for the train connection between IMT terminals. From the railway carrier's point of view the whole cargo (transport unit) is transported either as an individual set of coaches or as a group of sets of coaches or as the shuttle train. The biggest share of IMT cargos is transported in the shuttle trains which all belong to Nex train category. The consignment of the cargo must be all done in one railway station. It is all carried together on one transport route and delivered to one consignee in one railway station of destination. These IMT trains are usually set to go from one terminal to another or to a seaport.

Systems of train connections of IMT transport units can be operated on an individual line or on a specified line network. In the first case we speak of so-called “line system” and in the second case we speak of so-called “network system”.

The network system of train connections is characterized as a network service of individual terminals on a specified traffic network. This means that there is a space service of individual IMT terminals using line systems which are included into the traffic network. A system of shuttle trains connecting the individual IMT terminals is usually used in the network system. This network system is in the IMT area represented by the “Hub-and-Spoke“ system (Novák, 2006).

The “Hub-and-Spoke“ system is based on servicing shuttle trains with transport units and on reloading of the transport units between shuttle trains in a common node terminal (so-called “Hub terminal”), where the shuttle trains’ routes are crossing or ending (beginning). Shuttle trains from different directions arrive in specified time at the hub terminal where some transport units are reloaded onto another shuttle trains according to destination terminals of the individual crossing shuttle trains. Some transport units destined for attraction perimeter of the node terminal are reloaded onto road vehicles and delivered to the consignees on the road (Hartz, 2002). Similarly these crossing trains are used for transportation of transport units collected by road vehicles from the attraction perimeter of the node terminal. After the reloading the shuttle trains either continue their way to their destined terminals or to the node terminals. These shuttle trains finally go back to their starting terminals.

The “Hub-and-Spoke” technology can be combined with the line principle using the technology of multiple-section trains. The schematic representation of this technology is in Figure 1 (Novák, 2006, Vrenken et al, 2005). The network structure based on this technology is used mainly abroad. For example in Germany (IMT operator Kombiverkehr) this system is represented as “goods IC-concept”. It is a very similar system to the one used by passenger trains IC, ICE and EC categories (Heinrici, 2006).

The “Hub-and-Spoke“ technology is used mainly among terminals where the freight traffic volumes are on similar levels. There can however be cases where the freight traffic volumes from or to the node terminal can be different. In most cases one of the directions is very high and the others are significantly lower which means that in one direction the shuttle train is set out more often than shuttle trains in other directions (Dörr, 2003).

