TRANSPORT PROBLEMS 2024 Volume 19 Issue 2
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2023.19.2.13

Keywords: intermodal terminal; train loading; simulation model; FlexSim; process parameters

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THE IMPACT OF THE INTERMODAL TERMINAL OPERATION STRATEGY ON CONTAINER TRAIN LOADING DURATION

Summary. The aim of the article was to study the impact of various real-life factors determining the container train loading process duration. Various strategies of the crane operation were considered. Among the factors influencing the train loading duration, railcar hitching pin configuration, container weight, railcar capacity, and arrangement of containers in the storage yard were considered. The FlexSim simulation model of the container terminal was developed, covering the storage yard and the railway track. The analysis shows that the number of containers collected directly from the storage yard has the greatest impact on the train loading duration.

1. INTRODUCTION

Current market trends in the transport-shipping-logistics industry have increased the share in intermodal transport [29]. From 2013 to 2022, the number of intermodal units operated by Polish National Railways PKP systematically increased from 1 123 000 to 2 836 000 twenty-foot equivalent units (TEU) [32]. The values are presented in TEU, as this is one of the basic measurement units in intermodal transport.

The additional growth occurring after 2019 may be justified by the COVID-19 pandemic [29–34]. During the pandemic, it became important to minimize human contact with loads and to simplify the transport process. The fulfillment of these postulates is met by intermodal transport. Thanks to cooperation in the intermodal transport of rail, sea, and road transport, it is possible to achieve many benefits (e.g., time, cost) [7, 33]. The aspect of the impact of intermodal transport on the natural environment is also important; by reducing the share of road transport or by limiting additional cargo operations, this type of transport puts less pressure on the environment [33].

It should also be noted that the combination of the three mentioned modes of transport allows loads to be moved between any points. Sea transport is used on the longest section of the route. Subsequent long and medium sections of the route (150–500 km on average) are covered using rail transport. Rail transport also offers a favorable price-to-handled cargo ratio. However, it is often impossible to provide rail transport directly to the destination. Road transport is used in the final sections. Most often, the loads are deconsolidated into smaller units at the end of the last stage [3].

Transport between points is carried out using linear infrastructure (e.g., roads). In intermodal transport, however, point infrastructure is also a key to the efficient implementation of the process. Two characteristic types of transshipment terminals can be distinguished: sea intermodal terminals and inland

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intermodal terminals. Regardless of the type, the point must be equipped with appropriate infrastructure and superstructure. The basic task assigned to the terminal is to handle the transshipment of goods from one mode of transport to another. Terminals should also enable the storage of intermodal load units and their comprehensive service [24]. In this study, attention has been focused on inland terminals.

One characteristic of intermodal transport is the use of a standardized intermodal transport unit (ITU). Mainly used ITUs are containers of different types. Also, vehicle swap bodies, vehicle semi-trailers, railcars, or entire vehicles can be considered as ITUs. For the purposes of this study, units were divided according to their size and share in transport. This is one of the important elements determining the implementation of the loading process. The standard division of containers, considering their dimensions, includes containers of the following lengths: 10, 20, 30, and 40 ft [22]. It is customary to assume that the basic container (also used as a "converter" for the volume of intermodal transport) is a 20-ft container marked as TEU. Other containers are often taken as a multiple of TEU.

The main task of intermodal terminals is to perform reloading between transport modes. It should be implemented efficiently. The correct planning of such a process is a big challenge. Many factors, such as the time of arrival of the vehicle for service and the labor intensity of the task, should be considered. Of course, the arrival of the means of transport of various modes should be properly synchronized and planned. The process of loading and unloading ITUs onto an intermodal train generates significant labor [18].

The essence of the process is the movement of containers from the storage field to the railcars. Often, a storage field with containers arranged in a row is located along the track lane. When the train is ready for loading, the containers are moved using reloading equipment. The most popular of them used in this type of operation are gantry cranes. The last phase of container handling is fixing ITUs on the railcars. This is possible using container and railcar hitches. To ensure efficient implementation of the train loading process, factors such as delivery and shipment schedule, availability of loading equipment, list of the ITUs to be shipped, and set of train and unit parameters should be considered [4, 6, 14, 18]. The above-mentioned factors are the basis for taking up the issue of loading an intermodal train and the impact of selected factors on its duration (process time) in this study. Optimization of the loading process in the relevant aspects allows labor intensity, costs, and time to be reduced.

This study focuses on the impact of the intermodal train loading strategy on the duration of the process. Chapter 2 presents the literature review. Chapter 3 describes the methodology. Chapter 4 presents the mathematical and computer model. The results of a series of simulations are included in Chapter 5. The study ends with conclusions and a summary (Chapter 6).

2. LITERATURE REVIEW

Before proceeding to the practical part, a literature review was made to identify the current state of knowledge in the field of study's interest. It is crucial to identify the methods that are used to analyze selected processes taking place in intermodal terminals. Knowing the characteristics of the operation of intermodal terminals makes it possible to also indicate the areas of their operation that have been analyzed enough so far. Special attention was focused on intermodal inland terminals, the intermodal train service process, and the parameters having a real impact on the discussed process.

An interesting, general perspective on issues related to intermodal transport is provided by various types of reports. They are created both for the needs of given countries [38] or to cover a wider territory [29]. Although they do not present the details of the implementation of selected processes or details needed for their modeling, they help determine the development trends on the market (lists of transshipment volumes) as well as elements, such as types of cargo in transport and their market share, means of transport used, transport relations. In addition to reports, there are review publications in which the authors refer to the processes taking place within intermodal transport. The relationships between individual transport participants have been described by Crainic, Perboli, and Rosano [6].

One of the publications that had a significant impact on this study is the article of Bruns and Knust [4]. Their study contains a careful review of the literature. However, the description of the issue of loading an intermodal train remains crucial. Even though the authors used a different approach than a simulation model, the description of the process itself and the identified factors conditioning its implementation reveals a holistic view of the problem. They also addressed the topic of optimizing the loading process and considered elements such as the size of the container and the spacing of its assembly mounting points on the containers and on the railcars. The authors of publications related to the simulation of the operation of intermodal vehicles usually distinguish a group of factors influencing the process. These factors are further considered during modeling. Particularly valuable are those works in which a possibly holistic approach was applied. In this case, the main factors were restrictions on the weight of the train and the weight of the railcar. The process was also conditioned by factors such as [4]:

- the number and types of railcars to be handled (hitch pins, weight distribution, axle load, etc.),
- the number and types of containers (size, layout of anchor points, weight, center of gravity).

A more recent study by Heggen, Breakers, and Caris [8] was based on similar factors. The aim of the study was to maximize the usage of the loading space of the available railcars while respecting the given restrictions. The authors used a different approach for several aspects of train service compared to [4].

