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SIMULATION ANALYSIS OF THE IMPACT OF CONTAINER WAGON PIN CONFIGURATION ON THE TRAIN LOADING TIME IN THE INTERMODAL TERMINAL

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Abstract:

The article presents the issues of a container train loading at the land intermodal terminal. This issue was considered from the point of view of the distance covered by the loading devices and the duration of loading works, which was influenced by the arrangement of containers on the storage yard and the configuration of pins on the wagons. The conducted research was dictated by the small number of publications on loading an intermodal train, especially from the point of view of pin configuration on wagons. The vast majority of the literature is devoted in this field to marine intermodal terminals, which operating characteristics are different from inland terminals. The importance of this problem resulting from the growing turnover of containers transported by rail transport was also pointed out. The systematic increase of this type of transport and the depletion of the intermodal services' operating capability makes it necessary to improve the train loading process. For the purposes of the research, the issues of containers of various sizes loading onto wagons planning with various pin configurations were presented. A literature review was carried out in the field of train loading methods and strategies. A mathematical model was developed for the decision situation under consideration. The equations defining the most important elements of the considered problem were presented in the general form. This model was implemented in the FlexSim simulation environment. The constructed simulation model was used to develop 12 variants of the approach to an intermodal train loading. The train loading tests were performed both for the random arrangement of containers on the storage yard and for the random arrangement of pins on the wagons. The obtained results made it possible to determine how the knowledge of the arrangement of pins on the wagons influences the planning of train loading and increases the efficiency of loading devices.

Keywords: *wagon pin configuration, intermodal train loading, simulation analysis, FlexSim*

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1. Introduction

The starting point for considerations in this article is intermodal transport, which is the result of the containerization developing since the mid-twentieth century and the general increase in the mass of transported loads. In the simplest terms, intermodal transport consists of transporting cargo in one transport unit (e.g. a container) by various modes of transport along the transport route. It allows to combine the strengths of various modes of transport, and thus obtain a synergy effect, manifested in the form of increased transport efficiency and reduction of its external costs.

The number of transported intermodal units grows quite intensively from year to year. This entails the need to develop linear infrastructure (railway lines) as well as point infrastructure (interodal terminals), which will enable transhipment in the wagon-truck and truck-wagon relation. The reloading devices used in intermodal terminals (gantry cranes and reachstackers) are often unable to handle the rapidly increasing flows of cargo. In addition to the purchase of new handling equipment, one of the ways to solve this problem is to increase the efficiency of the devices through proper planning of their operation. Each of the reloading devices in the intermodal terminal used for reloading of intermodal units performs its work cyclically. Reduction of cycle time is possible by reducing the distance between the intermodal unit and the wagon to be loaded on and by elimination of empty cycles.

Planning the operation of a reloading device usually consists in determining the order in which the containers are loaded onto the train (the same applies to unloading the train). This plan includes the allocation of specific containers to specific wagons of a given train. This plan takes into account both different types and sizes of containers as well as different types and lengths / capacities of container wagons (wagons can be from 40 to 104 feet long). (Jacyna et al., 2017). When planning the loading of the train, a number of limitations should be taken into account. It is important not to exceed the capacity of a given wagon. This capacity is usually given in TEU (twenty feet equivalent unit). An additional limitation in the planning of train loading is the arrangement of containers (knowing their gross weight) so as not to exceed the axle loads of the wagons. If containers with dangerous goods are also to be transported on the train, their arrangement in relation to other containers must be considered. Due to the relatively similar height of all containers, this aspect is also important when planning the loading (this applies to a situation when a container wagon with a container may exceed the permissible vertical gauge on the train run).

Moreover, the train loading plan can often be additionally determined by e.g. maximizing the use of train capacity, the time it takes to reconfigure the pin on a given wagon due to the loading of different types of containers and the associated cost (pins require manual re-setting). The time and cost associated with moving the container from its place on the yard to the wagon are also of great importance. This involves planning the loading of containers due to the arrangement of different types of wagons in the train (Nehring and Jachimowski 2020). Based on the agreed train loading plan, the loading device is assigned to a task consisting of taking a specific container and putting it away on a wagon designated in the plan.

Particular difficulties in planning the work of the loading device and thus determining the loading plan are created by the arrangement of the pins on the wagons that are supposed to arrive at the intermodal terminal. Their configuration in the whole train is not known to the operator of the intermodal terminal. Therefore, in the further part of the article, the authors focused on the intermodal train loading planning for a situation taking into account the lack of knowledge of the current pin configuration on the wagons. For the purposes of this planning, a detailed review of the literature in this area was performed. The mathematical model was developed and then implemented in the FLEXSIM simulation environment in order to study it for various boundary conditions. The simulation research focused on the analysis of the approach to intermodal train loading planning from the point of view of the pin configuration on the wagons and the arrangement of containers on the storage yard.

2. Literature review

Basically, the problem of the intermodal train loading, in addition to the arrangement of the containers in the storage yard, is due to the diversity of railway wagons and the dimensions of the intermodal containers. The unification of intermodal units allows them to be adapted to the means of transport, but even here a problem may arise (e.g. not all ISO

containers will fit the pins of wagons that meet UIC standards instead of ISO standards).
Containers differ in dimensions, shape and purpose. The basis for container dimensioning in accordance with ISO standards is a module with a length of 40' (12,192 mm). This module is divided into smaller so that the spaces between the component modules are 3 inches (76 mm) long, as schematically shown in Figure 1 (PN ISO 668-1999).

