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Methodology for Optimal Placement of Containers in Trains in Case of Cargo Operations Along the Route

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ABSTRACT

A new approach to organisation of container block trains is considered based on the principles of passenger traffic. The technology assumes container train's traffic subject to the timetable with sale of cargo space in the train. The train is made up at the departure station and follows the established route with stops at intermediate container terminals or stations, where a container for which this station is designated as destination is removed and a new container is placed on the vacated place to be delivered to subsequent points of the route.

The objective of this study is to develop a methodology for optimal placement of containers in a block train intended for en route cargo handling operations. The technique involves an iterative search for such an order of placement of packages so that containers assigned to each intermediate point are as close to each other as possible. The technique is an authors' algorithm based on combinatorial optimisation methods.

The implementation of the proposed algorithm makes it possible to reduce the excessive mileage of handlers and loaders at intermediate points and, consequently, to increase speed of cargo operations when rearranging containers, as well as to reduce operating costs of using the loading facilities of the container terminal.

The proposed mathematical algorithm as compared to exhaustive search allows significantly reducing the number of iterations in search for a solution and can be implemented as software.

Keywords: *transport, railway, container train, container transportation, container flow, routing, combinatorial optimisation.*

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For the original Russian text of the article please see p. 174.

INTRODUCTION

Switching cargo to container transportation from other modes of transport and increasing the level of containerisation is one of the tasks facilitating the achievement of sustainable development goals, allowing to reduce carbon footprint of road transportation.

It is also among priority tasks of Russia's economic development, stipulated by national goals and strategic tasks[1], the implementation of this task will result in quadrupling the volume of transit railway container transportation by 2024.

China is the main global importer of containerised cargo [1]. An analysis of statistical data on loading and unloading of containers provided by JSC Russian Railways showed that the PRC accounts for 66 % of all imported railway container transportation to Russia. At the same time, 52 % of shipments from China are carried out by rail through the seaports of Primorsky region (Kray)[2].

Railway transit traffic on the route China–Europe–China through the territory of Russia in 2020 attained 3,6 million tons (an increase by 1,9 times) [2]. However, the share of sea transportation from China to Europe through the Suez Canal is still very high and accounts for about 90 % of the total Chinese-European trade [3].

To increase the range of competitive offerings in terms of alternative ways of container transportation compared to sea routes, it is necessary to develop technology to increase delivery speed, improve tariff policy and improve the level of service for cargo owners.

Currently, there are some Russian [4–9] and international [10–15] studies aimed at improving organisation of container transportation. For example, in [6] it is proposed to form a two-level regional structure of the container transportation system: first, a network of container terminals that accumulate goods from shippers, and second, a network of container storage and distribution centres that collect regional container flows and ensure building container trains. This approach makes it possible to massively adopt container block trains, but it still presupposes collection and accumulation of containers in large hubs, which increases time of initial and final operations. In literature, this technology is denoted by the term «hub and spoke», its implementation in the field of container transportation was studied, e.g., in [10–12].

Another option for increasing competitiveness of railway container transportation is considered in the study [9] and involves the use of differentiated lengths of container block trains. This approach allows reducing the total container delivery time but entails an increase in the cost of transportation and, accordingly, an increase in the transport tariff.

All designated domestic and international studies are built in accordance with the traditional rail cargo traffic system[3].

This article discusses a new approach to organisation of container block trains, previously not presented in the literature.

The *objective* of the study is to develop a methodology for optimal placement of containers in a block train intended for en route cargo handling operations. The technique involves an iterative search for such an arrangement of packages so that containers assigned to each intermediate point are as close to each other as possible. The technique is an authors' algorithm based on combinatorial optimisation *methods*.

The technology under consideration is based on the principle of organising passenger traffic: traffic is carried out according to the timetable with sale of individual space in a container train. It is assumed that trains with permanent number of platform wagons [flat-platform wagons fitted with securing equipment] will be intended for containers dispatched along a given route. Train stops are planned at intermediate stations equipped for loading and unloading handling equipment. While that train stops at a station the handler removes a container assigned to that intermediate station from the platform and installs on the

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[1] Decree of the President of the Russian Federation «On national goals and strategic objectives for development of the Russian Federation for the period up to 2024». [Electronic resource]: http://kremlin.ru/events/president/news/57425. Last accessed 20.12.2020.

[2] Authors' own calculations based on statistics of JSC Russian Railways.

[3] The recently adopted Precision-scheduled railroading (PSR) in the United States and its general impact on organisation of container transportation seemed still awaiting in-depth research publications to be integrated in the review of relevant literature. – *Editorial note.*

vacant place another container intended to be supplied to one of the following stations on the route. Other necessary technological operations (changing the locomotive and locomotive crew) are simultaneously performed as well.

The implementation of this technology will reduce container delivery time by eliminating sorting and shunting operations along the route and will facilitate and simplify the procedure of forwarding containerised goods for cargo owners. This eliminates the need to accumulate at a terminal a batch of containers intended to be delivered through a full route, while meeting the condition of the standard train length. Prospects for such a concept of organising container transportation are being considered by JSC Russian Railways [16].

A new approach to organisation of container transportation requires a lot of research and the solution of several scientific problems. In [17], a model was developed for determining the optimal routes of container trains, stations where they are assembled and disassembled in such a way as to ensure the minimum travel time and maximum train load, considering the needs of the regions in container transportation and constraints of the regional infrastructure.