In real working conditions, it is often necessary to act with uncertainty or information deficit. The analyzed process is no exception. In fact, the terminal manager does not always have complete information on what railcars will arrive at the terminal and what loads will need to be placed on them. This affects the possibility of preparing the containers for loading at that time. This factor has been considered in this publication by authors. Operation under conditions of uncertainty was also described by Jacyna and Semenov [11] as well as Staniuk et al. [26].

The issue of optimizing the loading of containers in the inland intermodal terminal was also taken up by Wang and Zhu [34]. The main analyzed problem was the operation of a gantry crane. The authors also considered the issue of placing containers on the storage field. Crane movements were divided into those with loads and without loads. It was assumed that several cranes could operate in the terminal, and each would have a separate and permanent work area. Contrary to the described publication, they referred to the operation of one crane [14]. Thus, many authors, despite addressing a similar issue, used a different approach.

Available publications have also analyzed container storage strategies [10]. The information contained in the work of Jachimowski et al. on the method and limitations of placing containers in the storage field is very important. Limitations and requirements related to the size of containers or the means of handling used will have a large impact on the implementation of processes. It is also worth noting that the aspects of ecology are increasingly taken into account (e.g., in terms of reducing greenhouse gas emissions), as evidenced by the aforementioned publication. The method of loading containers also affects the safety of transport.

A broader look at the functioning of the intermodal terminal facility is also provided by review publications [18, 21]. Their analysis not only provides the characteristics of the work (technologies used, market trends, current state) but also distinguishes the processes taking place in the terminals, along with their purpose, place, method of organization, and necessary elements. An example of such an approach is seen in the work of Ambrosino, Asta, and Crainic [1], who focused on highlighting optimization areas in intermodal terminals.

At the same time, it is worth noting that the facility in question is a reloading terminal. Due to its characteristics and the number of operations occurring within it, the authors discuss several related topics. These include the selection of internal transport means [13], monitoring the operation of road vehicles [5], and choosing the location of the terminal [19]. The last of these issues, choosing the location of logistics facilities, is a popular topic. When addressing this problem, a multi-criteria assessment method is often used. In addition to the location of the terminals, many authors are also interested in the facility's internal structure. This topic, in relation to intermodal terminals, was explored by Tadić, Krstić, and Zacewić [27]. A similar topic was investigated by Tadić et al. [36].

The authors of this study have already addressed the topic of loading an intermodal train set in the past [18]. The publication also uses a mathematical and simulation model. The problem of loading railcars with the use of containers prepared along the railway tracks for loading was described. Chosen restrictions related to the size of containers and railcars have been considered. The purpose of the constructed model was to minimize the distance traveled by the crane during loading. Reference was also made to the issue of reconfiguration of the mounting pins on railcars. A more general reference was made to the manner of operating an intermodal train in the work of Nehring and Jachimowski [17], the key element of which was the review of the literature and the highlighted factors influencing the train loading time.

Several publications have already used computer simulation to analyze transport processes [10, 12, 18]. Most of them used the FlexSim simulation environment. This software is characterized by universality and a high level of advancement of both built-in functions and those that can be programmed. The software is popularly used in process simulation and visualization. This is evidenced by numerous publications using the FlexSim software. FlexSim uses numerous dependencies derived from the queuing theory [23, 35, 36]. Of course, FlexSim is not the only method of computer analysis available. In the studies conducted by Bruns and Knust [4] as well as by Li, Otto, and Pesch [14], other solvers were used. The use of solvers is also a popular practice. Another simulation method (the AnyLogic platform) was used by Muravev et al. [16].

The analysis of the literature indicates that previous studies have not addressed the real-life issues of uncertainty related to the loading of an intermodal train. Although the list of containers to be loaded is usually known in advance, it may change during the loading process. The analyzed publications omit the very important issue of the distribution of containers in the storage yard and its impact on the loading of the train. The need to suddenly dig containers in the storage yard can significantly extend the process of train loading.

3. METHODOLOGY

The article considers the process of intermodal train loading. In this study, it was assumed that the containers to be loaded could be in one of two locations in the terminal. The majority of the containers are prepared for loading and placed along the railway track. The remaining containers are in the storage area and are not prepared for loading. These unprepared containers can be loaded onto the train in case of urgent unplanned situations. In such a case, the crane must usually perform many operations in order to dig out a container that is covered, for example, by three or four other containers. As mentioned in the literature review, in addition to the location of containers at the terminal, the weight of containers, the permissible axle loads of railcars, and the configuration of pins on railcars must also be taken into account when determining the optimal train loading plan. For this purpose, a mathematical model was initially constructed to illustrate the implementation of the selected process. Initial conditions (container sizes, railcar types, task size), variables, conditions, and constraints, as well as an optimization function, have been defined. The function is aimed at obtaining the shortest loading time for an intermodal train for the set conditions. Particularly important from the point of view of the study is the correct determination of the range of factors affecting the loading time of the train.

The mathematical model became the basis for the construction of a computer simulation model using the FlexSim software. The same assumptions and constraints that were used for the mathematical model were used for the simulation. Many simulation scenarios were created in the field of train loading strategy. Based on the series of simulations, an indication was obtained for which of the variants the loading time is the shortest.

4. MATHEMATICAL AND SIMULATION MODEL

4.1. Mathematical model

The constructed mathematical model became the starting point for further considerations. The goal of the model is to construct an objective function that will allow the solutions to be evaluated. The optimal solution will be the one with the lowest loading time. The model should take into account the factors affecting the loading process in a holistic way. In the model, the following notations were included:

$\boldsymbol{N}$ = {1, …, n, …., N} – set of containers to load;
$\boldsymbol{M}$ = {1, …, m, …., M} – set of handling railcars;
N – total number of containers handled;
M – total number of railcars handled;
$\boldsymbol{S_m}$ = {1, …, s_{mk}, …, S_{mk}} – set of slots on the m-th railcar;
S_{mk} – total number of slots on the m-th railcar;
s_{mk} –chosen slot on the m-th railcar;
L_{Smk} – length of the s_{mk} slot at the m-th railcar;
F_{Smk} – fixation type of the s_{mk} slot at the m-th railcar;
L_n – length type of the n-th container;
F_n – fixation type of the n-th container;
W_n – weight of the n-th container;
L_m – total length of the m-th railcar;
I^m = {I_1^m, …, I_u^m, …, I_U^m} – set of pin configurations for m-th railcar;
U – total number of possible pin configurations for the m-th railcar;
W_{max}^{m}– maximum payload for the m-th railcar;
W_{max}^{m1} – maximum payload for the front boogie of the m-th railcar;
W_{max}^{m2} – maximum payload for the rear boogie of the m-th railcar;
W^{m1}– measured payload for the front boogie of the m-th railcar;
W^{m2}– measured payload for the rear boogie of the m-th railcar;
(b_n, r_n, l_n) – coordinates of the position of the n-th container (bay, row, layer);
l_n' – the number of containers above the n-th container in the storage field;
$t_{mns_{mk}}$ – time of transporting of the n-th container to the s_{mk} slot on the m-th railcar;
$t_{l_n'}^{n}$ – time of additional necessary transport operations during the n-th container's handling;

