Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 96 **2017**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2017.96.6

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Jacyna, M., Gołębiowski, P., Krześniak, M. Some aspects of heuristic algorithms and their application in decision support tools for freight railway traffic organization. *Scientific Journal of Silesian University of Technology. Series Transport*. 2017, **96**, 59-69. ISSN: 0209-3324. DOI: https://doi.org/10.20858/sjsutst.2017.96.6.

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SOME ASPECTS OF HEURISTIC ALGORITHMS AND THEIR APPLICATION IN DECISION SUPPORT TOOLS FOR FREIGHT RAILWAY TRAFFIC ORGANIZATION

Summary. Rail traffic organization is a multifactorial decision-making problem. To achieve the best results and reduce the risk of error when deciding on its implementation, appropriate algorithms should be identified and implemented in the form of computer tools, allowing for the optimal solution to be obtained. This paper discusses the process of organizing freight traffic on the rail network. The algorithm of relocating loaded cars in a compact and dispersed system is discussed. In turn, it is been indicated that the movement of empty and loaded cars must follow a strictly defined timetable. A heuristic algorithm supporting decision-making in the area of rail freight traffic management is presented, divided between the concept development stage, the timetable design stage for the developed concept, and its implementation in the form of specialized tools. An example of how the application works is also presented.

Keywords: rail transport; railway organization; relocation of cars; timetable design

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1. INTRODUCTION

The movement of trains on the rail network, due to the need to maintain the highest degree of safety, must be appropriately ordered. This involves developing proper traffic organization for a given situation. This is not an easy task in light of the many factors affecting train traffic on the rail network. Among the most important for freight traffic, four groups of factors should be mentioned [18]:

- technical (e.g., ensuring the continuity and safety of transport, adjusting the number and size of trains to the size of freight flow, regulating the capacity of railway lines and stations)
- technological (e.g., minimizing transit time, regulating train service standards at railway stations, developing proper organization of train station operations)
- organizational (e.g., comprehensive fulfilment of transport demand, conducting train traffic according to documentation, ensuring transport efficiency, rational circulation and composition of trains, rational timetable construction, obtaining appropriate values of indicators, cooperation with external parties to ensure delivery on time)
- random (e.g., variable demand for transport, rolling stock and infrastructure failures)

At present, the customer plays a major role in the transport market. Operators (carriers) have to adapt to their needs. Transport services must therefore be provided at an appropriate level; otherwise, the potential sender may decide to choose another service provider. Rail carriers, on the one hand, must meet their customers' expectations in a timely, fast, reliable, efficient, economical and secure manner [15]; on the other hand, market expectations are clearly defined. Customer needs are important in terms of both passenger and freight traffic.

To adapt to the railway market, the infrastructure manager must strive to meet all needs: for operators and for customers. The proper preparation of a train timetable plays a major role in this process, due to the specificity of rail traffic, that is, to place the train path in time and space in a safe manner, respecting the needs of the customers. The problem with timetable construction involves the determination of train paths based on the traffic graph [1, 4, 8, 9, 17, 21]. In the process of assigning routes for trains, the priorities on the traffic graph should be taken into account [20], as well as multiple technical and operational factors, including railway traffic regulations [19].

The construction of a rational train timetable is not the only problem associated with the organization of rail traffic. In the case of freight traffic [3, 16], the issue of providing empty cars for loading at the dispatch station at a time specified by the sender is also important. The problem is therefore to designate stations with the appropriate number of cars of a specific type, which will allow for the needs of customers to be satisfied and transporting the cars to the dispatch station according to the pre-arranged timetable. Thus, it is a complex problem that occurs in all transport areas [12, 13, 24, 22, 27]. According to the literature, the subjects of research are, among others, the efficiency of supplies [11], their reliability [10] or efficiency [28]. Due to the complexity of these problems, decision-making tools play an important role in modern railway traffic organization.

The development of computer techniques allows us to solve complex process models. The use of IT in decision support processes is called a decision support system [23]. Depending on the complexity of the problem, user preferences and other factors, a correct system should be chosen, which is often a dedicated system created to solve this specific problem. A very important element in such a system is the algorithms used for solving the decision problem, which must be properly implemented. Due to the complexity of the problems to be resolved, genetic algorithms [14], neural networks [6] and other tools are employed.

