Operational Research in Engineering Sciences: Theory and Applications
Vol. 2, issue 1, 2019, pp. 51-71
ISSN: 2620-1607
eISSN: 2620-1747
DOI: https://doi.org/10.31181/oresta1901036r

AN OPTIMAL MANAGEMENT MODEL FOR EMPTY FREIGHT RAILCARS IN TRANSPORT NODES

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Received: 12 February 2019
Accepted: 04 April 2019
First online: 13 April 2019

Original scientific paper

Abstract. *The paper presents the actual problem of increasing the efficiency of empty railcars management in rail nodes. The problem lies in need to consider the several constraints. Firstly, railcars' owners are willing to load their rolling stock by specific goods for the given directions (consumers). Secondly, it is necessary to consider schedule and formation of trains between railway stations of the node when we developing the routes for movement of the empty railcars. Final constraint is based on compliance with the schedule of the railcars loading in the transport node. We propose the minimum of total time costs that railcar has spent in the specific transport node as the objective function. This problem is being sophisticated in terms of increased irregularity of railcar traffic flows, and as a result, it increases the loading factor of the individual railway stations in the transport node. Hence, it creates an uneven loading factor of railway stations in the node. In order to optimally manage empty railcars at rail nodes, both the mathematical model and its solving method are presented. One of the distinctive features of the developed model lies in the application of a fuzzy logic method to evaluate online the loading factor of railway stations in the rail node. Moreover, this model takes into account these evaluations by optimizing the distribution of empty railcars at the loading points. The present study puts forward the method and algorithm of the developed mathematical model for empty railcars management. They could additionally take into account the possibility to include empty railcars groups in the composition of trains moving on schedule within large railway nodes or in systems of railway transport at large industrial enterprises. The proposed model significantly reduces the complexity of operational planning of dispatchers for distributing the empty railcar traffic volumes. Furthermore, the developed model minimizes the total handling time of railcars in rail nodes and ensures the timely supply of empty railcars to the loading points.*

Key words: *rail transport, railcar traffic volume, empty railcars, station loading, train schedule, mathematical model, linear programming, fuzzy-logic.*

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1 Introduction

The railways in the countries of the former Soviet Union heritage the complex railway transport systems of large industrial enterprises, whose width of the rail gauge equals 1520 mm. Currently, the transport system is faced with a dramatic increase in railcar handling costs. As a result of the uncoordinated interaction between the mainline and the industrial rail transport, the total annual losses of a single metallurgical enterprise could reach up to 1.5 billion rubles ($45 million US dollars) (Osintsev and Rakhmangulov, 2013; Rakhmangulov et al. 2016).

An increase in these losses mainly occurs due to the increased complexity of the operational planning and management of railcar traffic in the railway transport node. The following factors might be the source of this intricacy:

- the growth and multiplicity of rail freight traffic in Russia and the CIS;
- a plenty of new private railcar owners;
- an increase in uneven railcar traffic;
- frequent and significant workload changes in railway stations and spans (Rakhmangulov, 2014).

According to these conditions, a possible way to solve this issue might be linked to the modernization of the freight traffic flow system in order to reduce the total railcar dead time in the transport nodes. Moreover, a lack of promptness with respect to the delivery of railcars is the main concern the railcar owner is faced with, which significantly raises their overpayment. This issue should, therefore, be considered as well.

The changes caused by the structural reform of the Federal railway transport have a significant impact on the functioning of the transport service systems (Rakhmangulov et al. 2014). The main factor of this reform is the transfer of freight railcars to the operating companies' properties. As a result, by the beginning of 2015, the proportion of private railcars increased up to 100%. At the same time, there is an outstripping growth of the value of the freight traffic flow in relation to the rail transport volume. This correlation indicates the irrational use of railcars.

The disadvantages of such a type of changes are as follows:

- a rise in empty railcar transit;
- a decrease in the reserves of the throughput and the capacity of railway stations and the span because of the enlargement of the effective railcar time usage;
- an increase in the new rolling stock necessity (Borodin and Sotnikov, 2011; Rakhmangulov et al. 2014).

The rail transport analysis of industrial enterprises depicts an increase in the railcar dead time by 20% on average during the last seven years (Kornilov and Varzhina, 2015).

As is shown in the Russian and foreign experience, a reduction in railcar dead time in industrial transport systems (ITSs) is achieved as a result of the variety of the accounting parameters of railcar volumes based on the methods for managing railcar traffic volumes in intelligent transport systems. These methods include linear and nonlinear optimization, dynamic optimization, simulation modelling (Lind, 2000; Berezhnaya and Berezhnoy, 2006; Lesin, 2011).

Based on the operational control methods for railcar exploitation, the problem of the acceleration of the railcar transit time in transport systems has been discussed in North America and in Europe (Clausen and Voll, 2013; Clausen and Rotmann, 2014). European researchers emphasized the mathematical and heuristic approaches to solving the optimization problems of the railcar traffic flow in rail transport nodes.

The discrete mathematical models and algorithms, their implementation and the development strategy of the railcar traffic flow planning within various speeds for a small transport network are proposed in the late 1990s (Carey and Lockwood, 1995; Dorfman and Medanic, 2004). Different ways were proposed at that time:

- the adjustment of the train traffic route on the basis of increasing the accuracy of a reaction to the high dynamics of the train schedule parameters (Pellegrini et al., 2014);
- the heuristic approaches to the railcar traffic flow management while simultaneously optimizing the solving of the problems of their movement in the railway transport node (Fugenschuh et al. 2008);
- an analysis of the empty railcar management methods (Spieckermann and Vosz, 1995).

The previous studies (Jha et al. 2008) are focused on the practical application of the modern heuristic methods based on the solution to the multi-product transportation problem. Later, these techniques were developed (Kauppi et al. 2006; D'Ariano, 2008) and, consequently, the optimization of the transport issue was described. The result of solving this issue implies the minimization of the costs of the private railcar movement in transport systems.