The model distinguishes the following variables:

- $\boldsymbol{x_{mns_m}}$ assigning a container to a selected slot on a railcar:

$$x_{mns_m} = \begin{cases} 1, & if\ the\ n-th\ container\ is\ assigned\ to\ the\ m\ railcar\ slot\ s_m \\ 0, & otherwise \end{cases} \tag{1}$$

- $\boldsymbol{y_{mns_m}}$ specifies the additional time resulting from the need to move certain containers in the storage yard in order to gain access to the collected container:

$$y_{mns_m} = \begin{cases} t_{l_n'}^{n}, & if\ any\ containers\ must\ be\ moved\ to\ access\ the\ n-th\ container \\ 0, & otherwise \end{cases} \tag{2}$$

For the parameters and variables listed, the objective criterion function takes the following form:

$$\boldsymbol{F(XYZ)} = \sum_{m\in\boldsymbol{M}}\sum_{n\in\boldsymbol{N}}\sum_{s_{mk}\in\boldsymbol{S_m}}\left(x_{mns_m}\cdot t_{mns_{mk}}^{\square} + y_{mns_m}\right) \rightarrow min \tag{3}$$

The following restrictions must also be taken into account:

- Each n-th container can be allocated to at most one m-th railcar and one slot s_{mk}:

$$\forall n \in \boldsymbol{N} \quad \sum_{m\in\boldsymbol{M}}\sum_{s_{mk}\in\boldsymbol{S_m}} x_{mns_m} \leq 1 \tag{4}$$

- The total length of containers assigned to the m-th railcar cannot excede the railcar length L_m:

$$\forall m \in \boldsymbol{M} \quad \sum_{n\in\boldsymbol{N}}\sum_{s_{mk}\in\boldsymbol{S_m}} x_{mns_m}\cdot L_n \leq L_m \tag{5}$$

- The total length of slots located on the m-th railcar (S_m) cannot excede the railcar length (L_m):

$$\forall m \in \boldsymbol{M} \quad \sum_{s_{mk}\in\boldsymbol{S_m}} L_{Smk} \leq L_m \tag{6}$$

- The fixation type of the n-th container assigned to s_{mk} at the m-th railcar must match the slot fixation:

$$\forall n \in \boldsymbol{N} \ \ \forall m \in \boldsymbol{M} \ \ s_{mk} \in \boldsymbol{S_m} \qquad \forall x_{mns_m} = 1 \rightarrow F_{Smk} = F_n \tag{7}$$

- The total weight of containers assigned to the m-th railcar cannot exceed its loading limit $\boldsymbol{W_{max}^{m}}$:

$$\forall m \in \boldsymbol{M} \qquad \sum_{n\in\boldsymbol{N}}\sum_{s_{mk}\in\boldsymbol{S_m}} x_{mns_m}\cdot W_n \leq W_{max}^{t} \tag{8}$$

- The load on any of the axles of the n-th railcar must not be exceeded:

$$\forall m \in \boldsymbol{M} \qquad W_{\square}^{m1} \leq W_{max}^{m1},\ W_{\square}^{m2} \leq W_{max}^{m2} \tag{9}$$

– The difference in the load on the axles of the m-th railcar must not exceed the ratio of 3:1:

$$\forall m \in \boldsymbol{M} \quad \frac{1}{3} \cdot W_{max}^{m2} \leq W_{max}^{m1} \leq 3 \cdot W_{max}^{m2} \tag{10}$$

A detailed method of calculating axle loads depending on the size, weight, and number of containers loaded on a railcar is described in [4]. In this study, an analogous method of calculating the axle load for railcars was used (see Figure 1). The example considers a situation with three containers (n_1, n_2, n_3). However, this approach can be used for any configuration. The support points of the railcar resulting from the position of the bogies and their two-axle construction are marked (B_1, B_2). The distance between the axles is marked as a_0. The containers' mass centers and masses are marked as w_1, w_2, and w_3, respectively. It was assumed that the container mass center is placed halfway along its length. The distances between containers' centers and selected axes are marked as a_1, a_2, and a_3. Adopting such assumptions allows the calculations presented below to be performed.

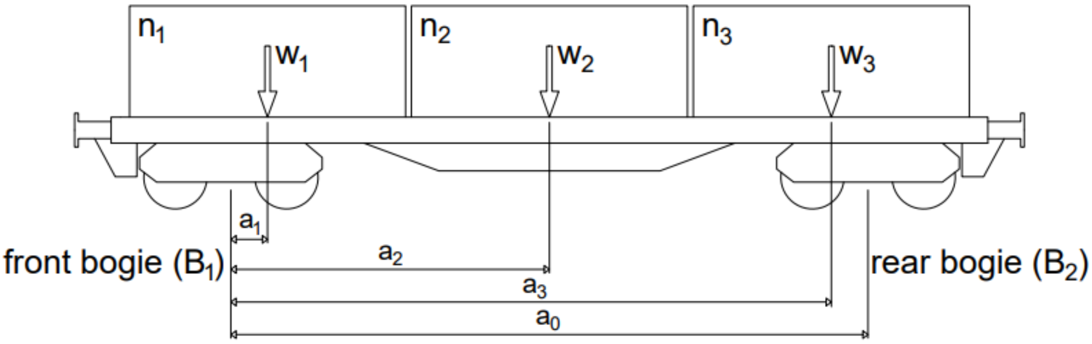

Fig. 1. Axle loads in an example railcar. Source: [4]

The axle load is calculated according to the Formula (11) for the front axle B1 and (12) the rear axle B2:

$$W_{\square}^{B1} = \frac{(a_0 - a_1)w_1}{a_0} + \frac{(a_0 - a_2)w_2}{a_0} + \frac{(a_0 - a_3)w_3}{a_0} + \frac{w_0}{2} \tag{11}$$

$$W_{\square}^{B2} = \frac{(a_1)\mathrm{w}_1}{a_0} + \frac{(a_2)\mathrm{w}_2}{a_0} + \frac{(a_3)\mathrm{w}_3}{a_0} + \frac{\mathrm{w}_0}{2} \tag{12}$$

Where:

$W_{\square}^{B1}$ – load on the front axle (fulcrum B_1),
$W_{\square}^{B2}$ – load on the rear axle (fulcrum B_2),
$\mathrm{w}_1, \mathrm{w}_2, \mathrm{w}_3$ – container weights, as appropriate for loads $\mathrm{n}_1, \mathrm{n}_2, \mathrm{n}_3$,
w_0 – weight of the empty railcar,
a_1, a_2, a_3 – distance of the center of gravity of the container from the front axle B_1,
a_0 – wheelbase of the railcar (distance between the support points of the bogies B_1 and B_2).

