Optimization of order for containers placement schedule in rail terminal operations

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1. Introduction

During the transportation of goods by rail, the processing of trains and performing rail terminal operations at the transshipment yard (TSY) in the railway station raise problems of optimization (Boysen et al.,2012; Boysen et al., 2011; Dotoli et al.,2013; Cicheński et al., 2017).

The work of the railway transshipment station includes the following processes:

1. Arrival of the train at the railway transshipment station.
2. Train service (unloading / loading of containers).
3. Departure of the train from the station.

Serving a train involves moving containers from one train to another, reloading the container from the train to storage area and from storage area to the train.

The components of a modern railway transshipment yard (Figure 1) are proposed in (Boysen et al., 2012):

1. A platform with parallel railway tracks on which trains are located;
2. Container storage area, which is located parallel to the tracks;
3. Gantry cranes are used to reload containers.

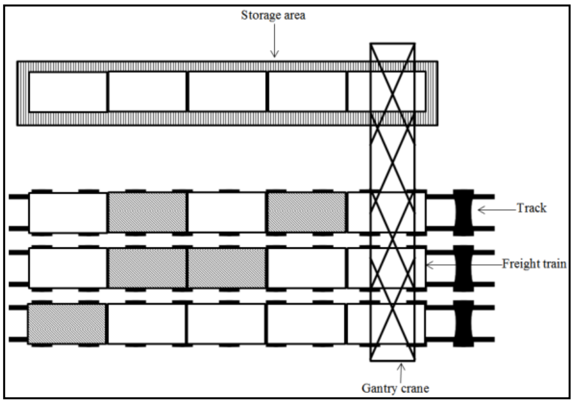


Figure 1 - Scheme of a railway transshipment yard

The operation of the transshipment yard is as follows: a train with containers (source train) arrives at the transshipment yard, containers from an incoming train are loaded onto the target train (if it is present at the station) or in the storage area. Containers from other trains and containers from the storage area can also be loaded onto the source train. At the end of processing, the train leaves the transshipment yard.

(Boysen et al., 2011 and 2012) describe the general problem of planning the work of a transshipment yard, in which the following levels are distinguished:

1. Service slot planning (transshipment yard scheduling problem, TYSP);
2. Assignment of trains to railway tracks in one slot;
3. Determining the position of the containers on trains;
4. Determining of zones of action of gantry cranes;
5. Determining the order of the moves of the containers done by the cranes.

(Boysen et al., 2012) solve the problem at level 1: the authors propose a mathematical model for creating a schedule for visiting trains at the transshipment yard. This approach aims at distributing the trains on service slots.

(Grebennik et al., 2017) extended the study of the level 1 problem and proceed to level 2. The authors propose to form time intervals for servicing trains (service slots) and to assign each train of such a service slot to a specific railway track of the transfer station. The proposed mathematical model is based on combinatorial configurations, see for example (Sachkov, 1996). (Grebennik et al., 2019) offer a solution of the level 3 problem which is based on the results of studies given in (Grebennik et al., 2017). The optimal position of the containers to be moved on the target train is determined. The combinatorial optimization model is proposed and analyzed.

In this paper, we consider the following hypotheses:

1. The cost of moving containers from the source train to the target train depends on the distance between the trains;
2. If the source train and the target train are in the same service slot, they must be located on the nearest tracks;
3. If the trains are assigned to different service slots, it is necessary to minimize the move of the gantry crane;
4. The cost of moving containers is estimated by the distance that the gantry crane travels.

This work is a continuation of the studies of (Boysen et al.,2012; Grebennik et al.,2017; Grebennik et al.,2019). Its purpose is to determine the optimal order of moves of containers between the trains and the storage area in the formed service slots.