The practical application of the operative management methods for industrial transport reflects in the implementation of the automated systems of the management of the railway transportation process. The researcher (Hailes, 2006; Kozlov, 2007) described how the methods were formed and how computerized systems were developed for the management of the railcar traffic flow in rail transport nodes and the ITS.

However, the mathematical models currently used in intelligent rail transport systems do not sufficiently take into account the complex and variable structure of railcar traffic volumes. Furthermore, these models do not consider the uneven workload of railway stations in the railway transport node. It can be explained that, due to the railcar owners' decisions, restrictions on their use of railcars often change. As a rule, such changes occur once at the beginning of the day (an estimated period). This feature allows us to consider the problem of the optimal empty railcar distribution in transport nodes as a static linear programming problem and also to modify it to the transport problem with additional constraints (Rakhmangulov et al. 2016).

According to the well-known models (Spieckermann and Vosz, 1995; Shenfeld et al. 2012), constraints on the supply of certain empty railcars by certain consignors in the railway transport node were previously implemented. However, delays in the supply of empty railcars for the workload associated with the inclusion of these railcars in the size of the trains moving between railway transport node stations according to the fixed or flexible schedule are not taken into account by these models. Such a flexible schedule can be formed in an operational mode by changing the train routes in the railway transport node and by choosing the stations with a low level of workload (a large amount of the capacity reserve) for the transportation of these types of trains.

The solution to the problem of the optimal control of empty railcars in the railway transport node, together with the abovementioned limitations, requires that operational data should be used by means of modern intelligent transport systems in railway transport (Kozlov et al. 2011; Crainic and Laporte, 1997).

2 A Mathematical Model of the Optimal Distribution of Empty Railcars in the Railway Transport Node

2.1. The Statement of the Operating Problem of Empty Railcar Flows

The effectiveness of the distribution of empty railroad cars in the railway transport node was deeply discussed in a previous study (Rakhmangulov et al. 2014). However, the disadvantage of this paper is the absence of real station workload data. Hence, the current research study presents a promising model combining the operating work level of railway stations and the allocation of empty railcars.

The objective function of the model minimizes the railcar-hours cost during the period of the storage of empty railroad cars in the railway transport node to the loading places.

$$\sum_{k=1}^{L}\sum_{i=1}^{M}\sum_{j=1}^{N} C_{kij} \cdot x_{kij} \rightarrow \min, \tag{1}$$

where C is the amount of the transit time from the railway station i to the railway station j of the empty railcars belonging to the group k (depending on their type and/or their belonging to a certain railcar owner); x is the number of the railcars belonging to the group k and included in the freight railcars flow (a block of railcars) between the stations i and j; L is the number of the empty railcar groups in the railway node at the beginning of the base period; M is the number of the railway stations in the railway node; N is the number of the loading points of the empty railcars in the railway node.

The following constraints should be satisfied during the planning of the distribution of empty railcars in the railway transport node:

- the distribution of all empty railcars situated in the railway node at the beginning of the base period:

$$\sum_{i=1}^{M} A_{ki} = \sum_{j=1}^{N} B_{kj} = A_k,\ k = 1, 2, \ldots, L, \tag{2}$$

where A_{ki}, B_{kj} are the number of the railcars belonging to the group *k* and, respectively, located at the departure stations (*i*) and at the empty railcar loading points (*j*).

- taking into consideration all of the empty railcars belonging to a certain group with respect to the railcar traffic flows in the railway transport node:

$$\sum_{i=1}^{M}\sum_{j=1}^{N} x_{kij} = A_k, k = 1, 2, \ldots L. \tag{3}$$

- always a positive value of the railcar traffic flows in the railway transport node:

$$x_{kij} \geq 0, k = 1, 2, \ldots L; i = 1, 2, \ldots M; \ j = 1, 2, \ldots N. \tag{4}$$

- taking into consideration the empty railcar block with respect to their addition to the train size departing from the railway station soon:

$$t_{ir-1} < (p_i + t_i\sigma_i) \leq t_{ir}, \tag{5}$$

where *r* is the sequence train number in the train departure schedule of the railway station *i*. In this case, the index *i* denotes any station of the railway transport node where at the current moment of time the empty railcars included in the train *r* are located; t_{ir} is the departure time of the train *r* from the railway station *i*; p_i is the potential of the *i*th TOR (Table of an Optimal Route) of the transport network describing the scheme of the railway transport node tracks, or the total time of railcar transit on their route from the starting route station to the *i*th station; t_{ir} is the dead time of the railcars at the station *i*; σ_i is the station workload factor (the calculation approach is presented in Section 2.2).

- taking into consideration the minimum transit time of the empty railcars inside the railway transport node (according to Formula (5), the dead time of the empty railcars before they can be added to the soonest train and the transit delay due to the operating work level of the railroad station should be taken into account)

$$p_j - p_{i_i} > p_{ij}, i = 1, 2, \ldots M; \ j = 1, 2, \ldots N, \tag{6}$$

where p_j is the potential of the *j*th TOR of the transport network, for which the *i*th peak is the preceding one of the empty railcar route; p_{ij} is the potential of the transport network arc connecting the peaks *i* and *j*, or the amount of the transit time of the empty railcars on the railway track which directly connects the stations *i* and *j*.