It should also be noted that the considered railcars have four axles: two for each bogie of the railcar. This means that the railcar has two support points and that each axle of a given bogie will be loaded evenly. Therefore, it remains crucial to examine the distribution into the front fulcrum (boogie B1) and the rear fulcrum (boogie B2).

4.2. Simulation model

FlexSim version 2021 Update 2 software was used to build the simulation model. Figure 2 shows the model that was constructed. The following items are visible: gantry crane (1), container storage field (2), containers prepared for the loading process next to the track lane (3), and the track lane with railcars ready for loading (4). It can be noticed that the railcars have a pre-defined pin arrangement, which determines the possibility of placing a given type of container on the railcars or necessitates pin reconfiguration. The gantry crane is capable of moving along the entire length of the train. The way the crane handles containers is determined by the established work algorithm. The sizes of objects in the model reflect their real-world dimensions. The model considered the random distribution of containers prepared for loading along the train. At the same time, the random configuration of the hitching pins on the railcars, assuming that the configuration of the pins on the railcars, corresponds to the number and size of the containers prepared for loading.

It was assumed that the containers in the storage yard are placed in a maximum of three layers. The most realistic situations were considered when the vast majority of containers prepared earlier for loading were loaded on the train. Nevertheless, the analyses were supplemented with variants in which all containers prepared along the track are loaded on the train and variants where all containers are taken from the storage yard in order to illustrate the impact of containers' early preparation along the track on the train loading time. The locations of containers taken for loading from the storage yard were described by uniform distribution. For the purposes of the study, the following variants of the share of containers prepared for loading and those collected from the storage yard were adopted (see Table 1).

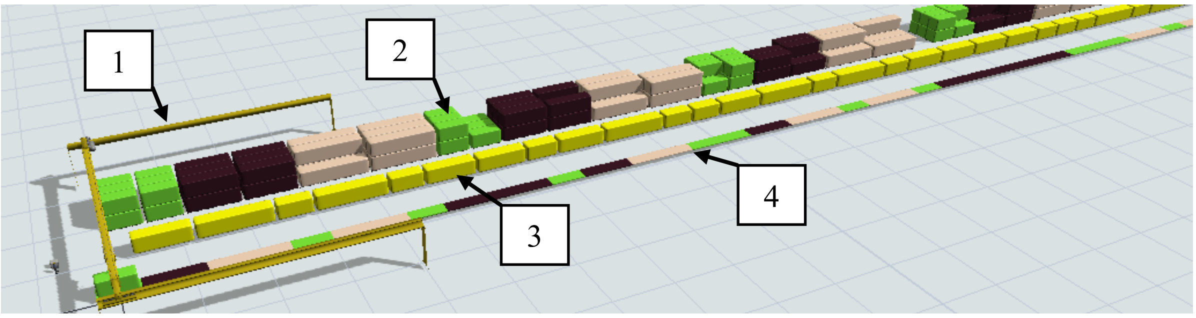

Fig. 2. Simulation model built in the FlexSim environment. Source: own elaboration

Table 1

Variants of the arrangement of containers for train loading. Source: own elaboration

	Percentage of containers ready for loading along the track Percentage of containers			
	Ready along the track	From the storage yard, located in the top layer	From the storage yard, located in layer 2	From the storage yard, located in the layer 1
Strategy S1	100	0	0	0
Strategy S2	80	34% (out of a total of 20% unprepared units)	33% (out of a total of 20% unprepared units)	33% (out of a total of 20% unprepared units)
Strategy S3	50	34% (out of a total of 50% unprepared units)	33% (out of a total of 50% unprepared units)	33% (out of a total of 50% unprepared units)
Strategy S4	0	34% (out of a total of 100% unprepared units)	33% (out of a total of 100% unprepared units)	33% (out of a total of 100% unprepared units)

Considering all the further described variants, strategies, and logics, 105 simulation scenarios were developed. They are presented in Table 2. The given percentages and other values have been adopted for the purposes of the study. In a real working environment, they may depend on the case under consideration.

The main factor affecting the implementation of the process is the logic of the crane's operation. In the analyzed model, five basic crane operation logics were considered:

- L1 – priority of the railcars – the algorithm chooses the first slot on the first railcar in the head of a train and then searches for the first matching container starting from the head of the yard.
- L2 – priority of the containers – opposite to L1.
- L3 – shortest distance from the railcar to the container – the algorithm chooses the first slot on the first railcar in the head of a train and then searches for the closest matching container.
- L4 – shortest distance from the container to the railcar – opposite to L3.
- L5 – shortest distance from the current container to the railcar and from the current railcar to the container (nearest neighbor algorithm). The algorithm chooses the first available container and then searches for the closest matching slot on the railcar.

Table 2

Simulation scenarios. Source: own elaboration

Scenario	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Crane operations logic (L1-L5)	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1
Storage yard cleaning (K1-K2)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	1
Share of containers from the yard [%] (S1-S4)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	20	20	20	20	20
Share of containers from layer 3 [%]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	34	34	34	34	34
Share of containers from layer 2 [%]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	33	33	33	33	33
Share of containers from layer 1 [%]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	33	33	33	33	33
Number of weight categories (W1-W3)	3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	3	3	3	3	3	3
Scenario	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Crane operations logic (L1-L5)	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2
Storage yard cleaning (K1-K2)	1	1	1	1	2	2	2	2	2	1	1	1	1	1	2	2	2	2	2	1	1
Share of containers from the yard [%] (S1-S4)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Share of containers from layer 3 [%]	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Share of containers from layer 2 [%]	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Share of containers from layer 1 [%]	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Number of weight categories (W1-W3)	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5
Scenario	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
Crane operations logic (L1-L5)	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3
Storage yard cleaning (K1-K2)	1	1	1	2	2	2	2	2	1	1	1	1	1	2	2	2	2	2	1	1	1
Share of containers from the yard [%] (S1-S4)	20	20	20	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Share of containers from layer 3 [%]	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Share of containers from layer 2 [%]	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Share of containers from layer 1 [%]	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Number of weight categories (W1-W3)	5	5	5	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4
Scenario	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
Crane operations logic (L1-L5)	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4
Storage yard cleaning (K1-K2)	1	1	2	2	2	2	2	1	1	1	1	1	2	2	2	2	2	1	1	1	1
Share of containers from the yard [%] (S1-S4)	50	50	50	50	50	50	50	50	50	50	50	50	100	100	100	100	100	100	100	100	100
Share of containers from layer 3 [%]	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Share of containers from layer 2 [%]	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Share of containers from layer 1 [%]	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Number of weight categories (W1-W3)	4	4	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3	3	3	3
Scenario	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
Crane operations logic (L1-L5)	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Storage yard cleaning (K1-K2)	1	2	2	2	2	2	1	1	1	1	1	2	2	2	2	2	1	1	1	1	1
Share of containers from the yard [%] (S1-S4)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Share of containers from layer 3 [%]	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Share of containers from layer 2 [%]	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Share of containers from layer 1 [%]	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Number of weight categories (W1-W3)	3	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5