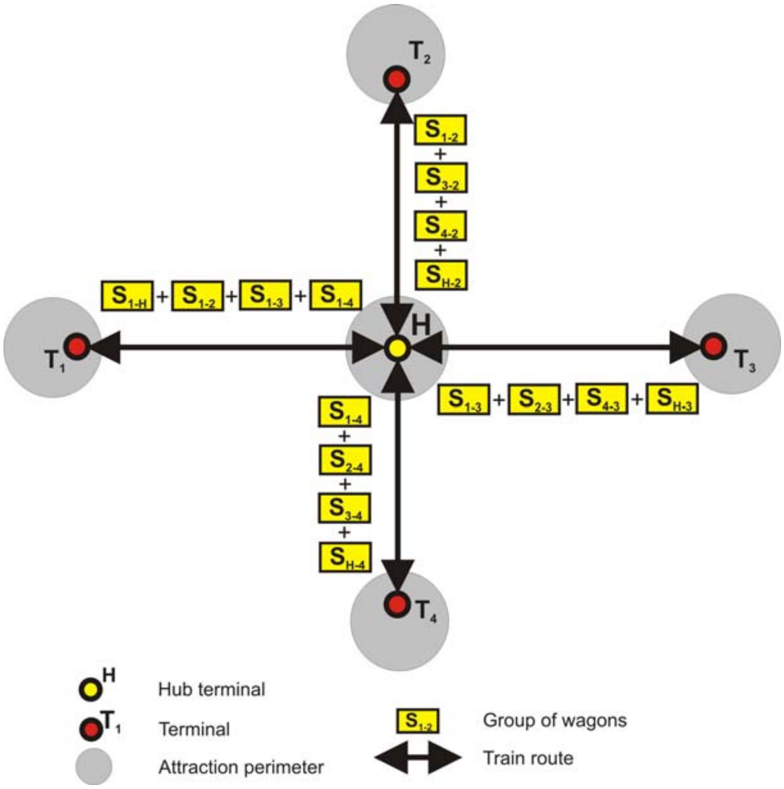

Fig. 1 *Logistic technology "Hub-and-Spoke"*

Practical application for this technology has been found not only abroad but also in the Czech Republic. Especially in transportation between seaports (Rotterdam, Bremerhaven, Hamburg) and some inland terminals (Praha-Uhříněves, Mělník, Lovosice) that have the position of node terminals (Bruyninckx, 2006). In these relations the freight traffic volumes are high and the trains are usually set out twice per day (24 hours). In other sequential directions (other terminals in the CR or adjacent countries) the freight traffic volumes are much lower and the train set out frequency is much lower (2 to 5 trains per week). Compared to classic "Hub-and-Spoke" technology the transportation costs are higher in case it is necessary to use parking spaces for the transport units during the reloads.

4. Train routes model for intermodal trains

The task of any transport problem solved by mathematic model is finding its attributes, analyse all his states and verify his scheduled parameters. That is subjected to right definition and dimensioning of system items, efficient regulation and organization of system.

General solution

In the node (node terminal) are assembled two groups of shipments for one train. In the first group are shipments, which enter the system in that node. Second group are shipments which came into that node on a train. If there exists a node *u* in time t_{ij}, the shipment will be brink by train s_{ij} on train path L_i, will be reloaded for time t'_{ir} to position on train path L_r and will wait for nearest train s_{rg} of that train path with depart at time t_{rg} (Černý and Kluvánek, 1989):

$$t_{rg} \geq t_{ij} + t'_{ir} \text{ [min]} \tag{1}$$

Providing that train s_{ij} departs from starting station at time t^{o}_{ij} and that travelling time to node *u* is d^{u}_{ij} than arrival time to t_{ij} can be formularized by 2 and 3:

$$t_{ij} = t^{o}_{ij} + d^{u}_{ij} \text{ [min]} \tag{2}$$

and for the train s_{rg}:

$$t_{rg} = t^{o}_{rg} + d^{u}_{rg} \text{ [min]} \tag{3}$$

Blackout time during waiting for reload can be formularized by 4:

$$t_{cz} = t^{o}_{rg} - t^{o}_{ij} + d^{u}_{rg} - d^{u}_{ij} - t'_{ir} \text{ [min]} \tag{4}$$

If we aren't able to influence last three timing logic clement, that means travelling times of each train d^{u}_{ij} and d^{u}_{rg} and reloading time t'_{ir}. Than we can lower the blackout time by increasing of t^{o}_{ij} value to:

$$t^{ox}_{ij} = t^{o}_{ij} + x_{ij} \text{ [min]} \tag{5}$$

or by lowering t^{o}_{rg} value to:

$$t^{ox}_{rg} = t^{o}_{rg} + x_{rg}\,; (x_{rg} < 0) \text{ [min]} \tag{6}$$

Now we can extend formula (1) to:

$$t^{o}_{rg} + x_{rg} + d^{u}_{rg} - t^{o}_{ij} - x_{ij} - d^{u}_{ij} - t'_{ir} \geq 0 \tag{7}$$

Beside boundary conditions like (7) there exist also another one which truthful the fact that time locations of trains s_{ij} won't be moved in time at will, but in bounds:

$$a_{ij} \leq t_{ij} + x_{ij} \leq b_{ij} \tag{8}$$

Similarly for trains s_{rg}:

$$a_{rg} \le t_{rg} + x_{rg} \le b_{rg} \tag{9}$$

Routes L_i and L_r are passing through node *u* and two lines of that routes s_{ij} and s_{rg} are coordinated if there exist two numbers x_{ij} and x_{rg}, which fulfil conditions (8) and (9). So we can make a directed graph *G=(S, H)*, where $(s_{ij}, s_{rg}) \in H$ if node *u* exists where we are able to coordinate those lines. Edges $h \in H$ determine which pairs of nodes can be coordinated but not all of pairs from set H can be coordinated at once by different value of x_{ij}. Therefore coordinated subgraph *G´=(S, H´)* must be found, where for all *i=1, … n*, *j=1, … m*$_i$ exist values x_{ij} fulfilling condition (7).