- an equilibrium between the potential (estimation) of the TOR peak of the transport network (*j*) and the summation of the potential of the preceding TOR peak (*i*) and the potential of the transport network arc connecting these peaks:

$$p_j = p_{i_i} + p_{ij} \tag{7}$$

- the interconnection of the transport network peaks – this condition is used to implement Formula (6) for the purpose of the verification of all the transport network peaks for which the station *i* is the preceding station. Transport network peaks might be checked via the algorithm presented in the third section of this study.

$$i = \lambda_j, i = 1,2,\ldots M;\ j = 1,2,\ldots N, \tag{8}$$

where λ_j is the index of the TOR peak (the railway station) which precedes the j^{th} station on the way of the empty railcars in the railway transport node, i.e.:

$$i \in S_{ij} = \{i,\ldots,\lambda_i, j\}.$$

- a constraint on the number of the railcars in the train *r* to which the empty railcars belonging to the railcar flow x_{kij} and being at the station *i* can be added:

$$x_{kij} \le Q_{ir}, \tag{9}$$

where Q_{ir} is the maximum train *r* size.

In Chapter 3, both the approach to and the example of solving a transport problem, specifically being the issue of the optimization of the distribution of empty railcars in the railway transport node.

2.2 The Assessment of the Throughput and the Handling Capacity of the Railway Station – A Fuzzy Logic Approach

Basically, the statement of the problem of the evaluation of the effectiveness of the throughput and the handling capacity of a railway station might be described as follows. There are many technological railway stations, each characterized by a reserve of the throughput and the handling capacity $A = \{a_1, a_2, \ldots a_i, \ldots, a_m\}$. In turn, each station is characterized by a set of the indicators that on their own part exert an influence on the throughput and the handling capacity reserves $K = \{K_1, K_2, \ldots, K_j, \ldots, K_n\}$. Thus, the station with the largest throughput and the handling capacity reserve should be chosen, i.e. the variant a_i from the set A.

Table 1 indicates the four-factor groups (Rakhmangulov et al. 2016) used in order to estimate the work of the railway station K. In the previous study (Rakhmangulov and Osintsev, 2011), each factor was found to have its own functions, qualitatively determining the influence of the ratio on the amount of the throughput and the handling capacity reserve at the railway station.

Table 1. The factors and indicators of the operational assessment of the railway station workload

Factor groups ID	Factor groups feature	Assessment indices of the railway station
Technical factors group	The characterization of the technical equipment of the station – railway tracks development, shunting and cargo facilities	The number of the automatic switches The number of the train locomotives Type of the shunting locomotives The blocking type in the railway spans The incline of the station railway tracks The presence of the technical inspection points of the railcars at the station The number of the railroad spans at the station The number of the loading areas The presence of the weighing facilities at the station The presence of the weighing facilities in the loading areas
Technological factors group	The characterization of the amount and complexity of the technological operations currently being performed at the station; the characterization of the availability of the railway track elements	The presence of shunting work in the railway span The presence of shunting work in the loading areas Exceeding the limit of the dead time during the loading operations Uneven goods arrival from the external network Uneven products loading The reconstruction of the railway station The reconstruction of the workshop The time of the day Visibility Air temperature The number of the railcars The availability of shunting locomotives
Subjective factors group	The characterization of the complexity of the operational management of the railway station under certain conditions: depending on the level of organization, informatization, automatization, the weather and climatic conditions, the time of the day, etc.	The sufficiency of the shunting facilities at the station The sufficiency of the receiving/shipping railway tracks at the station The sufficiency of the receiving/shipping railway tracks capacity at the station A sufficient number of the exits at the station The actual capacity of each railway span The level of the technical development and capacity of the loading areas The professional competence of the operating personnel The presence of unfavorable routes at the station The presence of the corner railway tracks at the station
Employees factors group	The characterization of the professional competence of the railway station management	The years of age of the railway station managers The railway station managers' education The railway station managers' work experience

As is shown in Figure 1 below, in order to estimate the reserve of the throughput and the handling capacity of the station, the methods of the fuzzy set theory can be applied (Andreichikov and Andreichikova, 2000; Harris, 2006; Rakhmangulov and Osintsev, 2011).