To get the best results and reduce the risk of error when deciding on the proper deployment of rail traffic on the network, appropriate algorithms for the solution must be identified [5], as well as their implementation in the form of computer tools, which will help in the decision-making process. The paper discusses in detail the procedure for organizing freight traffic on the rail network. The algorithm for moving cars from the dispatch station to the destination station in both compact and dispersed systems is also discussed. It has been indicated that the movement of both empty and loaded cars must be carried out according to a strictly defined timetable. A heuristic algorithm supporting decision-making in the area of rail freight traffic management is presented, divided between the concept development stage, timetable design stage for the developed concept, and its implementation in the form of specialized tools. An example of how the application works is also presented.

2. PROCEDURE OF FREIGHT TRAFFIC ORGANIZATION ON THE RAILWAY NETWORK

2.1. Introduction

The organization of rail traffic consists of [8]:

- planning communication routes (construction of transport offer)
- actual construction of the train timetable (building train traffic charts)
- allocation of platform edges or tracks at train stations
- rolling stock planning
- planning the work of teams serving vehicles (conductor and traction teams)
- regulating train operating standards at railway stations
- development of proper work organization of railway stations
- regulating the capacity of lines and railway stations

As mentioned in the introduction, this is not a simple problem to consider. The specificity of freight traffic organization is all the more complex, as the movement of freight trains must be adapted to passenger traffic, which has a higher priority [20]. In addition, shipments can be performed in two systems: compact and dispersed.

A compact system assumes that the transport of goods is performed using a fixed wagon set from the dispatch station to the destination station. With appropriate infrastructure in the transport nodes at both ends of the transport route (sufficient length of siding tracks, appropriate siding capacity etc.), this freight starts at the sender’s point of departure and ends at the receiving point of the recipient.

Dispersed transport is much more expensive than compact transport and requires a disproportionate amount of manoeuvring and expedition work. The dispersed transport system is based on the so-called node points system or a linear train system.

The node points system assumes the movement of individual wagon groups in accordance with accepted rules. Freight trains for dispersed transport are compiled from properly selected wagon consignments. The linear train system assumes that trains are run on a given route to collect small shipments, which are not suitable for compact transport due to the insufficient flow of cargo.

Technically, the dispersed movement is a very complicated process. Compared to compact transport, it involves more resources, including the need for more manoeuvring work. This method generates much higher costs than the compact system. Particular attention should be paid to the system used, as both the time and cost of moving wagons depend on the technology of moving loaded and empty cars.

Therefore, the problem of organizing freight traffic in rail transport is to provide a sufficient number of empty cars for loading at the time indicated by the customer, as well as transporting the cargo from the sender to the recipient according to the appropriate transport technology (compact or dispersed). Both the delivery of cars and the transportation from the sender to the recipient must follow a strictly defined timetable.

2.2. Algorithm for car relocation on the railway network

The algorithm for car relocation on the railway network is presented in fig. 1.