This work is a continuation of the research of the authors [17] and presents a methodology for optimal placement of containers in a train.

RESULTS

The method of optimal placement of containers in a train intended for en route cargo handling operations

The placement of containers on a train intended for en route cargo handling operations must be carried out reasonably. Their arbitrary placement at the origin point can result in excess handler mileage at intermediate points when carrying out cargo handling operations. That is, the problem arises of optimal placement of packages (containers) in the train so that containers assigned to each intermediate point are as close to each other as possible.

The placement problem belongs to the class of combinatorial optimisation problems. The solution methods are reduced to an enumeration of options to obtain the optimal value or the one close to the optimal value. The exhaustive search method is often impossible since when there are n objects that need to be optimally placed in a certain space, $n!$ placement options appear. For example, if it is necessary to optimally place only ten containers in a train, then finding of optimal arrangement will require to go through $10! = 3\,628\,800$ options. In this regard, various mathematical algorithms for partial enumeration have been developed that allow finding a solution close to the optimal one: the branch-and-bound method, the simulated annealing method, the ant colony algorithm, the genetic algorithm, and others [18–20].

In view of the specifics of the task at hand, a special author's algorithm has been developed to solve it based on existing mathematical methods.

The algorithm involves two stages.

At the first stage, after determining placement area for groups of containers moved from the same origin (place of loading) to the same destination (place of unloading) an initial placement matrix is formed.

At the second stage, the original matrix is subject to multiple transposition (permutation of pairs of columns) until an unimprovable value of the optimality criterion is obtained. The criterion of optimality is the conditional distance between containers to be unloaded at each intermediate point.

Here is a description of the algorithm.

Let's number the points (terminals) of container loading/unloading along the train route with natural numbers from 1 to N (Pic. 1).

For a train following this route, a correspondence matrix $[q(i, j)]$ of size $N \cdot N$ is given, where $q(i, j)$ denotes the number of containers sent from point i to point j. The correspondence matrix satisfies the following constraints:

1. $q(i, j) = 0$, if $j \leq i$ containers cannot be shipped and sent from point i to the previous points of the train route;

2. $\sum_{i=1}^{p} q(i,p) = \sum_{j=p}^{N} q(p,j)$: at each intermediate point $p = 2,3, \ldots, N\text{-}1$ as many containers $\sum_{j=p}^{N} q(p,j)$ are loaded into the train as were unloaded at this point $\sum_{i=1}^{p} q(i,p)$.

Such a matrix can be formed based on the algorithm for finding the optimal train route on a given network, developed in [17].

Let us denote by I_j the number of sources of flows of containers intended for supply to

Pic. 1. Numbering of the points of container loading/unloading along the route for the purpose of formalising the algorithm (developed by the authors).

destination point j, and by S_i – the number of destinations (channels) of container flows departed from point i.

We assume that at each loading point $p = 1,2, \dots, N\text{-}1$, containers sent to a specific point $j > p$ are loaded onto free cargo spaces next to each other, forming *cargo groups*. Thus, a group of cargo spaces G_{pj} is a set of cargo spaces located side by side without gaps, where containers sent from a given origin point p to a given point of destination j are placed. Note that in a train, along its entire length, several different groups G_{pj} of placement of containers delivered from the same point of departure p to destination point j may appear.

The total number of groups of cargo spaces K is defined by the following formula:

$$K = 1 + \sum_{i=2}^{N-1} S_i. \qquad (1)$$

In this formula, the first term (one) corresponds to the cargo group G_{pN} of containers sent from the point of assembling of the train $i = 1$ to the final point of the route $i = N$. This group contains $q(1, N)$ containers, it does not change when the train passes intermediate loading-unloading points, since the containers of this group are not handled at intermediate points of the route. Thus, the total number of groups of cargo spaces in the train K is determined by the number of pairs of cargo operations (loading-unloading) on the route. A single operation is carried out at the origin and destination point (only loading at the starting point and only unloading at the final point). At each intermediate point, both loading and unloading of containers is carried out, therefore, the required number of cargo spaces will be determined by the number of destinations of the flow from each point i, that is, by the term $\sum_{i=2}^{N-1} S_i$.

Let us agree to number the groups of cargo spaces with natural numbers from 1 to K, for example, from the locomotive to the tail of the train.

Further, at the first stage, the initial ($\chi = 0$) *matrix of arrangement of containers in the train* $[\alpha_{lk}]$ of size $(N\text{-}1) \cdot K$ is formed. Elements α_{lk} of the placement matrix will denote the number $q(i, j, k)$ of containers loaded at point i with assignment to point j, which occupy the k-th group space in the container train.

Let us describe the algorithm for forming the matrix of arrangement $[\alpha_{lk}]$.

Elements α_{1k} of the first row of the placement matrix are calculated from the correspondence matrix $[q(i, j)]$ as follows.

Looking from left to right the rows of the correspondence matrix $[q(i,j)]$ *starting from the second one*, select all *nonzero* elements from them and arrange them in a sequence (S_i – the number of destinations of the container flow sent from point i, that is, the number of *nonzero* elements in the i-th line):

$$\tilde{\alpha}_{11} = q(2, j_{21}),\ \tilde{\alpha}_{12} = q(2, j_{22}),\ \dots,$$
$$\tilde{\alpha}_{1,S_2} = q(2, j_{2,S_2});\ \tilde{\alpha}_{1,S_2+1} = q(3, j_{31}),$$
$$\tilde{\alpha}_{1,S_2+2} = q(3, j_{32}),\ \dots,\ \tilde{\alpha}_{1,S_2+S_3} = q(3, j_{3,S_3});$$
$$\dots\ ;\ \tilde{\alpha}_{1,K-1} = q(N-1, N)$$

– from formula (1) determining the number of groups of cargo spaces, this sequence contains exactly K-1 elements.