The following assumptions were made for the simulation study:

- the loading process is carried out using the RTG crane;
- containers are placed on an SGS 412z railcar with a capacity of 3 TEU (60 ft in total).
- parameters have been assigned to the railcar:

  - Permissible gross weight: 80 000 kg (for track class C); permissible load: 58 000 kg (for track class C); permissible axle load: 20 000 kg; permissible pressure on the support point: 40 000 kg; railcar tare weight: 22 000 kg.
- containers for loading have been selected in such a way as not to exceed the maximum permissible weight of the train set.
- there are three types of containers with mass gross weight: 20 ft (1C): 20 320 kg; 30 ft (1B): 25 400 kg; 40 ft (1A): 30 480 kg

In real conditions, the weight distribution of the load on the container should also be considered. The phenomenon when the load of one axle is three times (and more) greater than on the other is undesirable. This decreases the stability of the car while driving and an increase in the probability of railcar jumps. The goal is to use the space available on the train as efficiently as possible. Different gross weights of containers complicate their loading onto the train. The gross weights of the containers were classified into weight categories that can be loaded into the corresponding slots on the railcars. In the simulation model, the following variants of container weight categories were considered:

- Variant W1 – three different weight categories for each type of container,
- Variant W2 – four different weight categories for each type of container,
- Variant W3 – five different weight categories for each type of container.

Containers in the storage yard were placed in three layers. Extracting a container from the first or second layer may make it necessary to put aside other containers. The model assumes two variants of container handling:

- Variant K1 – after loading the container onto the train, the crane returns to the place where the container was extracted from in the storage yard and moves the previously put aside containers back;
- Variant K2 – after loading the container onto the train, the crane does not return to the place where the container was extracted from; thus, the moved containers are in different positions after loading.

The gantry parameters are:

- Container pick up/release time [s] – 5/10
- Gantry speed/trolley speed/lifting speed/lowering speed [m/s]– 2/2/0,43/0,43

5. RESULTS AND DISCUSSION

During the study of the simulation model, a total of 105 scenarios were analyzed. In each simulation, the following data were randomized in the model:

- Mounting pins on the railcars and the pins' configuration,
- Containers to be loaded,
- Arrangement of containers to be loaded along the railway track,
- Gross weight of containers in each number of weight categories,
- Permissible load of slots on railcars for a given number of container weight categories,
- Arrangement of containers in the storage yard.

Five replications of simulations were performed for each scenario. The total time of the crane's operation, in seconds, we determined. The simulation results are shown in Table 3. The successive columns of Table 3 show the results obtained for each of the five performed simulations, as well as the mean value and standard deviation. The obtained results were rounded to integer values. Graphical summaries of simulation results for the crane operation times are presented in Fig. 3. The analysis of the obtained results was carried out from the point of view of factors determining the loading time.

- Scenarios 1–15–are the most theoretical cases. It was assumed that all containers were ready for loading and waiting along the railway track. They differ in the crane operation logic (L1-L5) and the number of container weight categories (W1-W3). The train service time increased only slightly in scenarios with three and four weight categories. When five weight categories were considered, the crane operation time increased substantially. For example, in the case of Scenarios 6 and 11, the train loading time compared to Scenario 1 increased by 3% and 21%, respectively. What is worth noticing is that the L1 and L2 logics, in which loading was carried out for subsequent wagons and subsequent containers in turn, returned better results than the logics in which the basis for the decision to allocate a container to a railcar or a railcar to a container was the shortest distance. Only the L5 train loading logic identified with the nearest neighbor algorithm significantly improved the quality of the solutions.

- Scenarios 16–45-are the cases where 20% of containers loaded directly from the storage yard (i.e., those that have not been prepared for loading) were considered. Scenarios 16–25 assume three groups of weight categories for containers, Scenarios 26–35 assume four groups, and Scenarios 3645 assume five groups. It was also assumed that the containers loaded from the storage yard were evenly distributed in layers. Scenarios 16–20, 26–30, and 36–40 assumed the cleaning of containers moved around the yard in order to extract a specific container to be loaded. Other scenarios did not include cleaning. Focusing on the L5 logic and the number of weight categories in Scenarios 25, 35, and 45 do not include cleaning of containers after loading. The loading time in Scenario 35 compared to Scenario 25 decreased by 3%, in Scenario 45 compared to Scenario 25 increased by 5%.
- The factor with the greatest impact on the train loading time was the cleaning process (i.e., replacing moved earlier containers in the storage yard after loading the chosen container on the train). Comparing similar scenarios (Scenarios 20 and 25) revealed that the loading time in Scenario 20, which includes cleaning was 12% longer than in Scenario 25, which does not include a reshuffling process. Similarly, the loading time differs by 13% in Scenarios 30 and 35.
- Due to the fact that the number of weight categories of containers slightly affects the extension of the crane's operating time, further analyses focused on comparing scenarios where the share of containers loaded from the storage yard changed, as well as scenarios including the reshuffling of containers in the storage yard during the cleaning process.
- Simulation results for Scenarios 16–25, 46–55, and 76–85 are presented. In subsequent scenarios, the shares of containers collected from the yard were as follows: Scenarios 16–25: 20%; Scenarios 46–55: 50%; Scenarios 76–85: 100%. The simulation results presented in Table 3 show that the train loading time increases very quickly with the share of containers taken directly from the storage yard. Comparing the results obtained only from the point of view of the L5 logic (including cleaning the moved containers), the crane operation times for Scenarios 20, 50, and 80 were 7719 s, 11 580 s, and 13 100 s, respectively. This means that the average train loading time for Scenarios 50 and 80 increased by 50% and 63%, respectively, compared to Scenario 20. It should be noted that the increase in the number of containers taken from the yard from 50% to 100% increased the loading time by only 13%.

6. CONCLUSIONS

Considering the analysis of the results, the following conclusions can be drawn:

- The greatest impact on the train loading time was the number of containers that are not prepared for this loading, which makes it necessary to collect them from the storage yard. Satisfactory simulation results were obtained for scenarios where only 20% of the containers were loaded from the storage yard. With a 30% increase in this value (50% of containers loaded from the yard), the loading time increased by as much as 50%, which is not a proportional increase. It should be noted that when the share of containers loaded from the storage yard was increased from 50% to 100%, the train loading time increased by only 13%. This is because the distribution of containers prepared for loading along the track was random in all the scenarios with the share of containers from the yard less than 100%. Therefore, the loading time is not correlated with the number of containers taken from the storage yard.
- The best simulation results were obtained by using the L5 logic, where the crane work is managed in accordance with the nearest neighbor algorithm. In the case of scenarios assuming the preparation of all containers for loading along the track, the L1 and L2 logics returned better results than the L3 and L4 logics. This is due to the fact that the natural behavior of the crane operators is to handle the containers one by one.