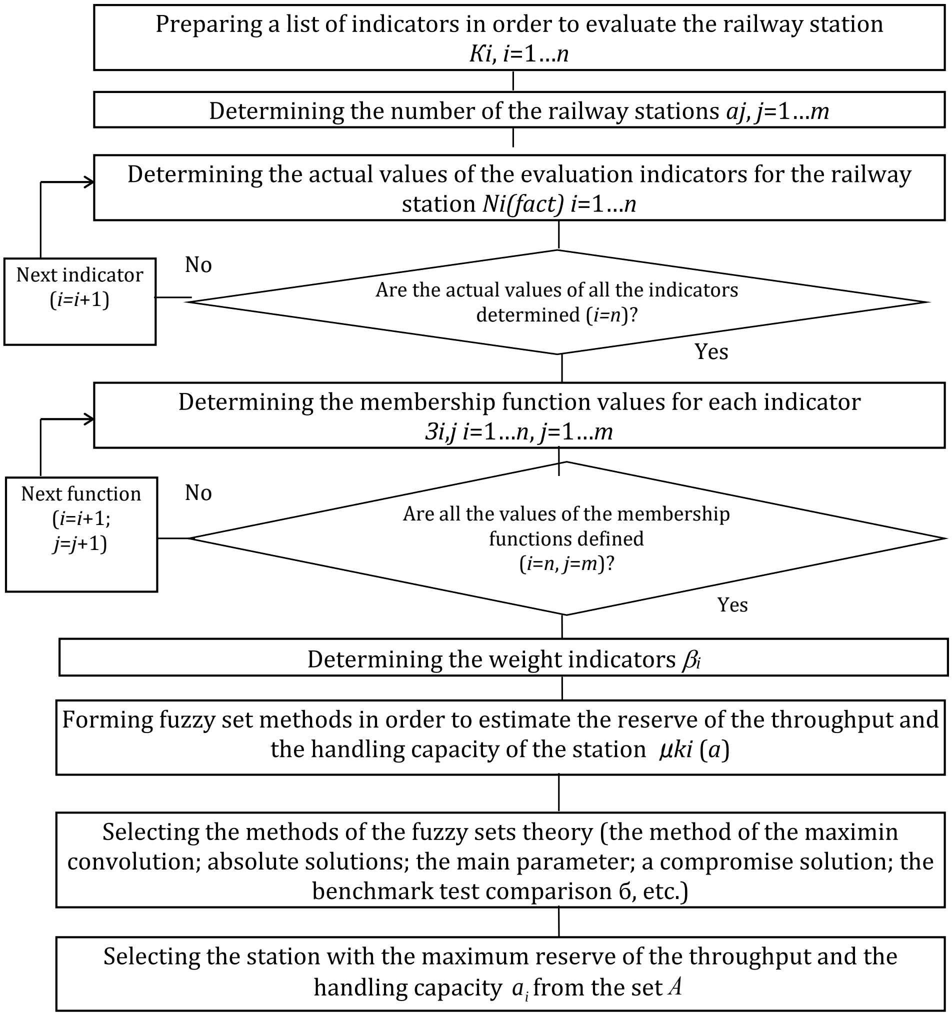


Figure 1. The algorithm for the estimation of the reserve of the throughput and the handling capacity of the station.

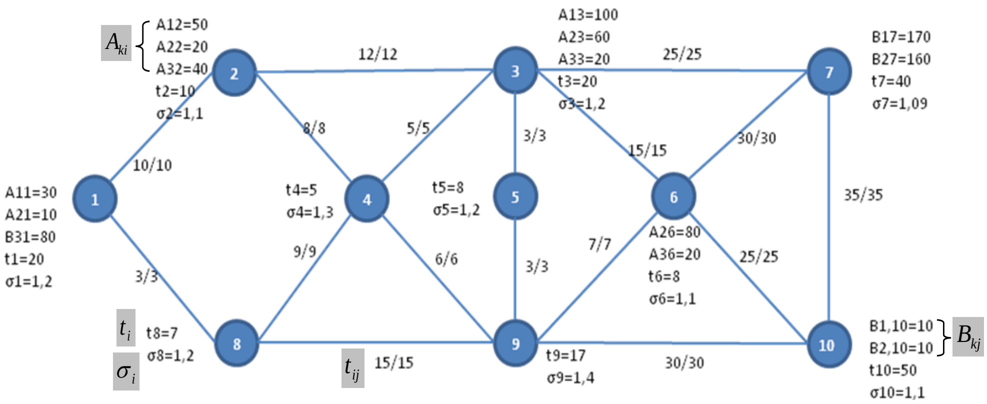
The numerical values of the reserve of the throughput and the handling capacity of stations are evaluated by the load factor of the station (σ_i) (Rakhmangulov and Osintsev, 2011). These values can be used to calculate the cost of the railcar hours during the passing of empty railcar flows on their routes.

3 The Calculation of the Plan for the Optimal Distribution of Empty Railcars in the Railway Transport Node. The Method, the Algorithm and an Example.

In previous studies (Rakhmangulov et al. 2014), several methods for the optimal distribution of empty railcars in the railway transport node were discussed. The practical implementation of the proposed model consists of the seven stages.

Stage 1 is associated with the preparation of the initial data characterizing the technical and technological indicators of the conditions of the transport network, the number of different railcar groups at the stations (Figure 2) and the train timetable inside the railway transport node (Table 2).

The railcar handling time at the stations $t_i\sigma_i$ is calculated based on the reserves of the throughput and the handling capacity of each station and the railcar handling time at a single station.



1 Peaks of the transport network (stations, loading areas) which are conventionally numbered with prime numbers;

A_{ki} is the number of the railcars of each group k which are located at each railway station i of the railway transport node, railcars;

B_{kj} is the exigency of the empty railcars at each j^{th} station or at the loading point, railcars;

t_i is the average handling time of transit railcars at the j^{th} station, min.;

σ_i is the coefficient of the station workload;

t_{ij} is the train movement time between the neighboring stations of the railway transport node, min.;

t_{ir} is the train timetable inside the railway transport node. The moments of the train departures for each r^{th} train at the railway station, min.;

Q_{ir} is the maximum number of the railcars that can be included in the train size r which is supposed to be sent according to the schedule from the station i at a moment of time t_{ir}, railcars.

Figure 2. An example of a transport network scheme with the initial data in order to calculate the optimal plan for the distribution of empty railcars in the railway transport node

Table 2. The train timetable between the stations inside the railway transport node

	j	t_{i1}	Q_{i1}	t_{i2}	Q_{i2}	t_{i3}	Q_{i3}	t_{i4}	Q_{i4}	t_{i5}	Q_{i5}
1	**2**	60	26	282	17	465	26	696	12	865	6
2	**1**	30	15	203	16	472	23	758	13	1115	10
2	**3**	90	16	223	11	437	17	758	24	1047	23
3	**2**	120	16	417	14	658	29	997	9	1062	8
2	**4**	30	9	146	29	300	20	615	19	865	17
4	**2**	360	28	528	20	762	19	1073	23	1213	5
1	**8**	100	27	191	17	493	11	662	8	940	23
8	**1**	80	24	435	26	578	29	746	13	853	8
8	**4**	70	7	393	24	635	28	834	28	1129	21
4	**8**	60	14	340	10	566	11	816	28	1161	17
4	**3**	40	12	212	7	364	26	469	5	740	15
3	**4**	50	6	131	24	385	5	586	15	912	29
3	**5**	90	14	206	11	531	16	616	30	937	17
5	**3**	80	20	425	25	769	21	1006	24	1360	28
4	**9**	45	10	373	13	452	21	657	22	929	9
9	**4**	60	8	154	11	262	10	493	18	576	16
8	**9**	90	10	400	16	700	15	837	15	1098	21
9	**8**	120	28	227	17	467	18	731	16	1060	17
5	**9**	140	10	492	9	623	7	790	26	1111	5
9	**5**	300	22	508	21	797	11	1030	8	1302	19
3	**6**	200	12	346	7	490	13	718	14	784	9
6	**3**	120	28	474	10	818	10	1096	7	1260	30
3	**7**	300	8	564	15	836	24	1032	27	1145	12
7	**3**	30	27	265	16	381	25	451	9	692	9
9	**6**	15	21	233	5	535	6	711	29	812	6
6	**9**	10	15	340	21	468	15	560	28	896	16
6	**7**	60	13	211	7	549	12	838	20	1024	18
7	**6**	70	25	321	5	525	26	870	29	1065	16
6	**10**	90	10	428	28	572	5	666	16	736	13
10	**6**	80	25	225	5	386	10	635	18	950	26
9	**10**	120	14	471	16	580	21	712	26	999	30
10	**9**	100	7	394	27	685	25	752	28	961	27
7	**10**	30	7	180	8	471	15	626	27	918	15
10	**7**	20	25	253	6	389	21	577	6	654	24