2. Problem definition

The problem analyzed in this paper is based on two problems: the transshipment yard scheduling problem (TYSP) and the containers placement in rail terminal operations problem (CPRTOP). A set of trains with a certain number of empty freight platforms and containers and their known location on the train is considered. All the trains arriving at a transfer station have to be allocated to service slots. The number of trains that can be serviced simultaneously (in one slot) should not exceed the number of parallel tracks at the transshipment yard. The optimal service slot is constructed as the solution of the combinatorial optimization problem. Trains that are served in a single service slot need to reload containers from train to train, from train to storage area, or from storage area to train. Given the coordinates of the location of the containers for moving and the coordinates of the free platforms in the target trains and storage area, the problem of the optimal containers placement is solved as combinatorial optimization problem. Based on the results of solving the problem at levels 1-3 (Grebennik et. al., 2017; Grebennik et. al., 2019) we assume that the following data are available and known: positions of the trains selected in one slot, the assignment of each train on a railway track and the assignment of each container to a specified platform in this slot. Therefore the problem of the relocation order of containers at a transshipment yard (ROCTY) can be stated as follows: let a service slot with specified locations of trains on the tracks is defined, the coordinates of containers and free platforms on trains and in the storage area are determined; for each container has to be moved, the 2D coordinates of the platform on which it has to be placed are known. Let us determine the order of relocation of containers with a gantry crane, minimizing the cost of servicing the entire service slot.

3. Mathematical model of the problem of relocation order of containers at a transshipment yard

Let $V = \{v_1, v_2, \dots, v_n\}$, where $v_i = (v_x^i, v_y^i)$, be set of coordinates of the geometric centers of the relocating containers on source trains and in the storage area, free platforms on target trains and in the storage area, n is the number of the containers and the free platforms. We form set $D = \{d_1, d_2, \dots, d_m\}$, where $d_i = (d_i^f, d_i^t)$ is ordered pair of elements from set V, for which the container relocation is intended from a source point of coordinates d_i^f to the target point of coordinates d_i^t, m is number of containers have to be moved.

Set a mixed graph $G = (V, E)$, where $V = \{v_1, v_2, \dots, v_n\}$ is set of vertices, $E = D \cup C$ is union of the set of arcs D (which correspond to the relocation of containers from place to place) and undirected edges C (which correspond to move of the gantry crane without container). Set of edges

C is constructed in such way that graph $G_1 = (V, C)$ is a complete undirected graph. For graph G, we calculate the edge length matrix $\|c_{ij}\|$based on the distance between the vertices of the graph which is calculated according to the Manhattan metric: $c_{ij} = |v_x^i - v_x^j| + |v_y^i - v_y^j|$, $i, j = \{1, 2, \dots, n\}$.

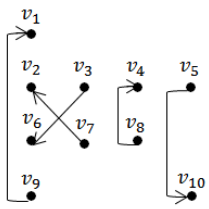
We firstly choose the initial position of the crane at one of the vertices of the graph G. Then, using the description of the crane problem given in (I. I. Melamed et. al., 1989), we construct the traveling salesman route in graph G, with the following condition if arcs come out of a vertex and edges are connected with it, then you can move along the edge only if you cannot move along the arc. In accordance with the approach in (I. I. Melamed et. al., 1989), we transform this problem into the traveling salesman problem, see for example (Applegate, 2006). For this purpose, we put the lengths of all arcs $d_i \in D, i = 1, \dots m,$ of the graph G equal to zero and then combine each pair of vertices connected by an arc into one vertex. In this case, the distance between the combined vertices is determined as follows. If vertex $\overline{v}_i$ is obtained by the union of vertices v_{i_1} and v_{i_2}, vertex $\overline{v}_j$ is obtained by the union of vertices v_{j_1} and v_{j_2}, then $\overline{v}_{ij} = \min\,(c_{i_1 j_1}, c_{i_1 j_2}, c_{i_2 j_1}, c_{i_2 j_2})$. Lastly, we solve the traveling salesman problem with the matrix $\overline{c}_{ij}$ using one of the known methods, for example, using one of the modern solvers Concorde TSP solver (available at http://www.math.uwaterloo.ca/tsp/concorde.html).

To obtain a solution to the crane problem, and then to solve the ROCTY problem, we return to the original graph G and add all arcs from the set D to the found traveling salesman route. The move route that is found as a result of solving the crane problem on graph G is the solution of the ROCTY problem.