Moving along the resulting sequence of nonzero elements from left to right, let us fill in the first line of the placement matrix according to the following rule.

If $\tilde{\alpha}_{1k} = q(i, j) \le q(1, i)$, then $\alpha_{1k} = \tilde{\alpha}_{1k}$. This means that if the k-th element of $\tilde{\alpha}_{1k}$ sequence, which, of course, is equal to some nonzero element $q(i,j)$ from the i-th row of the correspondence matrix, does not exceed the upper element of the i-th column, then we write it to the k-th position of the first row of the placement matrix, assigning it the notation $q(i, j, k)$.

Otherwise, if $\tilde{\alpha}_{1k} = q(i, j) > q(1, i)$,

then $\alpha_{1k} = q(i, j) - \sum_{s=2}^{j} q(s, i)$.

This means that otherwise, when the number of containers $q(i, j)$ does not fit into the group of $q(1, i)$ cargo spaces vacated after unloading, it is necessary to subtract the sum of all elements of the i-th column of the matrix of correspondences below the first upper one.

Table 1

Matrix of correspondences of a container train intended for en route cargo handling operations, transporting TEU (developed by the authors based on the methodology [17])

Departure point of containers	Destination point of containers					
	Primorsky region	Irkutsk region	Krasnoyarsk region	Sverdlovsk region	Perm region	St. Petersburg
Primorsky region	0	23	36	54	4	9
Irkutsk region	0	0	0	3	2	18
Krasnoyarsk region	0	0	0	12	6	18
Sverdlovsk region	0	0	0	0	2	67
Perm region	0	0	0	0	0	14
St. Petersburg	0	0	0	0	0	0

The remaining containers $\sum_{s=2}^{j} q(s,i)$ will be distributed to the spaces vacated after unloading of containers following from points $s > 1$ to the point i.

The last element of the first row of the arrangement matrix is set equal to $\alpha_{1K} = q(1, N)$ and it is denoted $q(1, N, K)$.

For the subsequent rows of the arrangement matrix 1 = 2, ..., N-1 the numerical values α_{lk} are rewritten as follows. The values α_{lk} are assigned the indices p and j in accordance with the correspondence matrix. If at the intermediate point p the containers are unloaded from i to p and the containers are loaded onto the vacant space to be transported from p to j, then the corresponding value α_{lk} is assigned the indices p and j, while the conditions are simultaneously fulfilled: $p = l$ and $p = j_{l-1}$. If there is no change of containers at point p on the cargo space (the containers have passed through point p in transit), then the indices of the previous line are overwritten, that is, $p = p_{l-1}$ and $j = j_{l-1}$.

For each row l of the matrix $[\alpha_{lk}]$, the conditional distance between the containers $r(l)$ (the distance of the unproductive run of the handler) to be loaded at the p-th point of departure is calculated as the sum of the elements $\alpha_{lk}(p, j)$ with indices p less than the number of this line l within the boundaries of the segment $[lk_{\min}; lk_{\max}]$, that is:

$$r(l) = \sum_{k_{\min}(l)}^{k_{\max}(l)} \alpha_{lk}(p, j), \text{ at } p < l \;, \qquad (2)$$

where $k_{\min}(l)$ is number of the leftmost column of row l, where the value $\alpha_{lk}(p, j)$ is written with the index $p = l$;

$k_{\max}(l)$ is number of the rightmost column of row l, where the value $\alpha_{lk}(p, j)$ is written with the index $p = l$.

Then the criterion of optimality of each solution χ is determined by the expression:

$$R(\chi) = \sum_{l=1}^{N-1} r(l) \;. \qquad (3)$$

The problem is to find such an arrangement matrix χ for which $R(\chi)$ takes the smallest value.

The essence of the proposed optimisation algorithm consists in successive transpositions (permutations of some pairs) of columns of the matrix χ according to the established rules and the elimination at each step of solutions with a minimum value of the optimality criterion $R(\chi)$. The idea behind this approach is based on the principle of a genetic algorithm.