For coordinated subgraph *G´* exist usually more possibilities for x_{ij} value, fulfilling for each pair of nodes $(x_{ij}, x_{rg}) \in H'$ conditions (7) and (8). The selection of final value will depend on consignment volume f_{ir}, which will be reloaded in a node from L_i to L_r. Here we establish a term optimal solution for coordinated pairs of trains. It is determined by subgraph *G´*, to which matches solution [22]:

$$X = \{x_{ij}\};\ i = 1,\dots.n;\ j = 1,\dots.m_i \tag{10}$$

for *i*, *j* fulfilling condition (8), for all $(s_{ij}, s_{rg}) \in H'$ fulfilling condition (7) and which minimize value of target function $\bar{u}$:

$$\bar{u} = \sum_{(s_{ij}, s_{rg}) \in H'} f_{ir}(t^o_{rg} + x_{rg} + d^u_{rg} - t^o_{ij} - x_{ij} - d^u_{ij} - t'_{ir}) \tag{11}$$

If we expect that values t^o, d^u, t' are constant according to optimization task the value of target function $\bar{u}$ is minimized after fulfilling above mentioned conditions:

$$\bar{u} = \sum_{(s_{ij}, s_{rg}) \in H'} f_{ir}(x_{rg} - x_{ij}) \tag{12}$$

Resultant form of target function depends on subtraction of values x_{ij} and x_{rg} which are additional times to arrival of a train on train route t_{ij} or departure of train on train route t_{rg}. So if we want to set up the target function for train route model we have to come out from formula (12) (Černý and Kluvánek, 1989).

Setting of mathematical model

Railroad time table set up is an intensive and long time process. The reason is in limited use of computer application. That is mainly in interactive processing of timing logic clement and automated generation of time table tools.

The whole travelling time for consignment in intermodal transport contains these components (Krýže, 2005):

- Travelling times between terminals,
- Time spent at stops on the train route,
- Waiting time (result of insufficient capacity of operation equipment),
- Synchronization time (time needed to reload of consignments between two trains).

Shortening of first three times is subjected to investments. On the contrary, synchronization time is determined by time table so that we are able to shorten the synchronization time only by change of organizational set-up (non-investment character). Therefore it would be better to work on optimization leading to minimization of synchronization time (Dirmeier, 1997).

Reloading process of transport units between two trains is on Figure 2. For modeling of that process it is important that stoppage time of one train must be prolonged for reloading of units from and to the second train. That fact makes this optimization much simpler, because for modelling of that process we need only one train of each route (Lindner and Redern, 1989). Another simplification comes from zero symmetry principle because than it is enough to take into optimization only one direction of each train route. The time location of the train in the opposite direction is clear. (Jentsch and Gröpler, 1995).