Table 3

Summary of simulation results for the crane operation time Source: own elaboration

Scenario	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Mean (95% Confidence Interval)	Std Dev	Scenario	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Mean (95% Confidence Interval)	Std Dev
1	7188	7641	5337	6365	6002	6506 ± 1144	921	54	1322	1194	1220	1171	1118	12054 ± 935	753
2	7190	7648	5326	6389	6001	6511 ± 1150	926	55	1077	1125	9762	9341	8743	9974 ± 1276	102
3	8905	8777	6531	7195	6216	7525 ± 1556	125	56	1868	1873	1870	2022	1498	18268 ± 2419	194
4	7782	8075	6999	7705	6598	7432 ± 759	611	57	1953	1866	1871	1978	1463	18267 ± 2594	208
5	5156	5245	4160	4850	4560	4794 ± 553	446	58	1580	1501	1495	1484	1168	14459 ± 1984	159
6	6717	8558	6106	6703	5561	6729 ± 1402	112	59	1597	1527	1565	1739	1241	15341 ± 2260	182
7	6727	8593	6094	6734	5568	6743 ± 1419	114	60	1281	1215	1286	1296	1067	12294 ± 1190	959
8	8682	9564	7356	7486	5894	7797 ± 1735	139	61	1382	1354	1402	1478	1205	13645 ± 1248	100
9	7823	8941	7534	8260	6129	7737 ± 1296	104	62	1440	1382	1438	1504	1156	13846 ± 1672	134
1	5116	5878	5029	5111	4287	5084 ± 700	563	63	1271	1092	1139	1237	9808	11445 ± 1448	116
1	8112	1044	7126	7296	6505	7896 ± 1905	153	64	1267	1218	1302	1392	1059	12479 ± 1530	123
1	8104	1048	7115	7326	6525	7911 ± 1919	154	65	1065	9847	1054	1128	8451	10155 ± 1342	108
1	9498	1159	8373	8442	7064	8994 ± 2099	169	66	1678	1743	1800	1618	1873	17428 ± 1243	100
1	8743	1119	7678	8363	7091	8613 ± 1955	157	67	1666	1787	1716	1587	1863	17239 ± 1324	106
1	5610	6884	5098	5175	5104	5574 ± 946	762	68	1509	1478	1376	1322	1563	14499 ± 1227	988
1	1034	1331	1190	1028	8534	10876 ± 2248	181	69	1509	1496	1514	1432	1516	14938 ± 435	350
1	1043	1254	1166	1023	8798	10736 ± 1781	143	70	1227	1224	1231	1110	1160	11911 ± 667	538
1	1130	1105	9929	9495	7429	9844 ± 1921	154	71	1292	1314	1427	1212	1452	13399 ± 1235	995
1	9966	1222	1016	9717	8653	10144 ± 1615	130	72	1304	1372	1393	1262	1420	13505 ± 813	655
2	7503	8731	8202	7476	6684	7719 ± 969	780	73	1220	1179	1162	1099	1067	11460 ± 768	618
2	8686	1102	9567	8521	6987	8956 ± 1838	148	74	1274	1289	1325	1214	1258	12725 ± 505	407
2	8763	1086	9349	8456	7110	8908 ± 1696	136	75	1013	1008	9611	9417	9137	9677 ± 534	430
2	1039	9745	8593	8062	6679	8695 ± 1806	145	76	2459	2222	2361	2464	2257	23533 ± 1389	111
2	9102	1096	8684	8685	7978	9082 ± 1398	112	77	2459	2304	2251	2417	2260	23385 ± 1173	945
2	6526	7885	7209	6801	5805	6845 ± 962	775	78	2019	1863	1811	2101	1689	18974 ± 2044	164
2	9465	1138	1129	1110	8826	10413 ± 1469	118	79	2013	1824	1828	1943	1751	18721 ± 1296	104
2	9711	1127	1161	1149	8713	10559 ± 1596	128	80	1360	1339	1293	1313	1242	13100 ± 564	455
2	1043	9036	9435	9691	8548	9429 ± 881	710	81	1736	1584	1564	1571	1587	16089 ± 894	720
2	9097	1045	1014	1058	8569	9772 ± 1106	891	82	1666	1544	1595	1660	1564	16065 ± 687	553
3	7120	7367	8352	7812	7242	7579 ± 627	505	83	1337	1216	1142	1208	1090	11993 ± 1153	929
3	8237	9447	9523	9152	7467	8765 ± 1102	888	84	1538	1347	1411	1386	1351	14072 ± 971	782
3	8326	9898	9441	9260	7349	8855 ± 1264	101	85	1130	9943	9770	1008	9615	10144 ± 837	674
3	9583	8309	8440	8713	7845	8578 ± 799	644	86	2523	2398	2342	2302	1867	22869 ± 3087	248
3	8078	9786	9039	9304	7555	8752 ± 1135	914	87	2502	2353	2274	2351	1973	22910 ± 2433	196
3	6302	6542	7151	6778	6272	6609 ± 454	366	88	2287	2054	1850	2051	1653	19794 ± 2968	239
3	1083	1369	1162	1224	8981	11475 ± 2164	174	89	1993	1907	1879	1918	1580	18556 ± 1981	159
3	1145	1340	1112	1254	8455	11397 ± 2330	187	90	1407	1292	1334	1350	1251	13271 ± 736	593
3	1222	1319	9837	1028	8270	10761 ± 2430	195	91	1825	1645	1592	1604	1351	16038 ± 2103	169
3	1033	1410	1059	1160	8578	11044 ± 2517	202	92	1846	1637	1656	1616	1313	16139 ± 2379	191
4	8665	1002	8184	8358	7081	8463 ± 1315	105	93	1253	1120	1205	1300	9821	11723 ± 1557	125
4	9176	1170	9574	9788	7925	9632 ± 1691	136	94	1498	1377	1428	1373	1231	13818 ± 1219	982
4	9985	1144	9143	9962	7365	9579 ± 1849	148	95	1164	9700	9944	1055	8906	10148 ± 1268	102
4	1133	1155	8670	8993	7484	9608 ± 2198	177	96	2228	2310	2080	2316	2240	22351 ± 1181	951
4	9390	1230	9431	1014	7960	9847 ± 1970	158	97	2213	2333	2148	2368	2194	22515 ± 1177	948
4	7210	8798	6876	6851	6366	7220 ± 1157	932	98	1792	2130	1962	1918	1586	18781 ± 2518	202
4	1869	1795	1820	1785	1704	17950 ± 749	604	99	1984	2007	1688	1979	1753	18825 ± 1857	149
4	1896	1746	1803	1821	1701	17940 ± 922	742	10	1427	1538	1328	1385	1246	13851 ± 1356	109
4	1599	1341	1297	1293	1291	13647 ± 1651	133	10	1681	1572	1583	1503	1607	15895 ± 798	642
4	1599	1481	1466	1493	1404	14892 ± 878	707	10	1587	1592	1582	1589	1538	15780 ± 275	221
5	1277	1196	1142	1116	1056	11580 ± 1041	839	10	1338	1291	1100	1287	1048	12132 ± 1607	129
5	1497	1339	1398	1300	1247	13567 ± 1194	962	10	1565	1450	1319	1491	1288	14229 ± 1446	116
5	1481	1320	1417	1350	1233	13609 ± 1175	946	10	1169	1070	9686	1091	9248	10450 ± 1221	983
5	1231	1141	1115	1068	1006	11124 ± 1042	839								