Stage 2 is linked to the construction of an optimal route set for all the stations which have empty railcars A_{ki}. For example, as is shown in Figure 2, the stations №1, №2, №3 and №6 are considered to be these types of stations.

The formation of an optimal route set is made by the constructing method of the Table of an Optimal Route (TOR) in the transport network (Rakhmangulov, 1999). The table of an optimal route consists of three columns (Figure 3). The first column contains the number of the stations i (the transport network peaks). The second column has the numbers of the preceding peaks λ_i. The third consists of the potentials of the peaks p_i. The shortest route to the i th peak is determined by the numbers of the preceding peaks. In the TOR constructing process, it is possible to repeatedly adjust the peak potentials and the numbers of the previous peaks. Thus, it is common to build several tables and transfer the results of the previous constructions to a new table.

The TOR constructing algorithm consists of the following actions:

1. The first and the second columns of TOR are filled in with the peak numbers of the transport network in ascending order. In the second column, the starting peaks are marked as the negative values. The third column is filled in by the starting potentials of the peaks. The initial potentials of the starting peaks are equal to zero. The initial potentials of all other peaks are taken as the number M – the largest possible number.

2. For each arc from the marked peak, the optimal arc condition $p_j - p_{i_i} > p_{ij}$ is checked. It means that a potential difference between the starting and the final arc peaks needs to be greater than the assessment value of the arc in-between these peaks. If this condition is satisfied, the usage of this arc is favorable. Then, as the preceding peak for the final arc peak (the second column is TOR) the peak number i (marked) is specified. The final peak potential is defined as the sum of the starting arc peak potential and the estimation of that arc, i.e. $p_j = p_{i_i} + p_{ij}$.

3. If the optimal arc condition fails, the next arc from the marked peak is checked.

4. If the optimal arc condition is checked for all the arcs from the marked peak, then the label from this peak is removed and the arcs from any next marked peaks are considered. After that, all calculations are repeated, starting with the second. The optimal route constructions are repeated as long as there is at least one marked peak in TOR.

Figure 3 shows the results of the TOR construction for the station №1.

Stage 3 is associated with the determination of the transportation time C_{kij} of the empty railcars delivered from the starting station of each route i to the final stations j, where there is an empty railcar exigency B_{kj}. In this case, the value C_{kij} might be equal to the final peak potential value of the corresponding route, i.e. $C_{kij} = p_j$. For example, since there are empty railcars of the groups №1 and №2 at the station №1, the transportation cost is only determined for those stations where there is the railcar exigency of this group.

	Starting table		The first iteration		The second iteration		The third iteration		The forth iteration		The fifth iteration		The sixth iteration	
i	**λi**	**pi**	**λi**	**pi**	**λi**	**pi**	**λi**	**pi**	**λi**	**pi**	**λi**	**pi**	**λi**	**pi**
1	-1	0	1	0	1	0	1	0	1	0	1	0	1	0
2	2	M	-1	70	1	70	1	70	1	70	1	70	1	70
3	3	M	3	M	-2	102	2	102	2	102	2	102	2	102
4	4	M	4	M	-2	154	-3	136	3	136	3	136	3	136
5	5	M	5	M	5	M	-3	209	-3	209	3	209	3	209
6	6	M	6	M	6	M	-3	215	-3	215	3	215	3	215
7	7	M	7	M	7	M	-3	325	-3	325	-3	325	3	325
8	8	M	-1	100	-1	100	-1	100	-1	100	-1	100	1	100
9	9	M	9	M	9	M	9	M	-4	379	-6	347	6	347
10	10	M	10	M	10	M	10	M	10	M	-6	453	6	453

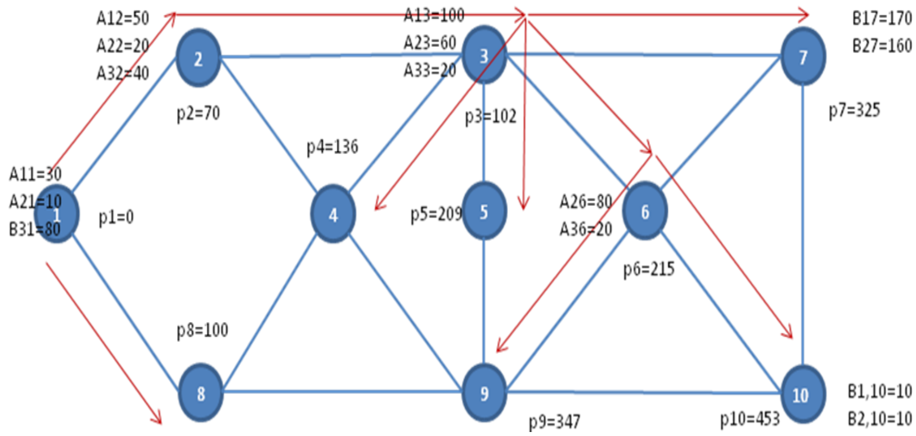


Figure 3. The example of the calculation of the optimal routes for the station i=1

There is demand of the first railcars group at the stations № 7 and №10.
$C_{1,1,7}$ = 325 min.;
$C_{1,1,10}$ = 453 min.;
There is demand of the second railcars group at the stations № 7 and №10.
$C_{2,1,7}$ = 325 min.;
$C_{2,1,10}$ = 453 min.