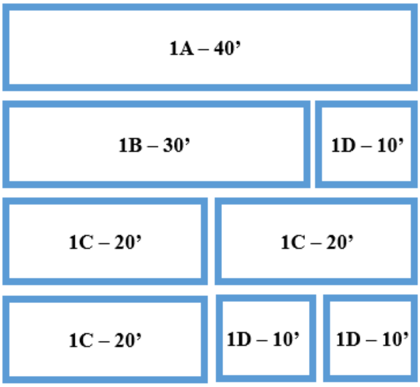

Fig. 1. Dimensional dependencies of ISO containers

Thanks to this, it is possible to transport containers of different lengths together on consecutive wagons or on container trailers, provided that the dimensions of the wagons and the pins configuration correspond to the same standards as the containers. The most popular containers in trade are those that meet ISO standards. Their list is included in the Table 1 (Jacyna et al., 2017).
The most frequently used in international transport are 20' and 40' containers. In Poland, in 2020, among various types of containers, the following were transported: 43.1% of 40' containers, 45.8% of 20' containers, 3.7% of 45' containers. The rest were 30', 35', 25' containers, swap bodies and semi-trailers.
As mentioned before, the large variety of containers makes it difficult to load them onto railway wagons. Most of the railway wagons used in Poland or in Europe have pins adapted to the transport of 10', 20', 30' and 40' containers. Examples of such wagons can be found in Kostrzewski et al. (2018). Therefore, further calculations are focused on containers of the following lengths: 40', 30' and 20'. It was also assumed that the most popular wagons will be used to service these containers. Their loading length is 60 'and the pin configuration allows for loading both 40', 30' and 20' containers. The research also took into account the possible need to change the pins configuration on the wagons that arrived to the intermodal terminal and wait for loading. In fact, such operations are performed by a designated employee of the intermodal terminal, who usually changes the position of these pins while walking along the train during the loading works (although it is possible to provide the terminal employee with prior instructions regarding the arrangement of containers on the train and the associated configuration change.

Table 1. List of containers included in ISO standards

Container mark	Length		Height		Widthe		Maximum gross weight	
	[mm]	[ft in]	[mm]	[ft in]	[mm]	[ft in]	[kg]	[lb]
2AA	14953	49'	2591	8'6"	2595	8'6 5/32"	30 480	67 200
2AAA	14953	49'	2896	9'6"	2595	8'6"	30 480	67 200
1A	12192	40'	2438	8	2438	8'	30 480	67 200
1AA	12192	40'	2591	8'6"	2438	8'	30 480	67 200
1AAA	12192	40'	2896	9'6"	2438	8'	30 480	67 200
1AX	12192	40'	<2438	8'	2438	8'	30 480	67 200
1B	9125	29'11 1"	2438	8'	2438	8'	25 400	56 000
1BB	9125	29'11 1"	2591	8'6"	2438	8'	25 400	56 000
1BBB	9125	29'11 1"	2896	9'6"	2438	8'	25 400	56 000
1BX	9125	29'11 1"	<2438	8'	2438	8'	25 400	56 000
1C	6058	19'10 1"	2438	8'	2438	8'	24 000	44 800
1CC	6058	19'10 1"	2591	8'6"	2438	8'	24 000	44 800
1CX	6058	19'10 1"	<2438	8'	2438	8'	24 000	44 800
1D	2991	9'9 3"	2438	8'	2438	8'	10 160	22 400
1DX	2991	9'9 3"	<2438	8'	2438	8'	10 160	22 400

The issue of intermodal train loading in the land intermodal terminal has not been widely considered so far. Most of the publications on intermodal terminals refer to sea terminals, the specificity of which in some areas differs from land terminals.
Froyland et al. (2008) research can be used as a first point to start further literature analyzes. Their research focusses on wider optimization area. The study concerns general containers operations in a land intermodal terminal realized by gantries. The study is based on the Port Botany terminal case. Their algorithm focusses on the container exchange, cranes scheduling and the allocation of the means of transport. Efficient space-time divisioning should be a result of the presented method. This model uses information about container sources (import, export, transit), time periods and transshipment equipment efficiency. The core of the work is a thorough literature review, which was also one of the important points when collecting information for this study.
Literature review has been made by Stahlbock and Voß (2008). The study is meant to present intermodal transport condition and perspectives for development. Intermodal transport is a fast-developing market branch. The study is comprehensive: it considers many land intermodal yard functioning areas (container handling equipment, human resources, assisting systems or optimization methods) and refers to the processes occurring in these areas. To each area possible optimization methods are added. It has also given overall look at the possible optimization methods (also to the train handling). Unfortunately study does not focus strictly on the train handling. Still some useful materials and information can be find.
Another helpful wide literature research has been presented by Caris et al. (2008). Authors in their study confirmed the importance of intermodal transport. This paper is more focused on optimal planning decisions. Possible solution methods are presented as references to the chosen scientific literature. During the optimization areas analysis the most important factors are decision levels. The authors' approach considers decisions time horizons. Relaying on the presented data it is visible that some researches has been made in the area of intermodal train handling. It seems that researches focus more on the terminal equipment functioning. It can be seen that many discussed approaches are based on some simplifications.
Some studies presents overall state of knowledge about the intermodal units handling in the yards. In Boysen et al. (2011) authors analyzed factors influencing handling process. The elaboration has a review character and refers to trends on intermodal market, terminals layouts or processes occurring. Pins configuration is presented as the one of the factors influencing load/unload process. It got an impact on train loading plan, time needed and the possibility of the container handling (concerning containers sizes and pin settings). One of the mentioned method of load planning is creating matrix defining which container can be assigned to which wagon. It allows to minimize number of wagons needed (Feo and Gonzalez-Velarde, 1995). Second approach considers another priority: time costs. It persues to pin re-setting operation limitation in order to minimize handling time (Bruns and Knust, 2010). In order to build realistic intermodal train handling model also other factors occurring need to be considered.
Heggen et al. (2018) published another study on multi-objective approach for the intermodal train planning. The aim of this research is, similarly to others, to utilize the train loading capacity, length, weight etc. Model focuses on intermodal operations. This time authors decided to build static and multi-objective model. As the problem solution optimal work schedule shall be obtained. Parameters considered in the study are ITUs' and wagons' types, number of wagons, weight restrictions, units' weight and dimensions etc. Vide range of factors has been taken into consideration. This study is based on Bruns and Knust (2010) research. However, it differs from Bruns and Knust's approach as the main factor is not the fixation type but the unit size.
One of the more recent studies analyzing aspects of modal terminal operation is Li et al. (2019) that again addresses the problem of crane scheduling (in both single-crane and multiple-crane yards). As it has already been mentioned, this issue is directly related to the one discussed in this article. Compared to other studies, a slightly more modern approach to the issue was used and dynamic programming methods were applied: an algorithm of conduct during train service and elements of the mathematical model were applied. For the purposes of our research, references to single-crane terminals will be particularly important.
More theoretical approach has been presented in literature revive by Crainic et al. (2018). Their study