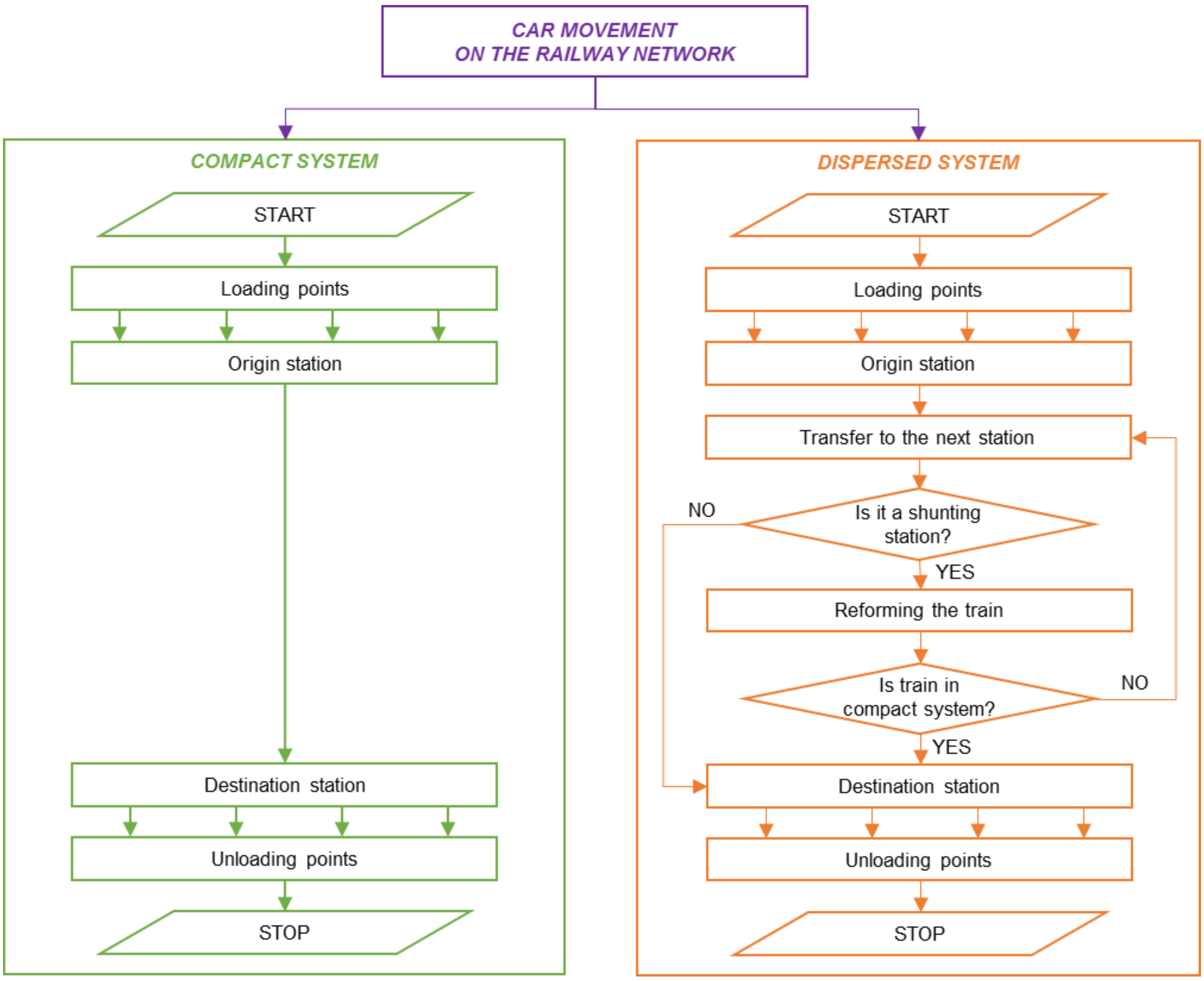

Fig. 1. The algorithm for car relocation on the railway network

As mentioned in Section 2.1, cars on the railway network can be moved using two technologies: a compact system, when the entire train is dispatched directly from the sender to the recipient; or the dispersed system, when the cars with cargo from the particular sender to the particular recipient are moved using different trains.

In a compact system, the cars located at station and line loading points of individual senders are moved to the dispatch station, where the train is formed. This entire train is then directed to the destination station, from where the cars are sent to station and line unloading points, i.e., to the final recipients. To run a compact train, it should be determined whether or not it is economically justified.

If the number of cars at the dispatch station does not allow a compact train to be run, the dispersed system is then used. After delivery from station and line loading points to the dispatch station, the cars are coupled with a train and routed to the nearest shunting station. This station collects consignments from several dispatch stations. After reforming them into one train, it is checked whether the newly created train, containing cars from various stations of origin to the same destination station, can be considered economically viable to be run in a compact system. If so, the train is routed to the destination station, from where the cars are distributed to station and line loading points in the destination area. If not, the train is routed to the next shunting station to repeat this step with more cars.

2.3. Assessment of traffic organization on the railway network

Moving cars in a compact or dispersed system, as well as the delivery of empty cars for loading, must be carried out according to a prepared timetable. It is created, based on a traffic graph, which is a graphical representation of train routes in a distance/time layout. The first stage of building a timetable is to determine the traffic graphs, which become the basis for the timetable. In order to prepare a traffic graph, it is necessary to specify the following set of input data:

- Set of control points and forwarding offices on the proposed train route (node elements of railway transport infrastructure)
- Set of sections on the proposed train route (linear elements of railway infrastructure)
- Structure of the traffic graph (possible time points and train states)
- Set of train types, which can be run on a given route
- Values of parameters determining the average stop time in a node
- Set of train numbers (identifiers) to be run
- Leading hours for each of the trains
- Duration time of each train's state
- Values of parameters determining the length of station distances
- Values of parameters determining the length of line distances