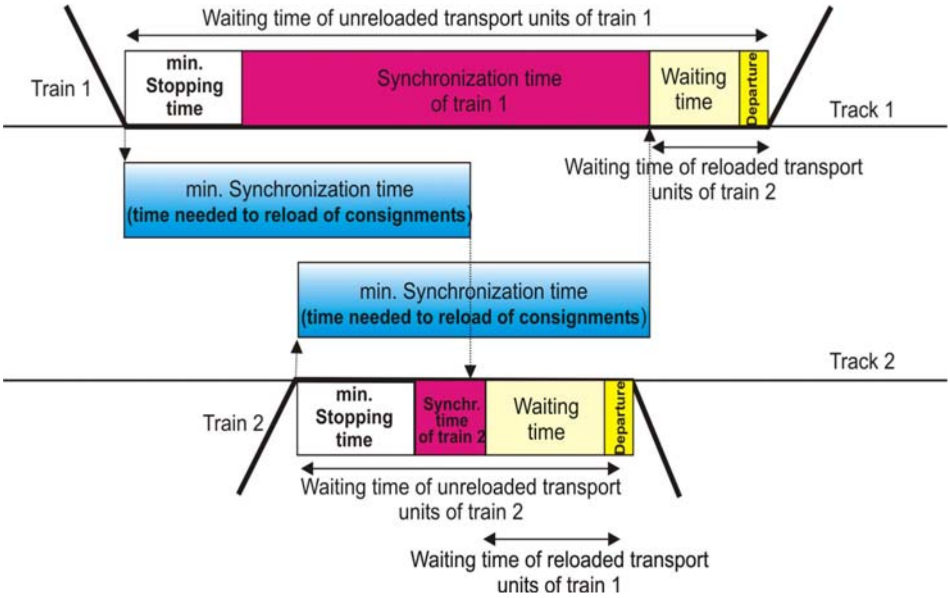

***Fig. 2** Consignment reloading process*

Speaking of transformation into mathematic model the authors found two different accesses: Krista (1996, 1999) assigned the problem to linear programming and solves it by simplex algorithm, Kolonko et al. (1996) solves it via genetic algorithms.

This method is in a couple of aspects different from the "classic" optimization methods. It uses random sample and that is why that method is non-deterministic. This means it can give us different result for each optimization. During the optimization this method holds "population of candidates for best bet". Only one member of that population is the best bet; the others are sample points where the best bet can be found later. That helps avoiding local optimums. Inspired by natural evolution this method makes periodically random mutations of one or more members from "population of candidates for best bet". That process gives us new candidates. Best members of population survive and the weak ones are eliminated. Disadvantage of that method is that we cannot recognize that solution is optimal; therefore we don't know a fixed rule for end of optimization. (Kolonko et al., 1996).

Both methods have some common features:

1. Target function is defined according to optimization criterions. It's derived from requirement for as short as possible travelling time at all stages (minimal network travelling time). Because the only one variable in this value is the waiting time for connecting intermodal train in terminal the value can be limited to sum of waiting times in all terminals. For ensuring favourable sequences for each consignment their volumes must be taken into account because whole travelling time is affected by volumes of reloaded consignments. Target function is then defined as minimum from sum of products of synchronization time for reloading of consignments to connecting train $T_{i\,synch}$ and volume of reloaded consignments f_i.

$$\min \bar{u} = \min_{\{T_{i\,synch}\}} \sum_{i=1}^{n} T_{i\,synch} * f_i \tag{13}$$

2. Besides travelling time, stay in terminal or reloading time models can take into account also other binding conditions like impossible occupation of single line stage by two opposite directed trains or operating intervals.

Authors don't seem as practical to break in the model all binding conditions because of excrescent problem complexity. But if we don't make it the computer's solution will include conflict situations. For their elimination there are two possibilities:

- We take into account the binding condition and repeat the calculation,
- User eliminates conflicts in the solution manually.
- Except common features exist some important differences:

1. Solution via simplex method needs target function and binding conditions in linear form, but basic problem isn't linear. Character of lag time table causes that reloading linkage (eventually binding condition) may not be set up between two train

routes during one period and leads to use of nonlinear function which returns division reminder after integer division. Linearization calls for integer parameter (pulse multiplier) t_m and pulse interval T, which enable pulse movement T_p. Then we have:

$$T_p = t_m * T \tag{14}$$

Such multipliers take the value from -10 to +10. For each reloading terminal (binding condition) a self pulse multiplier must be set up which figures as integer parameter (Krista, 1999). Number of parameters increases and complicates finding solution. On the contrary model which uses genetic algorithms don't call for linearity so parameters are only locations of trains represented by departures of each train routes from terminals.