can be used as a source of general knowledge about the intermodal transport. The types of mathematical models are described (static or dynamic, stochastic or deterministic). It can be used in order to expand knowledge on the intermodal transport functioning and it can have an indirect influence on the survey.
Another interesting study has been made by Ambrosino and Siri (2014). Authors consider problems connected strictly with the topic considered in our article i.e. train loading and planning of this process. Despite the fact that study focus on maritime container terminals, some useful information can be find. Again view on internal operation of terminal is expanded: the issue of reducing the number of unnecessary gantry movements or container reshuffling is presented. In case of maritime terminals destination of the trains issue can be skipped as it is supposed that all the trains are going to inland terminals. It is otherwise in the same inland terminals where train destination is more important and complex problem- in real-life study it shall be considered. Authors consider factors such as weight restrictions and possible slots for container placement on the wagon. Also 'costs' of operations are added to consideration. Mathematical model based on binary values is constructed. Its aim is to minimize costs of train loading operation. In other case also time (or any other factor) can be considered as mentioned 'cost'. Authors decided to use computer method based on programming which is slightly different that the planned approach.
One of the studies focusing on the considered problem is the one made by Bruns and Knust (2012). The authors' aim is to indicate best practices while intermodal train handling. Weight restrictions are considered. The mathematical model is based on the three linear programming formulations. Factors included and the most important model presumptions in the study are presented in the Table 2.

Table 2. Factors considered by Bruns and Knust (2012)

No.	Factor
1	place of train handling
2	number of handling wagons
3	types of wagons and ITUs
4	weight limits and restrictions
5	intermodal load units' types
6	storage area capacity

Bruns and Knust (2012) consider three main optimization mathematical models. First linear model assumes discrete weight distribution and that one load unit length-type fits onto one slot. The second approach also is based on discrete weight distribution. It also concerns the load unit fixation type. Last one uses continuous model of the weight restrictions. Unit length is considered too. What's more important, authors also discuss aspect important from view of this study: wagon pins configuration. Publication includes mathematical model and computer simulations which considers again train load planning. Publication can be very useful as it is one of the few studies that presents a holistic approach.
What's more important, authors also discuss aspect important from view of this study: wagon pins configuration. Publication includes mathematical model and computer simulations which considers again train load planning. Publication can be very useful as it is one of the few studies that presents a holistic approach.
Interesting approach has been presented by Dotoli and Epicoco (2015). Main criterium is a train commercial value, but also very important is the container layout and order on the wagons. The train planning process has been divided into two steps. First step leads to increasing the train commercial value (max number of ITUs, number of wagons, customer importance, transported goods etc.). Second step is containers shuffling on the train. In this step recommended position for each container is considered (head or tail of the train). Despite the fact that the pins are not mentioned, the elaboration presents strategies that can be used while formulating variants of the constructed model.
Some published models extend the issue of train service in intermodal terminals (Ambrosino et al., 2016). Additional specific service factors such as the presence of two gantries are considered. Unfortunately majority of the studies focus only on the seaport intermodal terminals whose functioning and specificity of the processes carried out differ slightly from those in the inland terminals. Despite this fact study is still very interesting as it presents multi-objective approach. Two main groups of variables with binary values were used. In addition, numerous factors such as number of wagons, number of train slots, weight restrictions, container size, weight, and value etc. were considered. Which, however, is important from the point of view of our research pin

configuration and the need to rearrange them were highlighted and considered as a separate factor. Therefore, the time of additional operations that are extremely important for the purpose of this study is also taken into account. Also optimization methods and computer test are included.

In Ambrosino et al. (2011) authors also decided to base their study on mathematical model. Point of interests is again intermodal train handling (in particular train loading plan). Similarly to mentioned previously publication aim of the constructed model and mathematical formulations is to assign containers of different sizes and weight to the wagons of the intermodal train reducing number of operations and maximizing train utilization. However, the publication focuses on the maritime terminal and not the land terminal. As with some of the other models discussed below, it is based on binary values that describe the condition of a given container and wagon. Study includes algorithm which might be also helpful while problem analyzing.