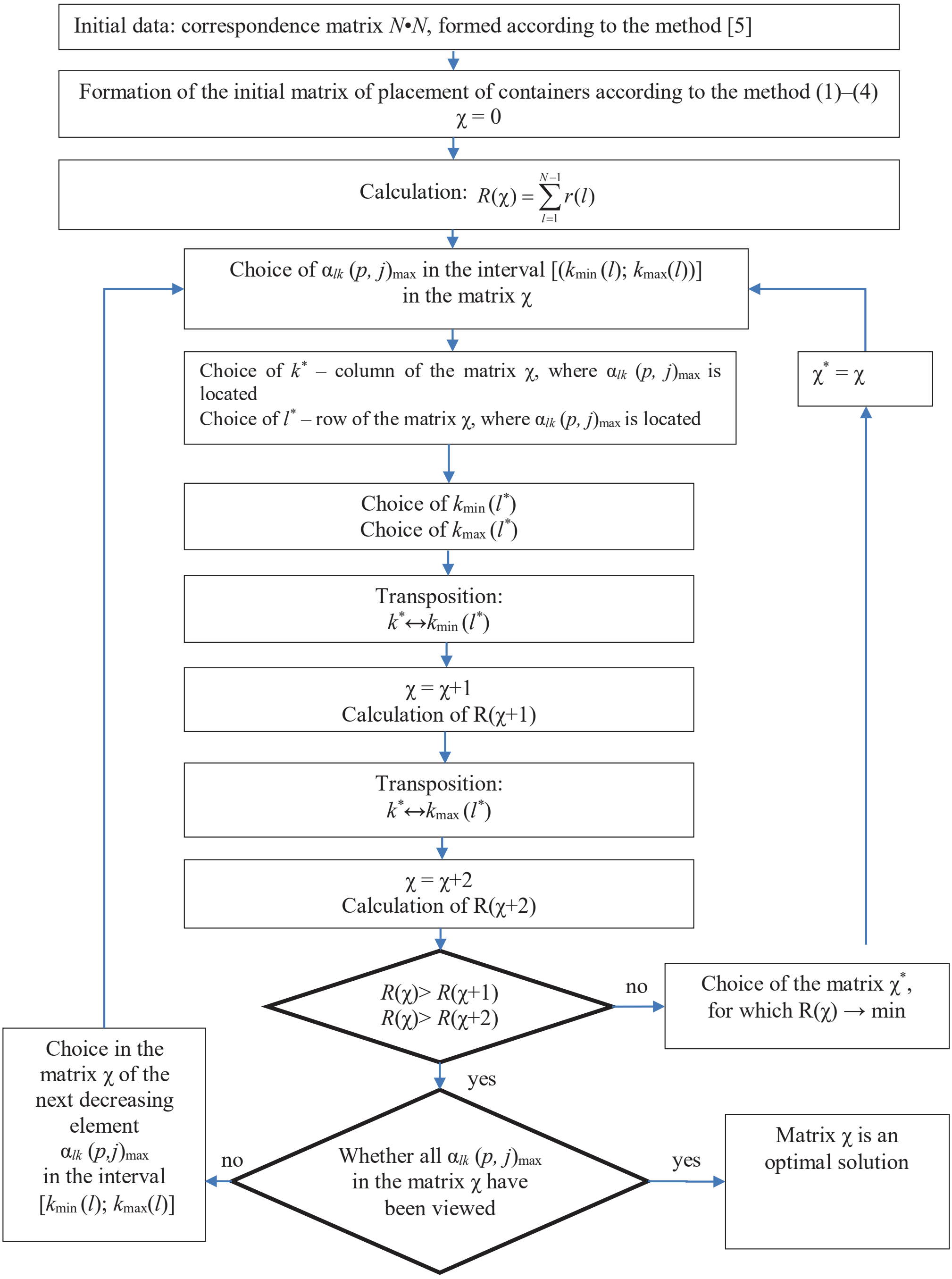
The sequence of operations using the algorithm for optimising placement of containers on the train is as follows:

The first step. The value $R(\chi)$ is calculated in the matrix of arrangement χ. Among the values of the matrix $\alpha_{lk}(p, j)$ in the interval $[(k_{\min}(l); k_{\max}(l))]$, we select the largest element, that is, the value that most affects the criterion $R(\chi)$.

The second step. We perform transposition (permutation of two columns) in the matrix χ: we swap position of the k-th column, in which the element $\alpha_{lk}(p, j)_{\max}$ selected at the first step is located, with the column where $\alpha_{lk\min}(p, j)$ is located in row l. We get the matrix $\chi+1$, and then calculate the value of $R(\chi+1)$.

The third step. We carry out the transposition in the matrix χ: k-th column, in which the element $\alpha_{lk}(p, j)_{\max}$ is located, is swapped with the column where the element $\alpha_{lk\max}(p, j)$ is located in row l. We get the matrix $\chi + 2$, and then calculate the value of $R(\chi+2)$.

The fourth step. If $R(\chi) < R(\chi+1)$ and $R(\chi) < R(\chi+2)$, then the permutations performed at steps 2 and 3 did not allow us to improve the solution, and we go to step 5. Otherwise, from the matrices $\chi + 1$ and $\chi + 2$ we choose the one



Pic. 2. Block diagram of the algorithm for finding the optimal placement of containers in a train intended for en route cargo handling operations (developed by the authors).

for which $R(\chi)$ takes the smallest value, the others are excluded from consideration, and then we go to step 6.

The fifth step. In the matrix of arrangement χ, we find the element α_{lk} $(p, j)_{max1}$ next in decreasing value in the interval $(k_{min}(l); k_{max}(l))$; the elements α_{lk} $(p, j)_{max}$, chosen earlier, are excluded from consideration. Then we go to step 2.