2. Simplex algorithm finds a certainly optimal solution. On the contrary genetic algorithm finds for each calculation different solution. That's why genetic algorithm must be used a number of times (the more calculations the higher possibility to find optimal solution). In the next step we analyze best values from genetic algorithm according to other criterions because all terms of real system cannot be added into target function. Here we can find that the best value from genetic algorithm will be for real system unsuitable and most suitable will be a little bit worse value. Advantage of genetic algorithm is that we find more suboptimal solutions from which each is optimal from some point of view. (Caprara et al, 2005).

For solution of problems with smaller volume of parameters both methods are suitable but with increasing number of parameters is solution time by linear model mouth-fitting. For those problems genetic algorithms are more suitable (Kasprzak, 1997).

As we noted previously we are able to implement into models condition about occupation of one track stage by two trains in opposite direction. On the other hand this condition makes solution much complicated and therefore wasn't intended for the model. Another simplification was the use of zero symmetry. It has reduced parameters representing instants of times of trains for half.

If we want to solve train route problem we have to define model inputs (sort and range of values). We used following inputs:

- Railroad network – graph (vertices and edges) of real railroad network; vertices are intermodal terminals, edges are tracks (Figure 3),
- Travelling times between vertices,
- Train routes – present proposed routes of each trains according to train's operation technology,
- Stopping time – minimal stopping time of train in node,
- Sort of pulse – each route has self pulse between 6 and 24 hours,
- Reloading time – time needed for reload of transport units between trains,

- Terminal outputs – volume of units reloaded in each node.

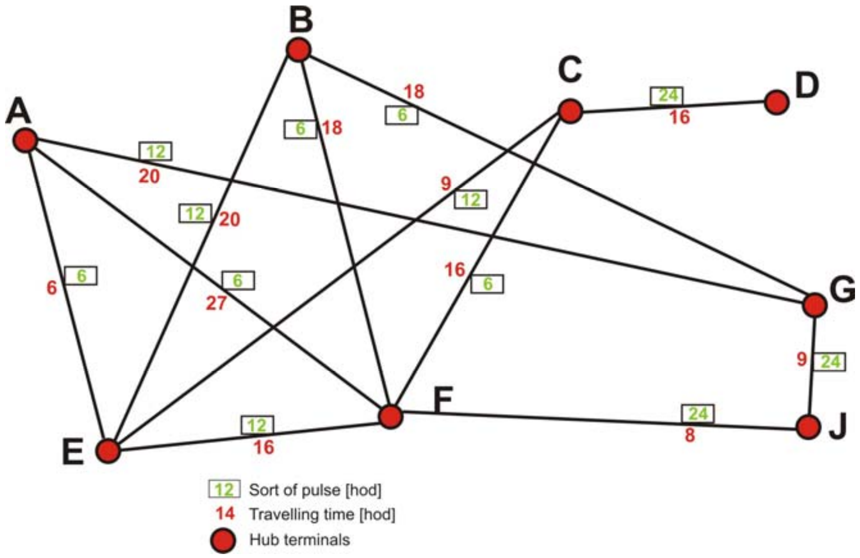

Fig. 3 *Cut of Railroad network*

Those values are in practical model substituted by more accurately value according to technical equipment of each terminal and used technology of manipulations. That model enables such type of correction but we have to observe changes of resultant value. Whence it follows that every change of any input can give us quite a different solution of the model.

For theoretic model proposal a network from Figure 3 has been chosen. Sixteen nodes (intermodal terminals) and 51 reloading links were added. Distances, travelling times between nodes and pulses were proposed. Pulses are 6, 12 or 24 hours. Those values come up to real pulses for intermodal transports. Reloading times were also valued (between 6 and 10 hours). This time is enough for unloading and loading of transport units. In the Figure 3 there are also ratings of each reloading link (importance of each node). This quantity is stipulated as link rating between each route. Value of rating is a tenth of reloaded transport units in TEU. It means that if we reload 10 TEU, the rating value is 1.

It is important to mention what kind of technology will be used while modelling the train tracks. Based on above mentioned characteristics and specifics of each system a “Hub-and-Spoke” line system is used in this model.