Very important observation about the intermodal transport market is that a lot of attention is paid to seaport terminals and aspects of inland intermodal terminals are often skip. One of the authors that also perceived this dependence was Dotoli et al. (2013). The elaboration took up the problem of optimizing the loading of an intermodal train in inland terminal taking into account it 'commercial value' and all the priorities for the chosen transportation task. In addition to the literature review, the article includes a mathematical model characteristic of the planning of intermodal train service in the terminal: a collection of wagons and containers to be loaded on them was distinguished. Each of the elements of these sets has specific parameters (weight, length, type etc.). The less obvious fact is that the authors take into account the destination of the containers or the degree of their filling (empty or loaded). A case study was also carried out using the MATLAB model and real data and terminal software from existing intermodal terminal.

Another publication considering train load planning optimization was Corry and Kozan (2008). Again train loading is presented as a complex process on which many factors have got influence. Aim of the process optimization shall be maximizing utilization of wagon capacity, reducing number of wagons needed, and time minimization. Loading process shall be well planned in order to be efficient. Main point of the study are mathematical model variations: base model and dynamic model adaptation. Each considers many container sizes. Authors also carried out series of computer simulations in order to explore the problem deeper. Despite the fact that the results are very analytical (no visualization of the process), they give a picture of what factors affect the loading of the train and what factors should be followed when planning it.

In Lai et al. (2008) authors decided to study the specific topic connected with intermodal train handling i.e. aerodynamical aspects of forming intermodal train. The argumentation of this study is supported by achieving energy savings, fuel efficiency and cost reduction thanks to optimized ITUs' layout on the intermodal train. Study uses integer-programing in order to support terminal operators. Similarly to some other mentioned mathematical models, this model assigns values '1' or '0' depending on the considered unit and wagon state. A dense unit layout on the intermodal train can lower the aerodynamic force. This the premise can be used when building a model for this publication.

Despite the fact that pin configuration is not a main point and factor considered by Corry and Kozan (2006), the study mentions this factor and also presents interesting approach to container assignment to wagon. Study considers inland intermodal terminal (ITUs flow between road and rail transport) and is based on mathematical model. Model assigns '1' to a container if it is matched to a wagon slot in a specific time or '0' if not. Every container parameters are identified. Pins are not a main point of the study but this approach can be very useful during model construction.

Study by Powell and Carvalho (1998) differs from the others presented. The study takes into account only intermodal flatcars and is based on dynamic math model (dynamic units' assignment to the wagons). The authors tries to improve intermodal terminals performance. This model concerns possible ITUs possible layouts on the wagon (also double stacking or mixing trailers and containers). Wagons parameters as length, capacity and number of axes can also vary according to study. The model tries to adjust train loading plan to the task.

It is expected that some of the problems considered by Boysen and Fliedner (2014) will affect the results of this study. The authors focused on determining crane working areas and considered factors influencing its efficiency (eg. number of tracks, number of gantries). As the results researchers obtained a view on how does the intermodal yard partition impacts the train handling. Our elaboration does not consider same elements/factors (such as more than one track). However it is expected the influence of different container set-ups and train unloading strategies can . In connection with the results of Boysen and Fliedner (2014) study it can give a wider view on intermodal train unloading time optimization.

Some general premises about train loading process can be found in many publications. They give an overview of the recommendations for the formation of an intermodal train. E.g. Li et al. (2017) focused on aerodynamical efficiency of the loaded train. The test results (illustrating, inter alia, the increase in the action of aerodynamic drag along with the increase in the distance between the containers on the wagons), can be used in this study. Broaden view on the process leads to considering not only time of train loading process as a priority but also allows to think about other aspects of optimizing load operation.

Many elaborations can indirectly influence approach to the problem considered. Even if the pin configuration is not mentioned, often ITUs layout on the train, which is dependent on wagon capacity and spacing, is considered. Even if the publication focuses on empty container flow (Kuzmicz and Pesch, 2019) or analyses container load/unload process in general (Zajac and Swieboda, 2015) it might be helpful while information research or model preparation.

Also Anghinolfi et. al. (2012) or Mantovani et. al. (2018) decided to broaden the scope of their research on the issue of intermodal train loading. First study focus on multiple train handling in the terminal. It also includes simple mathematical model. Unfortunately study is not very complex. Second study is more advanced. It considers very interesting area of rail intermodal transport i.e. double stacking of ITUs. Study is based on mathematic and computational model. However, this should be taken into account However, it should be taken into account that the system of such transport has a marginal application in Europe, the area of which is considered in this study. Elements of individual publications may be indirectly used in this study despite the fact that the considered train handling conditions is slightly different in our publication (i.e. single train, single crane at intermodal terminal).

Unfortunately it has been indicated that the lack of current researches make it difficult to work on the optimization of processes taking place in intermodal transport and reduce the possibility of referring to the actual market. The 2018 report of International Union of Railways states that the last wide research in this area has been made in 2009 (UIC, 2018).

The conducted analysis of the literature showed that the intermodal train loading in a land terminal may significantly affect the effectiveness of the entire process of passing an intermodal unit through the terminal. A detailed analysis of this effectiveness requires an approach to this issue taking into account many boundary conditions. One of the ways to study the behavior of transshipment processes over time is to conduct a discrete simulation. It was found that the research conducted so far in the literature on the subject did not address the issue of simulation analysis of intermodal train loading. The literature does not take into account the time necessary to change the pins configuration in a situation where the temporary arrangement of the pins on the wagons makes it impossible to load the containers intended for transport (e.g. most wagons have pins for 30' containers, while only a small part of them is intended for loading - the vast majority are e.g. 20' or 40' containers.