The sixth step. For the selected matrix, we repeat steps 1–4 until all columns with α_{lk} $(p, j)_{max}$ values have been considered, which

Table 2

The initial matrix of arrangement of containers in a train with en route cargo handling operations, $\alpha_{lk}(p, j)$ (TEU) (developed by the authors)

1	2	3	4	5	6	7	8	9	10	$r(i)$
$3_{(1,2)}$	$2_{(1,2)}$	$18_{(1,2)}$	$12_{(1,3)}$	$6(_{1,3)}$	$18_{(1,3)}$	$2_{(1,4)}$	$52_{(1,4)}$	$4_{(1,5)}$	$9_{(1,6)}$	0
$3_{(2,4)}$	$2_{(2,5)}$	$18_{(2,6)}$	$12_{(1,3)}$	$6_{(1,3)}$	$18_{(1,3)}$	$2_{(1,4)}$	$52_{(1,4)}$	$4_{(1,5)}$	$9_{(1,6)}$	0
$3_{(2,4)})$	$2_{(2,5)}$	$18_{(2,6)}$	$12_{(3,4)}$	$6_{(3,5)}$	$18_{(3,6)}$	$2_{(1,4)}$	$52_{(1,4)}$	$4_{(1,5)}$	$9_{(1,6)}$	0
$3_{(4,6)}$	$2_{(2,5)}$	$18_{(2,6)}$	$12_{(4,6)}$	$6_{(3,5)}$	$18_{(3,6)}$	$2_{(4,5)}$	$52_{(4,6)}$	$4_{(1,5)}$	$9_{(1,6)}$	44
$3_{(4,6)}$	$2_{(5,6)}$	$18_{(2,6)}$	$12_{(4,6)}$	$6_{(5,6)}$	$18_{(3,6)}$	$2_{(5,6)}$	$52_{(4,6)}$	$4_{(5,6)}$	$9_{(1,6)}$	100

Table 3

The result of approbation of the algorithm for finding optimal placement of containers in a train intended for en route cargo handling operations (developed by the authors)

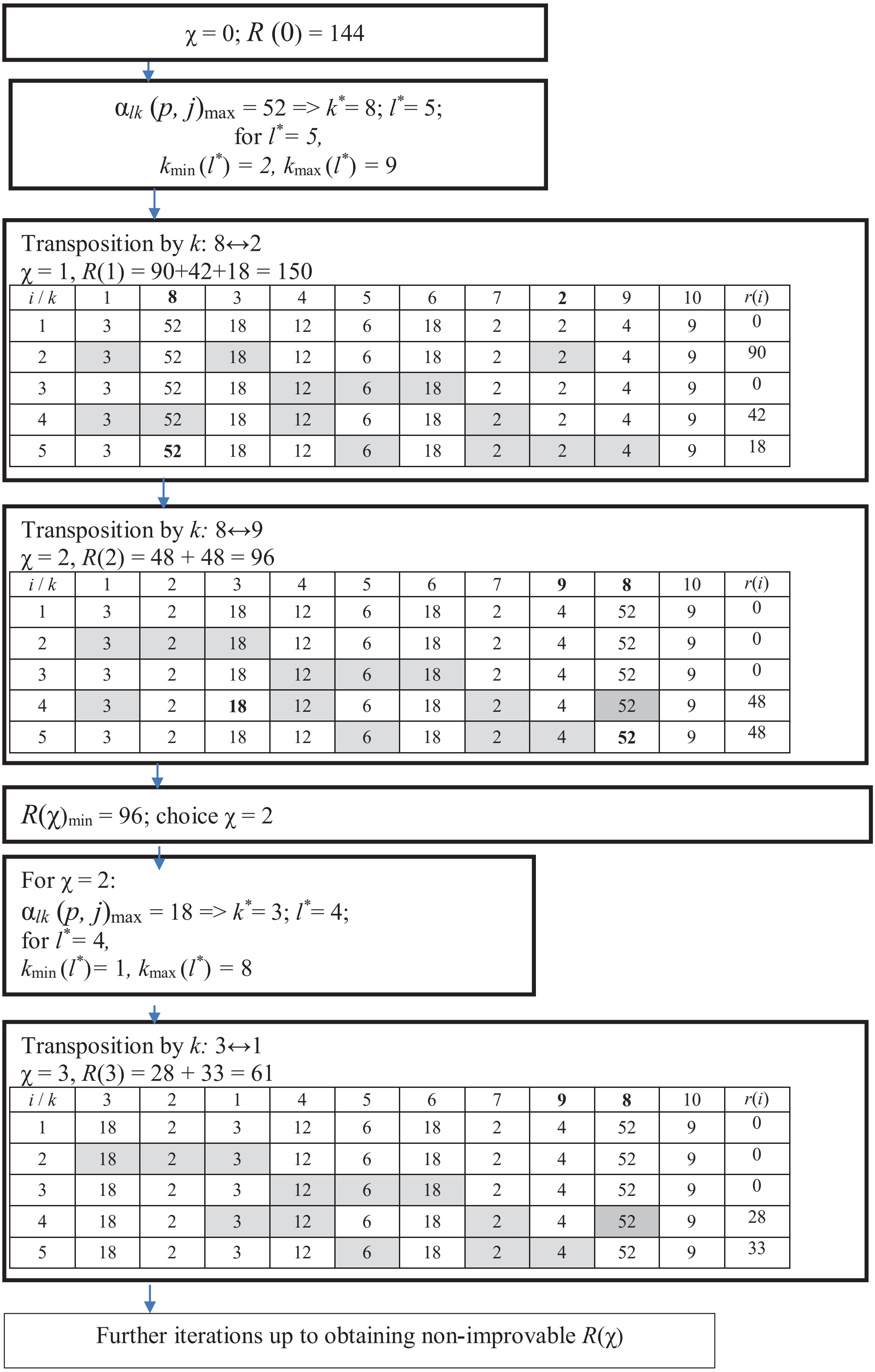
Solution option	The largest chosen element	Chosen column	Chosen row	Transposition	Criterion R(χ)	Solution choice
χ	α_{lk} (p, j)$_{max}$	k*	l*			
0	52	8	5	–	144	$R(\chi)_{min} = 96$ $\chi = 2$
1				8↔2	150	
2				8↔9	96	
3	18	3	4	3↔1	61	$R(\chi)_{min} = 61$ $\chi = 3$
4				3↔8	202	
5	18	6	4	6↔1	79	$R(\chi)_{min} = 61$ $\chi = 3$
6				6↔8	131	
7	18	6	5	6↔2	51	$R(\chi)_{min} = 49$ $\chi = 8$
8				6↔9	49	
9	12	4	5	4↔2	53	$R(\chi)_{min} = 35$ $\chi = 10$
10				4↔7	35	
11	6	5	4	5↔1	42	$R(\chi)_{min} = 35$ $\chi = 10$
12				5↔8	89	
13	4	9	3	9↔5	31	$R(\chi)_{min} = 31$ $\chi = 13$
14				9↔6	61	
15	4	9	4	9↔1	33	$R(\chi)_{min} = 31$ $\chi = 13$
16				9↔8	91	
17	3	1	5	1↔2	30	$R(\chi)_{min} = 30$ $\chi = 17$
18				1↔5	43	
19	2	2	4	2↔1	31	$R(\chi)_{min} = 30$ $\chi = 17$
20				2↔8	134	