Similarly, the values C_{kij} are defined for another railway starting station and for another railcar group. As a result, the transportation time matrix for the empty railcars k of each group belonging to the contact schedule (Table 3) is formulated.

Table 3. The transportation time matrix of the empty railcars as a part of the trains inside the railway transport node

The railcar group	The number of the railcars at the station A_{ki}	The number of the railcars at the station C_{kij} and the exigency of the empty railcars B_{kj} at the station	
k =1		B_{17}=170	$B_{1,10}$=10
	A_{11}=30	325	453
	A_{12}=50	288	150
	A_{13}=100	325	453
k =2		B_{27}=160	$B_{2,10}$=10
	A_{21}=10	325	453
	A_{22}=20	288	150
	A_{23}=60	325	453
	A_{26}=80	90	150
k =3		B_{31}=80	
	A_{32}=40	40	
	A_{33}=20	213	
	A_{36}=20	438	

Stage 4 is related to the calculation of the optimal values of the empty railcar flow x_{kij} (Formula 1) and is based on the solution to the static transport problem of linear programming in the matrix formulation (Rakhmangulov, 1999; Rakhmangulov et al., 2014) (Table 4). The standard Excel Macros "Solution search" was used to solve this example. However, in order to implement the developed algorithm as a part of the intelligent transport system of railway transport, it is recommended that specialized programs for solving transport problems or linear programming libraries, e.g. the Linear Programming Library (GIPALS32), should be used.

Table 4. The results of the calculation of the optimal size of the empty railcar flow inside the railway transport node

The railcar group	The number of the railcars at the station A_{ki}	The sizes of the empty railcar traffic flow x_{kij}	
k =1		B_{17}=170	$B_{1,10}$=10
	A_{11}=30	30	0
	A_{12}=50	40	10
	A_{13}=100	100	0
k =2		B_{27}=160	$B_{2,10}$=10
	A_{21}=10	10	0
	A_{22}=20	10	10
	A_{23}=60	60	0
	A_{26}=80	80	0
k =3		B_{31}=80	
	A_{32}=40	40	
	A_{33}=20	213	
	A_{36}=20	438	

Stage 5 is relevant to the preparation of the initial data in order to check the limit (Formula 9) of the number of the empty railcars in the train size (Table 5).

Table 5. Initial data to check the limit of the number of the empty railcars in the train size

The railcar group, k	**The starting station, i**	**The final station, j**	**The optimal size of the railcar block, x_{kij}, the railcar**	**The size of the undistributed empty railcar block, $\dot{x}_{kij}$, the railcar**	**The size of the distributed empty railcar block, x_{kij}, the railcar**	**Transportation time, C_{kij} min.**
3	2	1	40	25	15	40
2	6	7	80	67	13	90
1	2	10	10	1	9	150
2	2	10	10	10	0	150
3	3	1	20	4	16	213
1	2	7	40	40	0	288
2	2	7	10	10	0	288
1	1	7	30	22	8	325
1	3	7	100	100	0	325
2	1	7	10	10	0	325
2	3	7	60	60	0	325
3	6	1	20	5	15	438

If the condition $x_{kij} \le Q_{ir}$ fails for the train r on any of the route peaks, then the railcar block size x_{kij} is taken as the minimum value $x_{kij} = \min Q_{ir} \ for \ \forall i \in S_{ij}$, and the difference $\bar{x}_{kij} = x_{kij} - \min Q_{ir}$ is stored as an undistributed block.

If the condition $x_{kij} \le Q_{ir}$ is satisfied, the values Q_{ir} for all the route peaks are reduced by the block size $Q_{ir} = Q_{ir} - x_{kij}$. Consequently, the block x_{kij} is stored as distributed. If the value Q_{ir} becomes zero for the train r, then the train is excluded from further calculations (Table 6).

Table 6. The check results of the limit of the number of the empty railcars in the train size

No.1	r	Q_{ir}	No. 2	r	Q_{ir}	No. 3	r	Q_{ir}	No.4	r	Q_{ir}	No.5	r	Q_{ir}
2	1	15	1	-	-	-	-	-	-	-	-	-	-	-
6	1	13	7	-	-	-	-	-	-	-	-	-	-	-
2	1	9	4	1	10	9	1	14	10	-	-	-	-	-
2	1	0	4	1	1	9	1	5	10	-	-	-	-	-
3	1	16	2	2	16	1	-	-	-	-	-	-	-	-
2	1	0	4	1	1	9	1	5	10	2	6	7	-	-
2	1	0	4	1	1	9	1	5	10	2	6	7	-	-
1	1	26	2	1	16	3	1	8	7	-	-	-	-	-
3	1	0	7	-	-	-	-	-	-	-	-	-	-	-
1	1	18	2	1	8	3	1	0	7	-	-	-	-	-
3	1	0	7	-	-	-	-	-	-	-	-	-	-	-
6	1	15	9	1	28	8	2	26	1	-	-	-	-	-

As a result of the distribution of the railcar block x_{321} for the stations No. 2 and No. 1, the following consequences occur:

- the size of the block x_{321} decreases by 15 cars;
- the size of the block x_{267} decreases by 13 cars, and so on.