With the above-mentioned set of input data, it is possible to begin modelling the routing of trains on a traffic graph, based on the suggested leading hours. The problem is therefore to find the trains' paths $x(t,po(t))$ on the traffic graph. Each of the paths consists of train states (halt and move). Next, the prepared transportation offer should be checked for collisions with other train routes, with all identified collisions removed. To assess the quality of the resulting traffic graph, an indicator for operating costs $ko(t)$ of running all the trains has been used:

$$f_1(\mathbf{X}) = \sum_{t \in \boldsymbol{T}} ko(t) \cdot x\big(t, po(t)\big) \longrightarrow \min \tag{1}$$

where:

$t \in \boldsymbol{T}$ – a set of train connections, in which the starting node and the end node are the forwarding office where it is possible to respectively start and stop trains

A minimum value of this indicator is desired. The model should take into account the restrictions imposed on each train, which must be handled by only one train set, with the assigned number of sets not exceeding the total number of available sets. It is also important to establish the train numbers to be run: $poc(t) \in \boldsymbol{POC(t)}$ on particular routes t and the final leading hours for them, i.e., $gw(poc(t))$ (the final leading hour cannot be later than assumed in the case of empty cars' delivery and earlier in the case of starting a loaded train). Taking into account the technical limitations, it is important to ensure that each vertex in the traffic graph has only one successor and only one predecessor (excluding the start and end vertices, which have no predecessor and successor, respectively).

3. HEURISTIC ALGORITHM OF FREIGHT TRAFFIC ORGANIZATION ON THE NETWORK

As already mentioned above, the organization of freight traffic on the railway network is a complex decision-making process, on which customer satisfaction strongly depends. Taking into account the existing conditions, two stages can be distinguished in this process (see

fig. **2**):

- STAGE 1, which is performed by the railway carrier, consists of developing the plan for relocating empty cars to loading points and loaded cars to the recipients (using compact or dispersed system), as well as actual execution of the said plan.
- STAGE 2, which is performed by the infrastructure manager, consists of developing the timetable for moving empty and loaded cars on the network.

The customer who places the order with the railway carrier initiates the procedure of transporting the cargo from the sender to the receiver. In this order, the customer specifies the moment of delivering the cars to the loading point and the moment of completing the loading process (leading hours). Once the order is placed, the carrier checks if it is possible to be completed. Firstly, the necessary rolling stock to execute the order is identified and its location is established. If empty cars are on the dispatch station, they are delivered to the loading point, upon which loading begins. Otherwise, it should be verified whether the necessary cars are available in the area of the station (the boundaries of the area are determined by the railway company). If so, all the stations with available cars are listed, together with the cost of acquiring the rolling stock from each of the stations. The cost minimization criterion is applied and the station, which is to be the source of cars, is selected. If there are no suitable cars in the area, the search continues throughout the entire railway network. For all these stations, the cost minimization criterion is also applied, resulting in selecting the station to be the source of cars for a given order.

Empty cars, which are located outside of the dispatch station, are delivered for loading to this station. It is only possible after preparing the timetable for them to be safely relocated. This is done by the infrastructure manager, based on a request for route assignment made by the railway carrier. As part of the process, the timetable creators place specific train paths on the graphic timetable. The first step is to analyse and validate the application to assign a path for a train, submitted by the carrier (

fig. **2**). In the case of errors, the infrastructure manager returns the application to the carrier to be corrected. Otherwise, the application is accepted for inclusion in the timetable construction process.

Then the construction process starts. The constructor, based on the parameters declared in the application by the railway carrier, determines the values of all the elements necessary to develop a traffic graph. The process begins with collecting all the data necessary to properly build the traffic graph and loading the data into the software. Next, the traffic graphs, on which the train's path will be drawn, are chosen (if the train runs through multiple railway lines, it may be required to place it on multiple graphs).