increase the distance between containers of the same destination, and the methods of their permutation have not been used.

The block diagram of the algorithm for finding the optimal placement of containers in a train intended for en route cargo handling operations is shown in Pic. 2.

Approbation of the method of optimal placement of containers in a train intended for en route cargo handling operations

Let's consider a specific example of implementation of the proposed algorithm. Let the matrix of correspondences be formed for the route of a container train intended for en route



$\chi = 0; R(0) = 144$

$\alpha_{lk}(p, j)_{\max} = 52 \Rightarrow k^* = 8; l^* = 5;$
for $l^* = 5$,
$k_{\min}(l^*) = 2, k_{\max}(l^*) = 9$

Transposition by k: 8↔2
$\chi = 1, R(1) = 90+42+18 = 150$

i / k	1	**8**	3	4	5	6	7	**2**	9	10	$r(i)$
1	3	52	18	12	6	18	2	2	4	9	0
2	3	52	18	12	6	18	2	2	4	9	90
3	3	52	18	12	6	18	2	2	4	9	0
4	3	52	18	12	6	18	2	2	4	9	42
5	3	**52**	18	12	6	18	2	2	4	9	18

Transposition by k: 8↔9
$\chi = 2, R(2) = 48 + 48 = 96$

i / k	1	2	3	4	5	6	7	**9**	**8**	10	$r(i)$
1	3	2	18	12	6	18	2	4	52	9	0
2	3	2	18	12	6	18	2	4	52	9	0
3	3	2	18	12	6	18	2	4	52	9	0
4	3	2	**18**	12	6	18	2	4	52	9	48
5	3	2	18	12	6	18	2	4	**52**	9	48

$R(\chi)_{\min} = 96$; choice $\chi = 2$

For $\chi = 2$:
$\alpha_{lk}(p, j)_{\max} = 18 \Rightarrow k^* = 3; l^* = 4;$
for $l^* = 4$,
$k_{\min}(l^*) = 1, k_{\max}(l^*) = 8$

Transposition by k: 3↔1
$\chi = 3, R(3) = 28 + 33 = 61$

i / k	3	2	1	4	5	6	7	**9**	**8**	10	$r(i)$
1	18	2	3	12	6	18	2	4	52	9	0
2	18	2	3	12	6	18	2	4	52	9	0
3	18	2	3	12	6	18	2	4	52	9	0
4	18	2	3	12	6	18	2	4	52	9	28
5	18	2	3	12	6	18	2	4	52	9	33

Further iterations up to obtaining non-improvable $R(\chi)$

Pic. 3. Approbation of the algorithm for finding the optimal placement of containers in a train intended for en route cargo handling operations (a fragment) (developed by the authors).

Table 4

Optimal matrix for arrangement of containers in a train intended for en route cargo handling operations (developed by the authors)

3	1	2	7	9	5	4	6	8	10	$r(i)$
18(1,2)	3(1,2)	2(1,2)	2(1,4)	4(1,5)	6(1,3)	12(1,3)	18(1,3)	52(1,4)	9(1,6)	0
18(2,6)	3(2,4)	2(2,5)	2(1,4)	4(1,5)	6(1,3)	12(1,3)	18(1,3)	52(1,4)	9(1,6)	0
18(2,6)	3(2,4)	2(2,5)	2(1,4)	4(1,5)	6(3,5)	12(3,4)	18(3,6)	52(1,4)	9(1,6)	0
18(2,6)	3(4,6)	2(2,5)	2(4,5)	4(1,5)	6(3,5)	12(4,6)	18(3,6)	52(4,6)	9(1,6)	30
18(2,6)	3(4,6)	2(5,6)	2(5,6)	4(5,6)	6(5,6)	12(4,6)	18(3,6)	52(4,6)	9(1,6)	0

cargo handling operations: Primorsky region–Irkutsk region–Krasnoyarsk region–Sverdlovsk region–Perm region–St. Petersburg (Table 1).