Tables 7, 8 present the maximum possible number of empty railcars as a part of train size (initial data). Also, these tables include the distribution result of the railcar blocks x_{321}, x_{267}, $x_{12,10}$, $x_{22,10}$, x_{331}, x_{127}, x_{227}, x_{117}, x_{137}, x_{217}, x_{237}, x_{361}.

Table 7. The maximum possible number of the empty railcars in the train size (the initial data)

i	j	Q_{i1}	Q_{i2}	Q_{i3}	Q_{i4}	Q_{i5}
1	2	26	17	26	12	6
2	1	15	16	23	13	10
2	3	16	11	17	24	23
3	2	16	14	29	9	8
2	4	9	29	20	19	17
4	2	28	20	19	23	5
1	8	27	17	11	8	23
8	1	24	26	29	13	8
8	4	7	24	28	28	21
4	8	14	10	11	28	17
4	3	12	7	26	5	15
3	4	6	24	5	15	29
3	5	14	11	16	30	17
5	3	20	25	21	24	28
4	9	10	13	21	22	9
9	4	8	11	10	18	16
8	9	10	16	15	15	21
9	8	28	17	18	16	17
5	9	10	9	7	26	5
9	5	22	21	11	8	19

3	6	12	7	13	14	9
6	3	28	10	10	7	30
3	7	8	15	24	27	12
7	3	27	16	25	9	9
9	6	21	5	6	29	6
6	9	15	21	15	28	16
6	7	13	7	12	20	18
7	6	25	5	26	29	16
6	10	10	28	5	16	13
10	6	25	5	10	18	26
9	10	14	16	21	26	30
10	9	7	27	25	28	27
7	10	7	8	15	27	15
10	7	25	6	21	6	24

Table 8. The number of the empty railcars in the train size (after the distribution of the railcar blocks)

i	j	Q_{i1}	Q_{i2}	Q_{i3}	Q_{i4}	Q_{i5}
1	2	18	17	26	12	6
2	1	0	0	23	13	10
2	3	8	11	17	24	23
3	2	0	14	29	9	8
2	4	0	29	20	19	17
4	2	28	20	19	23	5
1	8	27	17	11	8	23
8	1	24	11	29	13	8
8	4	7	24	28	28	21
4	8	14	10	11	28	17
4	3	12	7	26	5	15
3	4	6	24	5	15	29
3	5	14	11	16	30	17
5	3	20	25	21	24	28
4	9	1	13	21	22	9
9	4	8	11	10	18	16
8	9	10	16	15	15	21
9	8	13	17	18	16	17
5	9	10	9	7	26	5
9	5	22	21	11	8	19
3	6	12	7	13	14	9
6	3	28	10	10	7	30
3	7	0	15	24	27	12
7	3	27	16	25	9	9
9	6	21	5	6	29	6
6	9	0	21	15	28	16
6	7	0	7	12	20	18
7	6	25	5	26	29	16
6	10	10	28	5	16	13
10	6	25	5	10	18	26
9	10	5	16	21	26	30
10	9	7	27	25	28	27
7	10	7	8	15	27	15
10	7	25	6	21	6	24

Stage 6 is related to the correction of leftover empty railcars at the stations (Table 9).

Table 9. The effect of the adjustment of the leftover empty railcars.

Undistributed railcar blocks			**Distributed railcar blocks**		
k	i	$\dot{x}_{kij}$	k	j	x_{kij}
1	1	22	1	7	0
1	2	1	1	7	8
1	2	40	1	7	0
1	3	100	1	10	9
2	1	10	2	7	13
2	2	10	2	7	0
2	2	10	2	7	0
2	3	60	2	7	0
2	6	67	2	10	0
3	2	25	3	1	15
3	3	4	3	1	16
3	6	5	3	1	15

A_{11}=22; A_{12}=41; A_{13}=100; A_{21}=10; A_{22}=20; A_{23}=60; A_{26}=67; A_{32}=25; A_{33}=4; A_{36}=5;

Total: 354 railcars

B_{17}=162; $B_{1,10}$=1; B_{27}=147; $B_{2,10}$=10; B_{31}=34

Total: 354 railcars

Thus, according to the adjustment, the following intermediate results are formed:

- a set of the distributed railcar blocks x_{kij} ;
- the routes of their transit S_{ij} ;
- the train numbers r which have distributed railcar groups in their train size (Table 10).

Table 10. The intermediate results of the optimal distribution of the empty railcars

k	i	j	x_{kij}	C_{kij}	No.1	r	No.2	r	No.3	r	No.4	r	No.5	r
1	1	7	8	325	1	1	2	1	3	1	7	-	-	-
1	2	10	9	150	2	1	4	1	9	1	10	-	-	-
2	6	7	13	90	6	1	7	-	-	-	-	-	-	-
3	2	1	15	40	2	1	1	-	-	-	-	-	-	-
3	3	1	16	213	3	1	2	2	1	-	-	-	-	-
3	6	1	15	438	6	1	9	1	8	2	1	-	-	-

Stage 7 is related to the correction of the initial data for the next iteration, and it includes:

1. the adjustment of the number of the empty railcars at the stations (Figure 4, the new values are marked in red).

2. the adjustment of the train schedule according to the contact itinerary. As a result of this adjustment, the trains that can no longer include empty railcars are removed from the train schedule (Table 11).