3. Methodology

3.1. Mathematical model

The mathematical model is based on the container and wagon categorization. Its aim is to minimize the amount of work necessary to complete the entire process of loading the ITUs waiting in the terminal onto the intermodal train wagons. Main considered criteria and parameters impacting the process are:

- number of wagons available and number of units to load;
- wagons length (each wagon can handle a total containers of 60ft length);
- loading units sizes (container types distinguished by their size. We consider three main size-types of containers: 20ft, 30ft and 40ft as the most popular types of containers);
- the initial pin configuration on the wagons (i.e. a configuration that can accommodate a total of 60ft containers. It means that possible basic

configurations are 20ft/20ft/20ft, 40ft/20ft, 20ft/40ft, 30ft/30ft).

Additionally, changes in the position of individual sizes of containers on the wagon are treated as a separate configurations i.e. 40ft/20ft is not equal to 20ft/40ft as changing from one configuration to another is associated with incurring an additional effort to move the container (each slot has a specific location assigned to each container in the storage yard) or change the pin layout.

In this model the configurations of the wagons are determined by matching the given types of container to the arrangement of corner hooks on the wagon (i.e. wagon configuration or the initial pin configuration). The configurations are used to model the setup costs for the changes of wagons, but do not exactly determine if a load unit fits onto a certain slot. The additional cost is zero if the container matches the given pin configuration on the wagon. Otherwise, the arrangement of the taps must be changed, which is associated with the aforementioned costs. If the container does not fit to the initial pin configuration, the configuration can be changed. In this case additional time and effort cost is added. The situation of changing the configuration of the pin settings takes place when a unit of a given size must be loaded to a certain slot but the slot is prepared for the unit of other size. This situation will take place especially at the end of the process, when, after filling the matching slots, several containers will be left for which the reconfiguration of the pins will be required (difference in the sizes of the containers arriving at the terminal and the ones in shipment).

We assume that the train is long enough to accommodate all the containers assigned to the loading. It is possible that after reconfiguring the pin pattern, the selected slot may remain empty. However, it should be remembered that the model is aimed at minimizing the time and effort necessary to carry out the loading, and for this reason, the aim will be to:

- shortening the distance covered by the crane during container transport (matching the container to the closest matching slot);
- reduction of the number of pin reconfiguration operations to a minimum.

In perfect conditions reconfiguration will not occur. In fact, their occurrence must be taken into account.

Needed for the mathematical model parameters are:

I – number of containers;

J – number of wagons;

$\boldsymbol{I} = \{1, \ldots, i, \ldots, I\}$ – set of containers;

$\boldsymbol{J} = \{1, \ldots, j, \ldots, J\}$ – set of wagons;

$\boldsymbol{L} = \{1, \ldots, o, p, \ldots L\}$ – set of containers and slots lengths;

l_i – i-th container length;

L_j – j-th wagon length;

$\boldsymbol{C_j^0}$ – initial pin configuration of j-th wagon;

s_j – slot on the j-th wagon;

$\boldsymbol{S_j} = \{s_1, s_2, s_{j3}, \ldots\}$– set of slots on j-th wagon;

l_s – type of slot (sot length) suitable for container with l length;

d_{ijs} – time (cost) of transporting container i to the s_{jn} slot on the wagon j;

t_{op} – time (cost) of slot reconfiguration operation from o to p configuration (length).

Before starting the calculations, it is necessary to have a list of slots for each j-th wagon ($\boldsymbol{S_j}$) with the l_s parameter (length) assigned to each slot.

First decision variable x_{ij} have an interpretation of the wagon's container allocation (1):

$$x_{ijs} = \begin{cases} 1, & \text{if container } i \text{ is allocated to a } s_j \\ & \text{slot on the } j \text{ wagon} \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

Second decision variable y_{ijs} verifies if the initial slot configuration of j-th wagon C_j^0 is suitable for containers allocated to a wagon (2):

$$y_{ijs} = \begin{cases} 0, & \text{if } s_j \text{ slot suitable for container } i \\ & \text{(charaterized by } l_i \text{ length)} \\ & \text{occurs on a wagon } j \\ \sum_{op} t_{op}\,, & \text{if the slot does not occurs} \\ & \text{and pin configuration needs} \\ & \text{to be changed} \end{cases} \quad (2)$$

Where:

$\sum_{op} t_{op}$ – summary time (cost) of operations on slots while reconfiguring them from the o to p type.

It must be also considered that usually one operation of changing the pin configuration results in another operation within a given wagon. This is the reason why not only t_{op} is considered but the sum of the time costs.