Terminal	Relation		Reloading [hod]	Rating value
	from	into		
E	A	H	6	5
	C	H	6	5
	B	H	6	5
	F	H	6	2
	C	I	6	4
	B	I	6	4
	A	I	6	4
	A	F	6	1
H	E	M	7	2
	E	I	7	1
M	H	N	8	4
I	H	F	7	5
	M	F	7	5
	E	N	7	4
	H	N	7	5
N	K	M	10	2
	M	F	10	2
	K	I	9	3
	M	P	9	4
	I	P	9	5

Fig. 4 *Reloading times and reloading link's ratings - example*

The solution results

The input data of the model have been transformed into used software Premium Solver Platform Version 7.0, Frontline Systems for Microsoft Excel 2003. Based on this product which uses the method of genetic algorithms the model solution has been run in Microsoft Excel 2003. For the needs of finding the optimal solution this computation has been run 200 times. Genetic algorithm finds solutions that can't be immediately classified as the optimal ones. The searching for the solution is random and there are usually different results each computation. The optimization has to been done several times (the more times the more probability of finding the optimal solution). It also seems to be eligible to choose a few best results and evaluate them following other criteria (Sevele and Schneider, 2005). Because we can't cover all the inputs existing in real world in our target function it is possible that the solution with its minimal value can be unsuitable in real life and on the contrary the best usable solution can be a solution with slightly worse value of target function. Finding of several suboptimal solutions can be therefore successfully used (Tuzar, 1996).

Very important advantage of this model is its variability. This is important especially during individual computations and can without any problems react to some input changes. This offers us the possibility to acquire more variable solutions.

The solution of this model can be interpreted either in a table or in graphic. The results in graphic are expressed as schematic representation of computed results of departures and arrivals of the trains in the nodes in a network graph where the vertices are different nodes marked A to P and the edges represent individual train connections. Each node has drawn in all the relevant connections with direction and time positions of all departures and arrivals. These time positions are in hours. Small frame with a value is attached to individual tracks. Theses values say what pulse has been using on that track. A cut of this graph can be seen in the following Figure 5.

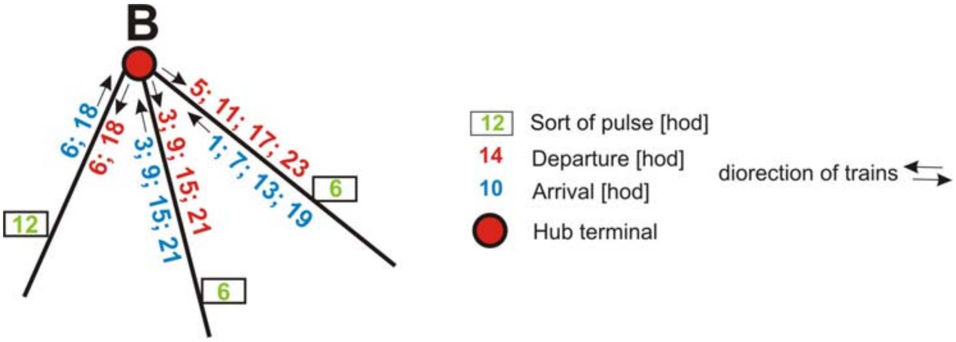

Fig. 5 *Cut of graphic expression of final model solution*

Results of 20 best solutions (10 % of the total count of found solutions) are shown in the following Figure 6.