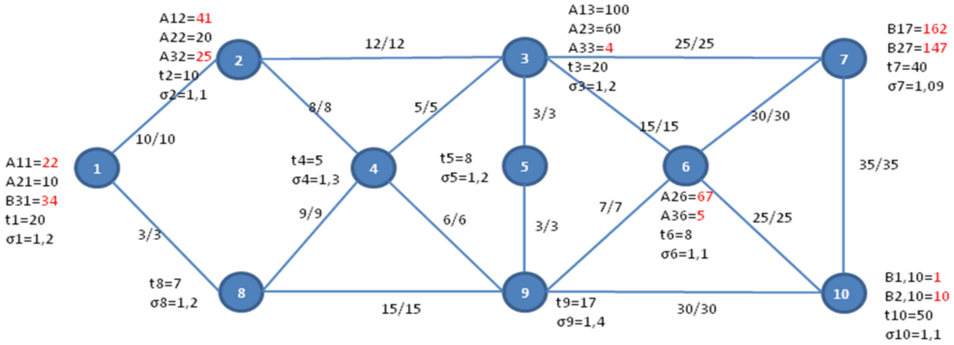


Figure 4. The results of the adjustment of the initial data for the second iteration (the correction of the transport network)

Table 11. The result of the train schedule adjustment inside the railway transport node

i	j	t_{i1}	Q_{i1}	t_{i2}	Q_{i2}	t_{i3}	Q_{i3}	t_{i4}	Q_{i4}	t_{i5}	Q_{i5}
1	**2**	60	26	282	17	465	26	696	12	865	6
2	**1**	-	15	203	0	472	23	758	13	1115	10
2	**3**	90	16	223	11	437	17	758	24	1047	23
3	**2**	-	16	417	14	658	29	997	9	1062	8
2	**4**	-	9	146	29	300	20	615	19	865	17
4	**2**	360	28	528	20	762	19	1073	23	1213	5
1	**8**	100	27	191	17	493	11	662	8	940	23
8	**1**	80	24	435	11	578	29	746	13	853	8
8	**4**	70	7	393	24	635	28	834	28	1129	21
4	**8**	60	14	340	10	566	11	816	28	1161	17
4	**3**	40	12	212	7	364	26	469	5	740	15
3	**4**	50	6	131	24	385	5	586	15	912	29
3	**5**	90	14	206	11	531	16	616	30	937	17
5	**3**	80	20	425	25	769	21	1006	24	1360	28
4	**9**	45	10	373	13	452	21	657	22	929	9
9	**4**	60	8	154	11	262	10	493	18	576	16
8	**9**	90	10	400	16	700	15	837	15	1098	21
9	**8**	120	28	227	17	467	18	731	16	1060	17
5	**9**	140	10	492	9	623	7	790	26	1111	5
9	**5**	300	22	508	21	797	11	1030	8	1302	19
3	**6**	200	12	346	7	490	13	718	14	784	9
6	**3**	120	28	474	10	818	10	1096	7	1260	30
3	**7**	-	8	564	15	836	24	1032	27	1145	12
7	**3**	30	27	265	16	381	25	451	9	692	9
9	**6**	15	21	233	5	535	6	711	29	812	6
6	**9**	-	15	340	21	468	15	560	28	896	16
6	**7**	-	13	211	7	549	12	838	20	1024	18
7	**6**	70	25	321	5	525	26	870	29	1065	16
6	**10**	90	10	428	28	572	5	666	16	736	13
10	**6**	80	25	225	5	386	10	635	18	950	26
9	**10**	120	14	471	16	580	21	712	26	999	30
10	**9**	100	7	394	27	685	25	752	28	961	27
7	**10**	30	7	180	8	471	15	626	27	918	15
10	**7**	20	25	253	6	389	21	577	6	654	24

Stages 2-7 of the described algorithm must be repeated until the very occurrence of undistributed railcar blocks. If there are such railcar blocks at the end of the estimated period, they are the leftover empty railcars carried forward to the next estimated period. This leftover can be eliminated by increasing the values Q_{ir} for the trains. After that, a full recalculation of the plan for the distribution of the empty railcars is required and should start with the first step of the algorithm.

4 Conclusion

The results of the present model are:

- a considerable cluster of the values x_{kij} that determines the optimal number of the railcars of each group in the blocks. These railcars are supposed to be delivered to the specific loading points (stations) during the estimated period (within one day);
- the optimal transit routes of the railcar blocks S_{ij} ;
- the scheduled number of the trains r for each station. The train size should include empty railcar blocks.

As a result, the proposed model, associated with the rational use of empty railcars, might lead to an around 15-20% decline in the dead time of empty railcars in the railway transport node.

The developed model, the method and the algorithm of its implementation can easily be integrated into the existing intelligent control systems of railway transport hubs. Current railway transport systems are ready and contain all the data necessary for the implementation of the present model.

At the same time, the disadvantage of this algorithm is the relatively low accuracy of compliance with the train schedule in the railway transport node and in the railway transport systems of industrial enterprises. In most cases, this type of schedule is not in place due to the fact that internal railway traffic is moderated by dispatchers and depends on the availability of specific railcars at the railway station, as well as on the current loading situation at this and closely located stations. Owing to the solid internal scheduled train flows in the railway transport node, there are still some stable freight traffic flows. However, it is worth noting that even for these trains frequent schedule breaches were observed due to uneven railway stations and the railway track workload.

Future studies are expected to bring about a solution to this problem. The prediction of the time of the train departure from the railway transport node stations by using BigData tools might be a possible way to carry it out. A promising approach to the improvement of the accuracy of train traffic forecasts inside the railway transport node implies using the simulation method in the operational mode. Based on the data of the availability and transit status of railcars, the modern simulation models of railway stations can enable an operational assessment of the possible scenarios of the operating workload of railway stations.

To sum it up, the current research study, specifically the promising tools and methods, might be helpful in improving the accuracy of the result of optimization during the distribution of empty railcars in the railway transport node.

Acknowledgements

This work is supported by the PJSC Magnitogorsk Iron and Steel Works (Contract «Mathematical support of the intelligent control module of the railcar traffic flow as part of the automated dispatching system of railway transport control» PJSC Magnitogorsk Iron and Steel Works, No. 01201274221).

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