The criterion function (2) has the interpretation of minimizing the time needed for the overall train loading operation concerning containers transportation operations and all needed reconfiguration operations on the wagons:

$$F(XY) = \sum_{i\in I}\sum_{j\in J}\sum_{s\in S} d_{ijs}x_{ijs} + \sum_{i\in I}\sum_{j\in J}\sum_{s\in S} y_{ijs} \rightarrow min \quad (3)$$

The constraints imposed on the values of decision variables are as follows:

– Every container can be allocated to at most one wagon and one slot:

$$\forall i \in I \quad \sum_{j\in J}\sum_{s\in S} x_{ijs} \leq 1 \quad (4)$$

– Total length of containers on the given wagon cannot excide the wagon length:

$$\forall j \in J \quad \sum_{i\in I}\sum_{s\in S} x_{ijs} \cdot l_i \leq L_j \quad (5)$$

– Total length of slots located on the wagon cannot excide the wagon length:

$$\forall j \in J \quad \sum_{i\in I}\sum_{s\in S} x_{ijs} \cdot l_s \leq L_j \quad (6)$$

– Length of the slot must complies with the assigned container:

$$\forall j \in J \quad \forall i \in I \quad \forall s \in S \quad l_i = l_s \quad (7)$$

– Variable x_{ijs} can have only binary values:

$$\forall j \in J \quad \forall i \in I \quad \forall s \in S \quad x_{ijs} = \{0, 1\} \quad (8)$$

– Variable y_{ijs} can only have positive values greater than zero:

$$\forall j \in J \quad \forall i \in I \quad \forall s \in S \quad y_{ijs} \geq 0 \quad (9)$$

– Costs d_{ijs} can only have positive values greater than zero:

$$\forall j \in J \quad \forall i \in I \quad \forall s \in S \quad d_{ijs} \geq 0 \quad (10)$$

The developed model is general, and its purpose is primarily to present the characteristics of the decision problem. Depending on the needs, it can be specified to study specific phenomena or support in a particular decision problem.

Next paragraph presents model construction in the virtual simulation environment. For the model creation FlexSim software has been used. Similarly to the mathematical model, the virtual model's aim is to minimize time needed for the train loading operation realization. Additionally, the energy aspect of the operation was considered. Given examples consider three simulation variants- each under a different conditions and limitations (described in the next paragraph.

3.2. Simulation model

In recent years in order to improve logistics processes and transport means, scientists very often use simulation tools and advanced algorithms, see (Jacyna et al. 2014), (Lewczuk 2015), (Klodawski et al. 2018). This is due to the stochastic nature of the input data (Jacyna and Semenov 2020) to the problems and the need to implement transport and handling processes in real time, see (Jacyna-Gołda et al 2014). Usually, simulation methods are used to analyze the performance of the intermodal terminal in terms of the location of the terminal's functional areas or the efficiency assessment of the handling equipment (Szczepański et al. 2021). The simulation is used to test optimization methods and algorithms before they are implemented in intermodal transport units flow management and control systems in the terminal. Simulation models of the selected processes performed in the intermodal terminal were formulated by Veeke et al. (1999), Duinkerken et al. (2000). Most of the literature regarding simulation research focuses on AGV usage in the marine intermodal terminals.

Simulation models addressing the implementation of containers operations at land intermodal terminals have been developed recently. In Jachimowski et al. (2018), the authors, using a simulation model in FlexSim, investigated the impact of various strategies of placing containers on a storage yard on the loading time of an intermodal train and energy consumption by transshipment devices. In turn, in Jacyna et al. (2020), the authors used a simulation model, also developed in the FlexSim environment, to sequence road vehicles picking up containers from an intermodal terminal.

In this article, the authors consider the problem of an intermodal train loading. We focus on the study of

various approaches to container loading in a simulation model from the point of view of the pins configuration on intermodal wagons. The practice of containers loading shows that the intermodal terminal operator doesn't know the pins configuration on the wagons before the arrival of the intermodal train. Hence, a container stored in the vicinity of a railway wagon, in the event of an incorrect pin configuration, must be loaded onto a wagon with the correct configuration, and at the same time positioned at a further distance from the container. The solution to this problem is a longer loading cycles of devices (resulting from the need to cover longer distances), or the need for manual reconfiguration of pins on the wagons by terminal employees. It is also possible to check the pin configuration in advance by the railway carrier and notify that to the terminal operator. Thanks to that the terminal operator is able to prepare a loading plan for the reloading device. Any deviation from the loading plan resulting from incorrect information and pin configuration, or even ignorance of it, extend the duration of loading operations, extend loading cycles and, consequently, costs. The use of the simulation tool made it possible to study the characteristics relating to the train loading (loading cycles duration, time of pins configuration change) as a function of the arrangement of containers on the storage yard.
As a result, different strategies for the arrangement of the pins the train and the containers in the yard were analyzed:

- The containers intended for loading onto an intermodal train are placed on the storage yard along the loading tracks in the same order as the pin configuration on subsequent wagons of the intermodal train (in the further part of the article marked as the S1 strategy).
- The containers intended for loading onto the intermodal train are placed in the storage yard along the loading tracks in a random order that does not correspond to the random pin configuration on the wagons. This strategy assumes that the pins configuration throughout the train corresponds to the number / dimensions of the containers intended for loading, so that changing their configuration is not necessary (in the further part of the article marked as the S2 strategy).
- The containers intended for loading onto the intermodal train are placed in the storage yard along the loading tracks in a random order that does not correspond to the random pin configuration on the wagons. This strategy assumes that the configuration of the hitch pins does not correspond to the dimensions / number of containers, therefore it will be necessary to change the configuration of the pins by an employee of the transshipment terminal (in the further part of the article marked as the S3 strategy).

An important issue for the above-mentioned strategies is to establish the way in which the containers are allocated to the wagons. This method directly affects the distance traveled by the loading device. The article considers the following ways:

- For each of the containers prepared on the storage yard along the loading tracks (counting from the beginning of the storage yard), railway wagons are assigned one by one (counting from the beginning of the train composition), in the further part of the article marked as the W1 strategy).
- For each of the following wagons (counting from the beginning of the train), containers prepared in the storage yard along the loading tracks are allocated one after the other (counting from the beginning of the storage yard), in the further part of the article marked as the W2 strategy).
- For each wagon (counting from the beginning of the train), containers are assigned (placed on the storage yard counting from its beginning), which correspond to the pin configuration on the wagon and are closest to a given wagon, in the further part of the article marked as the W3 strategy).