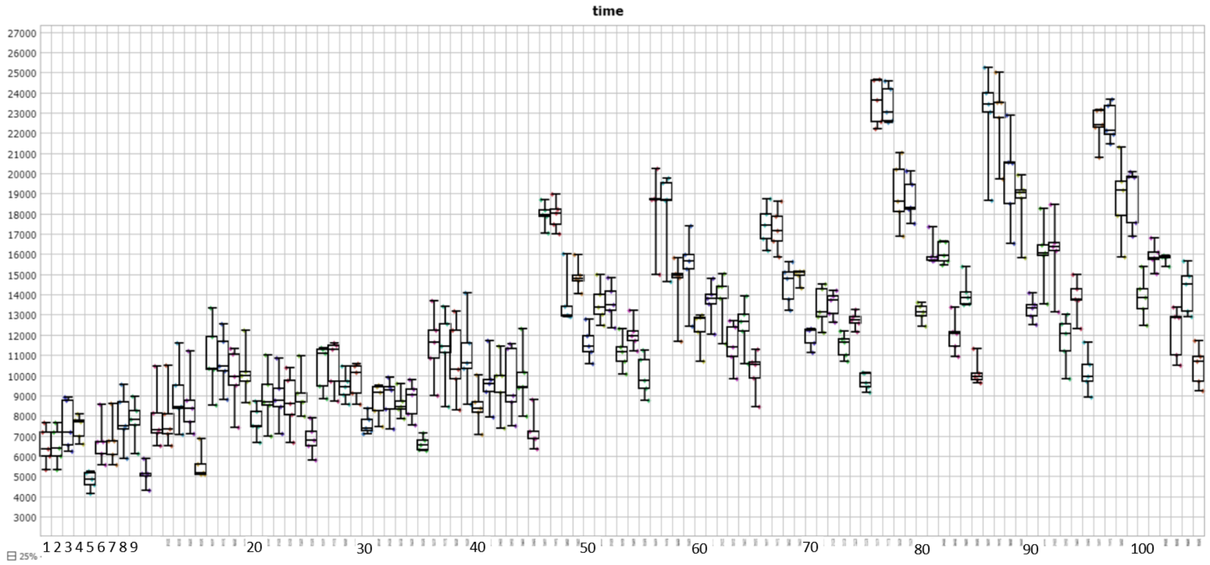

Fig. 3. Graphical summary of the simulation results for crane operation time. Source: own elaboration

- A small number of weight categories (up to four categories) does not have a significant impact on the train loading time. Increasing the number of weight categories from three to four resulted in a slight (3%) increase in the loading process time. The introduction of fifth weight category resulted in an 18% increase in loading time compared to scenarios with four weight categories.

The authors' plans for further developing the study involve the implementation of advanced heuristic algorithms to enhance research and expand the model. This approach aims to optimize logistics processes and improve the efficiency of intermodal transportation. Furthermore, the authors intend to gather real-world data to ensure the practical applicability of the constructed model.

References

1. Ambrosino, D. & Asta, A. & Crainic, T.G. Optimization challenges and literature overview in the intermodal rail-sea terminal. *Transportation Research Procedia*. 2021. Vol. 52. P. 163-170. DOI: 10.1016/j.trpro.2021.01.089.
2. Basallo-Triana, M.J. & Vidal-Holguín, C.J. & Bravo-Bastidas, J.J. Planning and design of intermodal hub networks: a literature review. *Computers & Operations Research*. 2021. Vol. 136. No. 105469. DOI: 10.1016/j.cor.2021.105469.
3. Bergqvist, R. & Monios, J. Inbound logistics, the last mile and intermodal high capacity transport. *World Review of Intermodal Transport Research*. 2016. Vol. 6. No. 1. P. 74-92. DOI: 10.1504/WRITR.2016.078157.
4. Bruns, F. & Knust, S. Optimized load planning of trains in intermodal transportation. *OR Spectrum*. 2010. Vol. 34. P. 511-533. DOI: 10.1007/s00291-010-0232-1.
5. Carboni, A. & Deflorio, F. & Chiara, B.D. Monitoring truck's operations at freight intermodal terminals: traffic observation by scanning on-board devices. *Intelligent Transport Systems*. 2020. Vol. 14. No. 12. P. 1638-1646. DOI: 10.1049/iet-its.2019.0680.
6. Crainic, T.G. & Perboli, G. & Rosano, M. Simulation of intermodal freight transportation systems: a taxonomy. *European Journal of Operational Research*. 2018. Vol. 270. No. 1. P. 401-418. DOI: 10.1016/j.ejor.2017.11.061.
7. Dărăbanț, S. & Ștefănescu, P. & Crișan, R. Economic benefits of developing intermodal transport in the European Union. *Annals of the University of Oradea. Economic Science Series*. 2012. Vol. 21. No. 2. P. 81-87.