All these solutions have the value of target function (sum of product of waiting times during reload and weight of reloading links representing amount of transhipped transport units) between 110 and 195. From the table it is clear that if we choose a simple sum of synchronization times the best solution will be no. 5. On the contrary the solution no. 1 - the best one according to the target function – will be on the 5th spot. It is necessary to say that the weights of the transhipped transport units that significantly influence the results are only theoretically estimated. Therefore it is valid to investigate also other solutions.

standings	$\Sigma\ T_{sync}$	$\Sigma\ T_{sync}$ * Raiting value
1.	39	110
2.	33	115
3.	37	116
4.	38	120
5.	29	125
6.	41	128
7.	51	132
8.	48	136
9.	53	141
10.	60	158
11.	59	159
12.	52	162
13.	53	163

14.	64	168
15.	71	175
16.	70	184
17.	67	185
18.	66	189
19.	78	191
20.	72	195

Fig. 6 *Resultant value of target function* for 20 best results

It has to be said that this designed theoretical model is directed to phase of preparation of possible timetable of IMT trains. Therefore the computations are based on a premise that the timetables are adhered and there are no reserves for elimination of possible delays. It is possible to solve this by increasing the route times but it leads to lower quality of the connection because is slows the whole transport. However, in the future it is possible to take these delays into account because in practice this happens quite often with the transport trains.

Another very important factor while modelling the train routes and looking for advantageous reloading links (from time point of view) is a question of delaying of transport units which are not transhipped in the specified terminal and carry on in their shuttle train. Here we have a problem how to evaluate these transport units or whether to evaluate given “non-link” so that the transport units are influenced by the reloading link as little as possible. Currently it can be solved by minimizing the stay of each train to a minimum possible value but it can’t be done with all trains. There it will be good to concern even these “non-linked” transport units in future computations. This would also be able to define as another criterion of quality of transportation in IMT system.

5. Conclusion

The presented method of optimization of train time positions minimizes the transportation time in given system of IMT cargo transport through minimization of time spent waiting on the sequential train in the terminal. This method can be used in other traffic systems especially in public passenger traffic, i.e. in regional railway traffic, bus traffic or in the multi-traffic systems.

It is necessary to realize that the change of route time or change of line interval (or any other input) can result in a significant change of total solution for time positions of other lines. Because of this in countries with working pulse timetables are usually enforced conceptions where the main criterion for investment intensions is the planned timetable.

On principle it is possible to involve into the optimization also inputs that remained constant during this article. The main inputs will be route times theirs shortening might lead to ensuring additional sequential connections in the terminals. Experiments looking for balance between route time and investment costs have already been described (Kolonko et al., 1996).

Lectored by: prof. Ing. Bedřich Duchoň, CSc.

Submited: 5.2.2008

The presented results are part of the task MSM 0021627505 “Theory of transport systems".

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Resumé

INTERMODAL TRANSPORT: CREATION OF SYSTEMATIC TIME TABLES

Jaromir ŠIROKY, Vaclav CEMPIREK, Petr NACHTIGALL

Příspěvek informuje o modelování tras vlaků kombinované přepravy. Pro toto modelování byl využit model využívající genetické algoritmy. Modelování vlakových tras spočívá v minimalizaci doby synchronizace překládky přepravních jednotek v kombinované přepravě.

Summary

MODEL SYSTEMATICKÝCH JÍZDNÍCH ŘÁDŮ VLAKŮ KOMBINOVANÉ PŘEPRAVY

Jaromir ŠIROKY, Vaclav CEMPIREK, Petr NACHTIGALL

The paper acquaints readers with simulation of train routes in combined transport, using genetic algorithms. The simulation is based on minimization of synchronization time for reload of transport units in combined transport. Asset of the publication is in description of each part of transport time including planned and unplanned time factors. Original part of publication is in proposed model of combined train's route optimization on traffic network. Merits of the work are that results can be used for quality improvement of railroad cargo transport. Scientific asset is in proposed model, which can be used for further combined train's route proposing.

Zusammenfassung

DAS MODELL DES TAKTFAHRPLANS DER KOMBIVERKEHRSZÜGE

Jaromir ŠIROKY, Vaclav CEMPIREK, Petr NACHTIGALL

In diesem Beitrag sind die Ergebnisse der Modellierung der Linienkonstruktion des Kombiverklehrszüge präsentiert. Die Verknüpfung von Linien untereinander erfolgt in Knotenterminals. Das bedeutet: Minimieren die Synchronisationszeit zwischen dem Umschlag der Verkehrsbehältern im Kombiverkehr.