Considering the problem of the distance covered by the loading device (gantry crane), the total train loading time as well as the necessity to change pin configuration above containers distribution strategies well analyzed together with the assignment to wagons strategies. Moreover we assumed that there can be just one person, who is 1 o 2 people responsible for the pin configuration change. As a result, 12 variants were obtained, which were analyzed using a simulation tool. These variants are summarized in the Table 3.

Table 3. Variants numbers depending on the containers distribution strategy and number of workers changing the pin configuration

Variant number	1	2	3	4	5	6	7	8	9	10	11	12
Strategy No. S1, S2, S3	1	1	1	2	2	2	3	3	3	3	3	3
No. of workers for pin change	-	-	-	-	-	-	1	1	1	2	2	2
Strategy No. W1, W2, W3	1	2	3	1	2	3	1	2	3	1	2	3

For the purposes of the research, a simulation model of containers transshipment process from the storage yard to train was developed. The model was built in FlexSim environment. It is a software that allows for intuitive mapping and optimization of any transport processes, regardless of their scale. Thanks to the extensive library of 3D objects, it is possible to reproduce the analyzed process (eg the movement of a container through an intermodal terminal). In addition, the ability to visualize the process allows for even more accurate mapping and analysis.

To conduct analyzes, the following assumptions were necessary:

- Containers ISO 1A, 1B and 1C were the subject of the research. In the study 65 containers were loaded on the wagons.
- The trains consists of rail 30 cars. Every car is 19,9 m long and has 3 TEU capacity.
- Containers were stored in one layer in the first row of the storage block.
- The distance between the wagons and the storage yard was 10 m.
- Konecranes RTG gantry crane was used as a loading device. This choice was dictated by the quite common use of this type of gantry at railroad intermodal terminals. Its technical parameters relevant to the covered distance are shown in table 3.
- Wagons are loaded starting from the first car at the head of in the train
- Loading was carried out by a single gantry crane powered by electricity.
- The average time of container capture was 15s.
- The average time of container release was 25s.
- The pin configuration time for a single container is 40s (depending on the situation, a given wagon may require the pin change for max 3 containers).

Technical parameters of the chosen for the model gantry has been presented in Table 4. Schematically, a fragment of the constructed simulation model is presented in Figure 2.

Table 4. Technical parameters of the Konecranes RTG crane

Parameter	Value m/s
Lifting/ lowering speed	0,43
Trolley speed	1,16
Gantry speed	2,16

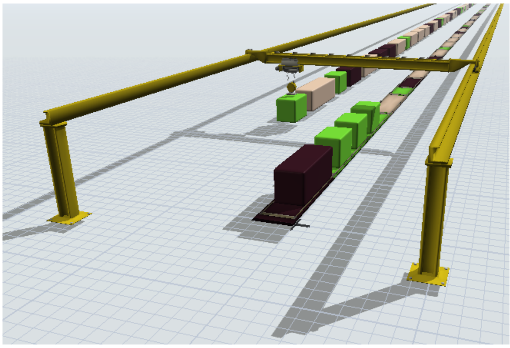

Fig. 2. A fragment of the simulation model prepared in the FlexSim tool

4. Results of the simulation

Due to the random distribution of containers on the storage yard as well as a random pin configuration on wagons in some variants, computational experiments were performed for 5 random samples. The results of the obtained calculations are shown in Table 5. Crane working time, pin change time and train loading time are given in seconds. Crane distance is given in meters.

In Table 6 as well as in Figures 3-6, the average values of characteristics from the Table 5 are presented. The minimum value of the distance covered by the crane (see figure 3) was obtained for variant 1. This is obvious situation, because in that case the containers distribution on the storage yard was equal to the pin configuration on the wagons. Changes made to strategies W1, W2 and W3 in variants 2 and 3 had no significant influence on the crane distance. A significant extension of the distance traveled by the crane can be noticed in the case of the random

arrangement of the containers on the storage yard and the random configuration of pin on the wagons. In this situation, the distance covered by the gantry crane increases three times in variant 3 and 4 and four times in variant 5. It follows that the prior knowledge of the pin configuration on the wagons is of great importance for planning the work of the loading device. Employing workers whose task is to change the pin configuration in accordance with the order in which the containers prepared for loading are placed allows the distance covered by the crane to be shortened to the values obtained in variants 1- 3.
The crane operation time presented in figure 4 does not increase in variants 4-6 as fast as the distance covered by the crane. This is due to the quite significant accelerations and speeds achieved by the gantry. In addition, the container pick-up and release times also quite significantly affect the time of a single crane cycle. The characteristics showing the time of changing the pin configuration (see figure 5) indicate that the use of 2 workers does not reduce the total time of this operation by half.
Particularly important for the considerations in this article is the characteristic showing the total duration of a train loading (see figure 6). This characteristic shows that the change in the configuration of pins by the terminal employees (variants 7-12) does not result in a reduction of the total duration of the intermodal train loading operation, even in the event of a random distribution of containers on the storage yard and a random configuration of the pins. Only in variant 6, where the W3 strategy of allocation of containers to wagons was used, the total loading time of an intermodal train is longer than in variants 7-12.