This route is formed based on the author's algorithm presented in [17].

We will form the initial matrix of arrangement of containers.

Let's determine the number of group spaces in the train: K = 9 + 1 = 10 seats. Therefore, we obtain a 5 • 10 arrangement matrix. Using the developed technique, we calculate the values $\alpha_{lk}(p, j)$ which is the number of containers loaded at point *i* with destination point *j*, which occupy the *k*-th group space in a container train, and then we shall develop a container arrangement matrix (Table 2).

Those cells in the matrix are highlighted with coloured background, where the container flow to be unloaded at the point corresponding to the line number is indicated.

Let us calculate the value of the optimality criterion $R(\chi)$ for the original matrix:

$R(0) = 44 + 100 = 144$ TEU.

In practice, the obtained value of $R(\chi)$ means that when carrying out cargo operations with containers at intermediate stations, a handler performs an excessive mileage of 144 • 6,1 = 878,4 meters.

Based on the proposed algorithm, we perform multiple transpositions of the columns of the arrangement matrix. A fragment of the algorithm is shown in Pic. 3.

The result of executing the steps of the algorithm is shown in Table 3.

As a result of 17 iterations, a matrix for arranging containers in a train intended for en route cargo handling operations was obtained (Table 4), further iterations do not lead to a decrease in the value of the objective function $R(17)_{\min} = 30$ TEU.

As a result, we obtain the following matrix of optimal placement of containers (Table 4).

Thus, under the given conditions, optimisation of placement of containers in the train makes it possible to reduce the excessive mileage of the loader at intermediate points from 144 • 6,1 = 878,4 meters to 30 • 6,1 = 183 meters, that is, 4,8 times. This will increase speed of cargo operations when relocating containers and reduce operating costs of using loading facilities and vehicles of container terminals.

The proposed algorithm makes it possible to significantly reduce the number of iterations during the search for a solution in comparison with the exhaustive search method and can be subject to implementation as software product.

CONCLUSIONS

The approach to organisation of container block trains presented in the work assumes organisation of traffic according to the principle of passenger traffic: the train is assembled at the station of origin, operates according to the timetable and along the established route with station stops at intermediate container terminals, where containers assigned for this station are removed and containers assigned for next stations are placed on empty spaces on platform wagons. The implementation of the proposed technology will increase competitiveness of railway container transportation both in domestic and transit traffic, create conditions for containerising additional cargo by reducing delivery times and improving quality of transportation services.

The paper presents the authors' method of optimal placement of containers in a train within the framework of the proposed technology for organising traffic. Arbitrary placement of containers at the origin point can cause excessive handlers' mileage at intermediate points during cargo operations. The proposed technique makes it possible to place containers in the train in such a way that the containers intended for each intermediate point were as close as possible to each other. Compared to the exhaustive search method, the algorithm significantly reduces the number of iterations during the search for a solution.

REFERENCES

1. Song Chunhui. Research on Transportation Development of Container Port Starts. *International Core Journal of Engineering*, 2020, Vol. 6, Iss. 9, pp. 292–300. DOI: 10.6919/ICJE.202009_6(9).0037. Last accessed 20.12.2020.

2. Transit of goods in containers in China–Europe–China traffic through the Russian Railways network doubled in January-November [*Tranzit gruzov v konteinerakh v soobshchenii Kitay–Evropa–Kitay po seti RZD udvoilsya v yanvare-noyabre*]. *RZD partner.ru*. [Electronic resource]: https://www.rzd-partner.ru/zhd-transport/news/tranzit-gruzov-v-konteynerakh-v-soobshchenii-kitay-evropa-kitay-po-seti-oao-rzhd-udvoilsya-v-yanvare/. Last accessed 20.12.2020.

3. China–Europe: overland container breakthrough in spite of «economics» [*Kitay–Evropa: sukhoputniy konteinerniy proryv vopreki «ekonomiksu»*]. TELS Expert. 29.01.2019. [Electronic resource]: https://telsgroup.ru/media_center/tels_in_the_press/4691.html. Last accessed 20.12.2020.

4. Say, V. M., Kochneva, D. I. Modelling of Assessment of a Region's Need for Container Transportation. *World of Transport and Transportation*, 2018, Vol. 16, Iss. 4, pp. 160–178. [Electronic resource]: https://mirtr.elpub.ru/jour/article/view/1500. Last accessed 20.12.2020.

5. Kochneva, D., Say, V., Siziy, S. Economic and Mathematical Evaluation Model of Interaction Between Container Transportation System and Russian Regions. International Scientific Siberian Transport Forum. Springer, Cham, 2019, pp. 782–790. DOI: 10.1007/978-3-030-37919-3_77. Last accessed 20.12.2020.

6. Moskvichev, O. V., Moskvicheva, E. E., Nikonov, Yu. S. On the issue of consolidation and delivery of single and group container shipments as part of container trains [*K voprosu konsolidatsii i dostavki odinochnykh i gruppovykh konteinernykh otpravok v sostave konteinernykh poezdov*]. *Transport Urala*, 2014, Iss. 2, pp. 15–18. [Electronic resource]: https://www.studmed.ru/transport-urala-2014-02-41-_219e37113a7.html. Last accessed 20.12.2020.