4. An example of solving the ROCTY problem

Let $V = \{v_1, v_2, \dots, v_{10}\}$ be set of vertices, where $v_1 = (1,0)$, $v_2 = (1,1)$, $v_3 = (2,1)$, $v_4 = (3,1)$, $v_5 = (4,1)$, $v_6 = (1,2)$, $v_7 = (2,2)$, $v_8 = (3,2)$, $v_9 = (1,3)$, $v_{10} = (4,3)$; $D = \{d_1, d_2, d_3, d_4, d_5\}$ be set of arcs, where $d_1 = (v_9, v_1)$, $d_2 = (v_3, v_6)$, $d_3 = (v_7, v_2)$, $d_4 = (v_8, v_4)$, $d_5 = (v_5, v_{10})$; Figure 2.a describes the set of vertices V and set of arcs D, which connect pairs of vertices from set V; Figure 2.b shows the calculated distance matrix $\|c_{ij}\|$.

a)



b)

	v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8	v_9	v_{10}
v_1	0	1	2	3	4	2	3	4	100	6
v_2	1	0	2	3	3	1	100	3	2	5
v_3	2	2	0	1	2	2	1	2	3	4
v_4	3	3	1	0	1	3	2	100	4	3
v_5	4	3	2	1	0	4	3	2	5	2
v_6	2	1	100	3	4	0	1	2	1	4
v_7	3	2	1	2	3	1	0	1	2	3
v_8	4	3	2	1	2	2	1	0	3	2
v_9	3	2	3	4	5	1	2	3	0	3
v_{10}	6	5	4	3	100	4	3	2	3	0

Figure 2 – a) Vertices and arcs of the graph, b) Distance matrix $\|c_{ij}\|$

Combine the vertices connected by arcs: $\overline{v}_1 = v_9 \leftrightarrow v_1$; $\overline{v}_2 = v_7 \leftrightarrow v_2$; $\overline{v}_3 = v_3 \leftrightarrow v_6$; $\overline{v}_4 = v_8 \leftrightarrow v_4$; $\overline{v}_5 = v_5 \leftrightarrow v_{10}$. Distance matrix $\|\overline{c}_{ij}\|$ for complete graph with vertices $\overline{V} = \{\overline{v}_1, \overline{v}_2, \overline{v}_3, \overline{v}_4, \overline{v}_5\}$ is represented on Figure 3. To solve the traveling salesman problem with a matrix $\|\overline{c}_{ij}\|$ we use a public web service, as a result of which a closed route of moves between the vertices is obtained $\overline{V} = \{\overline{v}_1, \dots, \overline{v}_5\}$: $\overline{v}_4 \rightarrow \overline{v}_5 \rightarrow \overline{v}_3 \rightarrow \overline{v}_1 \rightarrow \overline{v}_2 \rightarrow \overline{v}_4$.

	$\overline{v}_1$	$\overline{v}_2$	$\overline{v}_3$	$\overline{v}_4$	$\overline{v}_5$
$\overline{v}_1$	0	1	1	3	3
$\overline{v}_2$	1	0	1	1	3
$\overline{v}_3$	1	1	0	1	2
$\overline{v}_4$	3	1	1	0	1
$\overline{v}_5$	3	3	2	1	0

Figure 3 – Distance matrix $\|\overline{c}_{ij}\|$

To construct the gantry crane path along the vertices of the original graph G, we add all arcs of the set D to the found closed route. The result of such a transformation will be the route of the gantry crane over the set of vertices $V = \{v_1, v_2, \dots, v_{10}\}$,; the final solution for the input dataset is: $v_8 \to v_4 \to v_5 \to v_{10} \to v_3 \to v_6 \to v_9 \to v_1 \to v_7 \to v_2 \to v_8$.

5. Conclusions

The paper considers the problems of the functioning of the railway transshipment yard. The known problems of the transshipment yard scheduling problem (TYSP) and the containers placement in rail terminal operations problem (CPRTOP) are presented. Based on their solutions, problem of the relocation order of containers at a transshipment yard (ROCTY) is formulated. An optimization model of the ROCTY problem is constructed, which can be transformed into the traveling salesman problem. Based on the solution of the traveling salesman problem, the solution of the ROCTY problem is constructed. A computational experiment is carried out, its results are discussed.

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