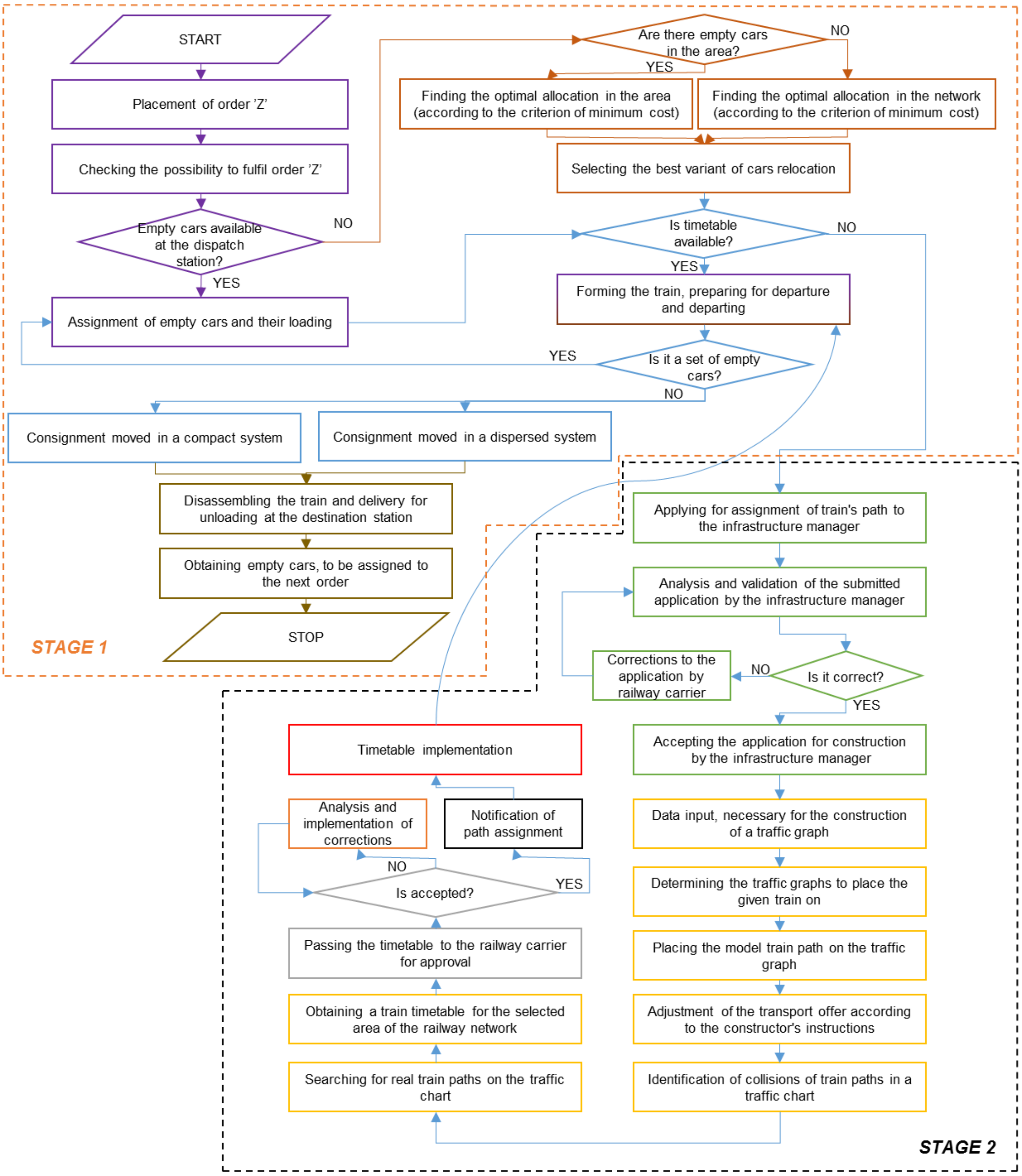

Fig. 2. Heuristic algorithm of freight traffic organization on the railway network

After that, the model path is applied to the traffic graph. Such a path may not meet all the restrictions, while some collisions between trains may appear and the appropriate safety level of railway traffic may not be met. This routing is based on the declared leading hour, with the process conducted using the A* algorithm for finding the shortest path in a graph [25]. Each arc is described by the time required to travel by it. After the model path is applied to the traffic graph, some corrections in the scheduled hours can be made to adjust the prepared transport offer to fit customer needs. Collision detection should then be performed between that particular train and other trains running through the network. The axis-aligned bounding box algorithm is used for this purpose [2]. If any collisions are found, they should be eliminated, which is the actual routing of the train. With that process, the appropriate level of traffic safety is ensured. The bees algorithm is used in the process [26]. In this way, a timetable in graphical form is obtained, which can be transformed into a tabular format.

The prepared timetable is passed for approval to the railway carrier, who may accept or reject the proposal, in whole or in part. If so, the timetable is passed back to the competent construction and approval representatives. After introducing the corrections and approving them, a notification of the assigned routes is given and the timetable is implemented.

After obtaining the timetable, in the case of both empty and loaded cars, a train should be formed and dispatched. The transportation of loaded cars from the sender to the recipient can be carried out according to the two transport technologies described in Section 3. After arriving at the destination station, the set of cars is disassembled, with the cars unloaded and remaining empty at the destination station, ready for another loading.