7. Rezer, S. M., Rezer, A. V., Levin, S. B., Nosyrev, I. I. Mathematical modeling of cargo transportation in special containers [*Matematicheskoe modelirovanie perevozok gruzov v spetskonteinerakh*]. *Transport: nauka, tekhnika, upravlenie. Nauchniy informatsionniy sbornik*, 2019, Iss. 5, pp. 3–10. [Electronic resource]: https://www.elibrary.ru/item.asp?id=37820325. Last accessed 20.12.2020.

8. Kirillova, A. G. Actual aspects of development of international transport corridors on the territory of Russia [*Aktualnie aspekty razvitiya mezhdunarodnykh transportnykh koridorov na territorii Rossii*]. *Transport Rossiiskoi Federatsii. Zhurnal o nauke, praktike, ekonomike*, 2018, Iss. 2 (75), pp. 51–54. [Electronic resource]: https://cyberleninka.ru/article/n/aktualnye-aspekty-razvitiya-mezhdunarodnyh-transportnyh-koridorov-na-territorii-rossii/pdf. Last accessed 20.12.2020.

9. Basyrov, I. M., Bilenko, G. M., Basyrov, M. A. Shortened container block trains in multimodal transportation [*Ukorochennie konteinernie blok-poezda v multimodalnykh perevozkakh*]. *Byulleten' transportnoi informatsii*, 2020, Iss. 1, pp. 4–9. [Electronic resource]: https://www.elibrary.ru/item.asp?id=41804989. Last accessed 20.12.2020.

10. Sun, Yan; Li, Xinya. Fuzzy programming approaches for modeling a customer-centred freight routing problem in the road-rail intermodal hub-and-spoke network with fuzzy soft time windows and multiple sources of time uncertainty. *Mathematics*, 2019, Vol. 7, Iss. 8, pp. 739. DOI: 10.3390/math7080739. Last accessed 20.12.2020.

11. Sholihah, S. A. [*et al*]. Coordination model in hinterland chain of hub-and-spoke export trade logistics. *Journal of Industrial Engineering and Management*, 2018, Vol. 11, Iss. 4, pp. 776–793. DOI: 10.3926/jiem.2538. Last accessed 20.12.2020.

12. Zhao, Yiran; Yang, Zhongzhen; Haralambides, H. Optimizing the transport of export containers along China's coronary artery: The Yangtze River. *Journal of Transport Geography*, 2019, Vol. 77, pp. 11–25. DOI: 10.1016/j.jtrangeo.2019.04.005. Last accessed 20.12.2020.

13. Mantovani, S., Gianluca, M. [*et al*]. The load planning problem for double-stack intermodal trains. *European Journal of Operational Research,* 2018, Vol. 267, Iss. 1, pp. 107–119. DOI: 10.1016/j.ejor.2017.11.016. Last accessed 20.12.2020.

14. Fomin, O. [*et al*]. Research of stability of containers in the combined trains during transportation by railroad ferry. *MM Science Journal*, 2020, Vol. 1, pp. 3728–3733. DOI: 10.17973/MMSJ.2020_03_2019043. Last accessed 20.12.2020.

15. Morganti, G. [*et al*]. Block planning for intermodal rail: Methodology and case study. *Transportation Research Procedia*, 2020, Vol. 47, pp. 19–26. DOI:10.1016/j.trpro.2020.03.068. Last accessed 20.12.2020.

16.Vinogradov, S. A. Container will buy a ticket as a passenger [*Konteineru prodadut bilet kak passazhiru*]. Gudok, Internet-edition, 20.07.2020. [Electronic resource]: https://gudok.ru/ content/first_person/1528250/. Last accessed 01.10.2020.

17. Kochneva, D.I., Chang, Hao. Planning model of block container trains with cargo operations en route [*Model' planirovaniya marshrutnykh konteinernykh poezdov s gruzovymi operatsiyami v puti sledovaniya*]. *Vestnik URGUPS*, 2020, Iss. 4, pp. 46–56. [Electronic resource]: https://www.usurt.ru/vestnik/arxiv/vestnik_UrGUPS_4_2020.pdf. Last accessed 01.10.2020.

18. Chernyshev, Yu. O., Kubil, V. N. Review of dynamic transport routing problems [*Obzor dinamicheskikh zadach marshrutizatsii transporta*]. *Programmnie produkty i sistemy*, 2020, Vol. 33, Iss. 3, pp. 491–501. [Electronic resource]: https://cyberleninka.ru/article/n/obzor-dinamicheskih-zadach-marshrutizatsii-transporta/pdf. Last accessed 01.10.2020.

19. Maksimov, P. A., Simakov, V. K., Govorov, V. R. Multi-vertex graphs: search for an optimal solution to transport problems [*Mnogovershinnie grafy: poisk optimalnogo resheniya transportnykh problem*]. *Transportnoe delo Rossii*, 2020, Iss. 2, pp. 94–96. [Electronic resource]: https://www.elibrary.ru/download/elibrary_43022651_46125466.pdf. Last accessed 01.10.2020.

20. Saveliev, M. V. On complexity of a problem of combinatorial optimization [*O slozhnosti odnoi zadachi kombinatornoi optimizatsii*]. *Matematicheskie mashiny i sistemy*, 2016, Iss. 4, pp. 106–110. [Electronic resource]: https://cyberleninka.ru/article/n/o-slozhnosti-odnoy-zadachi-kombinatornoy-optimizatsii/pdf. Last accessed 01.10.2020. ●