8. Heggen, H. & Breakers, K. & Caris, A. A Multi-objective approach for intermodal train load planning. *European Journal of Operational Research*. 2018. Vol. 40. No. 2. P. 341–366. DOI: 10.1007/s00291-017-0503-1.
9. Jachimowski, R. Review of transport decision problems in the marine intermodal terminal. *Archives of Transport*. 2017. Vol. 44. No. 4. P. 35-45. DOI: 10.5604/01.3001.0010.6160.
10. Jachimowski, R. & Szczepański, E. & Kłodawski, M. & Markowska, K. & Dąbrowski, J. Selection of a container storage strategy at the rail-road intermodal terminal as a function of minimization of the energy expenditure of transshipment devices and CO_2 emissions. *Annual Set The Environment Protection*. 2018. Vol. 20. No. 2. P. 965-988.
11. Jacyna, M. & Semenov, I. Models of vehicle service system supply under information uncertainty. *Maintenance and Reliability*. 2020. Vol. 22. No. 4. P. 694-704. DOI: 10.17531/EIN.2020.4.13.
12. Jacyna, M. & Jachimowski, R. & Szczepański, E. & Izdebski, M. Road vehicle sequencing problem in a railroad intermodal terminal – simulation research. *Bulletin of the Polish Academy of Sciences. Technical Sciences*. 2020. Vol. 68. No. 5. P. 1135-1148. DOI: 10.24425/bpasts.2020.134643.
13. Krstić, M.D. & Tadić, S.R. & Brnjac, N. & Zečević, S. Intermodal terminal handling equipment selection using a fuzzy multi-criteria decision-making model. *Promet – Traffic & Transportation*. 2019. Vol. 31. No. 1. P. 89-100. DOI: 10.7307/ptt.v31i1.2949.
14. Li, C. & Otto, A. & Pesch, E. Solving the single crane scheduling problem at rail transshipment yards. *Discrete Applied Mathematics*. 2018. Vol. 264. P. 134-147. DOI: 10.1016/j.dam.2018.07.021.
15. Mindur, L. Combined/intermodal transport – the global trends. *Transport Problems.* 2021. Vol. 16(3). P. 65-75. DOI: 10.21307/tp-2021-042.
16. Muravev, D. & Hu, H. & Rakhmangulov, A. & Mishkurov, P. Multi-agent optimization of the intermodal terminal main parameters by using AnyLogic simulation platform: case study on the Ningbo-Zhoushan Port. *International Journal of Information Management*. 2021. Vol. 57. No. 102133. DOI: 10.1016/j.ijinfomgt.2020.102133.
17. Nehring, K. & Jachimowski, R. Modelling of container train handling in the land intermodal terminal. In: *9th Carpathian Logistics Congress - Conference Proceedings*. 2020. Vol. 1. No. 1. P. 242-249.
18. Nehring, K. & Kłodawski, M. & Jachimowski, R. & Klimek, P. & Vašek, R. Simulation analysis of the impact of container wagon pin configuration on the train loading time in the intermodal terminal. *Archives of Transport.* 2021. Vol. 60. No. 4. P. 155-169. DOI: 10.5604/01.3001.0015.6928.
19. Oudani, M. Intermodal terminal location problem under fuzzy restrictions. In: *2020 IEEE 13th International Colloquium of Logistics and Supply Chain Management (LOGISTIQUA).* Fez, Morocco. 2020. P. 1-5. DOI: 10.1109/LOGISTIQUA49782.2020.9353871.
20. Pekin, E. & Macharis, C. & Meers, D. & Rietveld, P. Location analysis model for Belgian intermodal terminals: importance of the value of time in the intermodal transport chain. *Computers in Industry*. 2013. Vol. 64. No. 2. P. 113-120. DOI: 10.1016/j.compind.2012.06.001.
21. Pencheva, V. & Asenov, A. & Sładkowski, A. & Ivanov, B. & Georgiev, I. Current issues of multimodal and intermodal cargo transportation. In: *Modern Trends and Research in Intermodal Transportation. Studies in Systems, Decision and Control*. Springer. 2022. P. 51-124. DOI: 10.1007/978-3-030-87120-8_2.
22. PN-ISO 668:2018-05. *Cargo containers series 1 - Classification, dimensions and maximum gross weights*. Warsaw: Polish Committee for Standardization.
23. Rece, L. & Vlase, S. & Ciuiu, D. & Neculoiu, G. & Mocanu, S. & Modrea, A. Queueing theory-based mathematical models applied to enterprise organization and industrial production optimization. *Mathematics*. 2022. Vol. 10. No. 2520. DOI: 10.3390/math10142520.
24. Šakalys, R. & Batarlienė, N. Research on intermodal terminal interaction in international transport corridors. *Procedia Engineering*. 2017. Vol. 187. P. 281-288. DOI: 10.1016/j.proeng.2017.04.376.
25. Sładkowski, A. (ed.) Modern trends and research in intermodal transportation. In: *Studies in Systems, Decision and Control*. Springer. 2022. Vol. 400. 569 p.

26. Staniuk, W. & Staniuk, M. & Chamier-Gliszczynski, N. & Jacyna, M. & Kłodawski, M. Decision-making under the risk, uncertainty and COVID-19 pandemic conditions applying the PL9A method of logistics planning – case study. *Energies*. 2022. Vol. 15(2). No. 639. DOI: 10.3390/en15020639.
27. Tadić, S. & Krstić, M. & Zacewić, N. Defining the typical structures of the intermodal terminals. *Quantitative Methods in Logistics*. 2020. Vol. 67-86. DOI: 10.37528/FTTE/9786673954196.004.
28. Tadić, S. & Krstić, M. & Roso, V. & Brnjac, N. Planning an intermodal terminal for the sustainable transport networks. *Sustainability*. 2019. Vol. 11(4102). DOI: 10.3390/su11154102.
29. UIRR: International Union For Rail Road Combined Transport. UIC Freight Department. *2020 Report on Combined Transport in Europe*. 2021. 30 p.
30. UTK. *Rok 2018 w przewozach intermodalnych. Podsumowanie Prezesa UTK*. Urząd Transportu Kolejowego. 2018. 14 p. Available at: https://utk.gov.pl/download/1/48023/ Podsumowanieprzewozowintermodalnychw2018v1.pdf. [In Polish: UTK. *2018 in intermodal transport. Summary of President of UTK*. Office of Rail Transport].
31. UTK, 2021. *Dane- transport intermodalny.* Urząd Transportu Kolejowego. [In Polish: UTK, 2021. *Data - intermodal transport*. Office of Rail Transport]. 2021. 13 p. Available at: https://dane.utk.gov.pl/sts/transport-intermodalny.
32. UTK, 2022. *Przewozy intermodalne 2022*. Urząd Transportu Kolejowego. [In Polish: UTK, 2022. *Intermodal transport 2022*. Office of Rail Transport]. 2022. 14 p. Available at: utk.gov.pl/download/1/69937/Przewozyintermodalne2021.pdf.
33. Viorela-Georgiana, S.C. Intermodal transport - a way of achieving sustainable development. *Constanta Maritime University Annals*. 2015. Vol. 22. P. 145-148.
34. Wang, L. & Zhu, X. container loading optimization in rail–truck intermodal terminals considering energy consumption. *Sustainability*. 2019. Vol. 11(8). No. 2383. DOI: 10.3390/su11082383.
35. Zabielska, A. & Jacyna, M. & Lasota, M. & Nehring, K. Evaluation of the efficiency of the delivery process in the technical object of transport infrastructure with the application of a simulation model. *Maintenance and Reliability*. 2023. Vol. 25. No. 1. P. 1-13. DOI: 10.17531/ein.2023.1.1.
36. Żak, J. & Jacyna, M. & Gołębiowski, P. The use of the queueing theory for the analysis of transport processes. *Logistics and Transport*. 2019. Vol. 41. No. 1. P. 91-100. DOI: 10.26411/83-1734-2015-1-41-13-19.

Received 14.11.2022; accepted in revised form 12.06.2024