4. CASE STUDY

The freight traffic organization algorithms presented in Section 3 have been implemented in two computer applications. The algorithm for the displacement of load and empty cars (STAGE 1;

fig. **2**) is the basis for the ModPCar application. The timetable construction algorithm (STAGE 2;

fig. **2**) is implemented in the BEERJ application, which allows for the shaping of the railway transport offer and the construction of traffic graphs, as well as presenting it in a tabular format. An example of the applications' output is shown in tab. **1**.

Tab. 1

Sample output of ModPCar and BEERJ software

Plan for loaded cars										**Plan for empty cars**					
Order number	From station	Order number	From station	Order number	From station	Order number	From station	Order number	From station	Order number	From station	Order number	From station	Order number	From station
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
1	ST_118	ST_59	0	42	Eaos	17-02-04 13:20	17-02-06 12:00	17-02-08 02:19	17-02-09 09:24	1	17-02-04 12:35	17-02-04 13:20	ST_81	ST_118	42
2	ST_102	ST_85	0	42	Eaos	17-02-06 11:00	17-02-06 12:00	17-02-07 19:59	17-02-10 11:27	2	17-02-06 10:42	17-02-06 11:00	ST_91	ST_102	42

Plan for loaded cars										Plan for empty cars					
Order number	From station	Order number	From station	Order number	From station	Order number	From station	Order number	From station	Order number	From station	Order number	From station	Order number	From station
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
3	ST_84	ST_123	0	10	Eaos	17-02-07 03:01	17-02-07 04:00	17-02-07 19:08	17-02-10 02:16	3	17-02-07 02:25	17-02-07 03:01	ST_91	ST_84	10
4	ST_107	ST_1	0	40	Eaos	17-02-07 03:01	17-02-07 04:00	17-02-08 05:16	17-02-09 01:18	4a	17-02-07 02:10	17-02-07 03:01	ST_91	ST_107	37
										4b	17-02-07 03:01	17-02-07 03:01	ST_107	ST_107	3

In the sample case for the ModPCar software, four customer orders have been included. In the left part of the table, the proposed plan for loaded cars' relocation is presented, separately for each order. Columns 8 and 9 contain the most important customer requirements, i.e., the times of arrival and departure, which are not subject to change. At the beginning of the analysis at each of these stations, there are not enough cars to satisfy demand. In the first case, in order to fulfil the customer's request, empty cars must be delivered to the dispatch station as early as two days in advance. In the second case, the buffer is one day long, while, in the third case, it is only less than an hour earlier. In the cases described above, all cars are delivered from one station only. Order 4 represents a different situation. At station ST_107 (the dispatch station for loaded cars), there are three empty cars. The rest should be collected from the neighbouring station, ST_91.

The hours in Columns 7, 10 and 12 were determined using the BEERJ application. Based on the leading hours in Columns 8 and 9, reverse and forward routing were performed, respectively, while model train paths were mapped onto the actual traffic graph. In light of the collisions of proposed paths, they were corrected and real train paths in time and space were obtained. For some orders, the correction required to launch the trains was up to two days earlier.

5. SUMMARY AND CONCLUSIONS

The organization of railway traffic is a vital matter to consider because it allows for trains to be managed on the railway network in an orderly fashion, within the given time and space constraints. Its introduction guarantees timely, fast, reliable and safe movement of rolling stock. A train timetable is an expected outcome of correctly implemented traffic organization, as it satisfies the requirements of various stakeholder groups.

The organization of freight traffic on the railway network consists of, on the one hand, the plans of cars' movement prepared by the operator (railway carrier) and, on the other hand, the rational construction of timetables for trains being run: whether to move loaded or empty cars. To introduce the correct form of traffic organization, one should start by establishing which stations will become the supply of empty cars for loading. This should be done, based on the cost minimization criterion. Car delivery should occur before the time indicated by the customer, so that they are ready for loading. Such functionality is provided by the ModPCar application.

Afterwards, from the moment the loading ends, the shipment should be completed as fast as possible. It is therefore important to develop suitable timetables for a comprehensive transport service. When routing the train, the leading hours indicated by the customer should be taken into account, as well as the need to meet all safety requirements and avoid collisions with existing train routes on the traffic graph. Such functionality is provided by the BEERJ application, developed as an aid for designing the timetables according to the current needs of the user.

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Received 12.03.2017; accepted in revised form 07.08.2017