Table 5. Simulation results obtained in FlexSim environment

Variant No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Crane distance Iteration 1	1925	2009	2002	7201	5662	6049	2245	2086	1975	2017	2010	2168
Crane distance it. 2	1982	1910	1945	4778	5139	9481	1971	2049	2058	2149	2106	2150
Crane distance it. 3	1943	2006	2034	6177	6499	8130	2017	2190	2113	2020	1943	2146
Crane distance it. 4	1938	1932	1925	5450	5104	8504	2114	2089	2009	2192	2155	2043
Crane distance it. 5	1888	1991	2076	6338	5908	14760	2016	2071	2148	1885	2110	2036
Crane working time it. 1	4881	5004	4803	6579	5883	6239	5305	4891	4689	4789	4801	5008
Crane working time it. 2	4854	4762	4752	5691	5642	7736	4782	4808	5030	5031	4947	5136
Crane working time it. 3	4808	4936	4961	6234	6573	7207	4881	5064	4813	4848	4645	4950
Crane working time it. 4	4897	4759	4747	6049	5589	7409	5016	4987	4699	5217	5062	4848
Crane working time it. 5	4637	4935	4879	6508	6224	10099	4850	4815	5016	4591	5092	4985
Pin change time it. 1	-	-	-	-	-	-	2176	1724	1851	1151	1115	1155
Pin change time it. 2	-	-	-	-	-	-	1935	2092	2055	1154	1037	1118
Pin change time it. 3	-	-	-	-	-	-	2061	1927	2015	1191	1114	1276
Pin change time it. 4	-	-	-	-	-	-	1818	2055	1935	1279	1140	989
Pin change time it. 5	-	-	-	-	-	-	2180	2020	2059	1151	1074	995
Train loading time it. 1	4881	5004	4803	6579	5883	6239	7482	6615	6540	5940	5916	6162
Train loading time it. 2	4854	4762	4752	5691	5642	7736	6717	6899	7085	6186	5984	6254
Train loading time it. 3	4808	4936	4961	6234	6573	7207	6942	6992	6828	6039	5758	6226
Train loading time it. 4	4897	4759	4747	6049	5589	7409	6834	7042	6634	6496	6201	5837
Train loading time it. 5	4637	4935	4879	6508	6224	10099	7029	6835	7075	5742	6166	5980

Table 6. Average values of the simulation results

Variant No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Avg. crane distance	1935	1970	1996	5989	5662	9385	2073	2097	2061	2053	2065	2109
Avg. crane working time	4815	4879	4828	6212	5982	7738	4967	4913	4849	4895	4909	4985
Avg. pin change time	0	0	0	0	0	0	2034	1964	1983	1185	1096	1106
Avg. train loading time	4815	4879	4828	6212	5982	7738	7001	6877	6832	6081	6005	6092

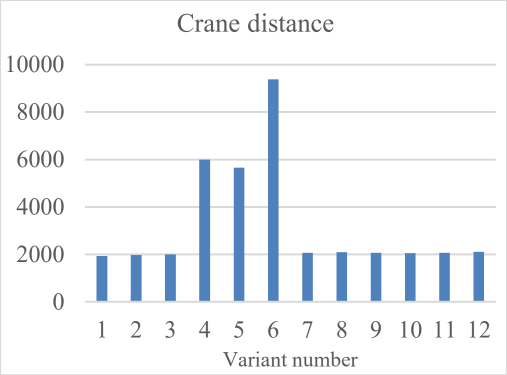

Fig. 3. Distance covered by the crane

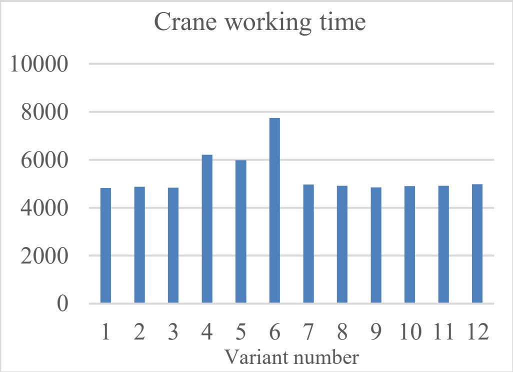

Fig. 4. Crane working time

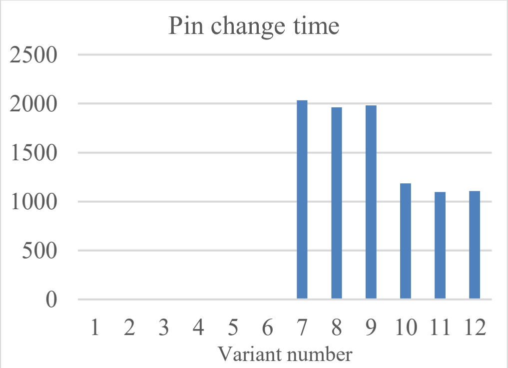

Fig. 5. Pin configuration change time

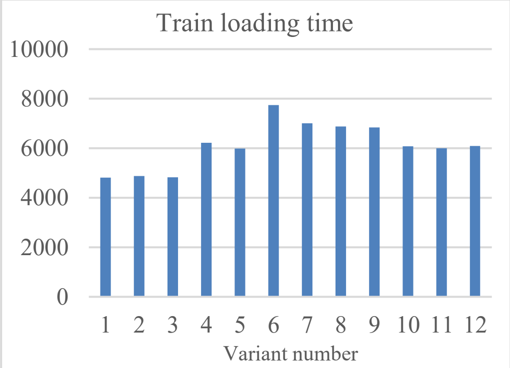

Fig. 6. Total train loading time

5. Summary

The research carried out in the article using a simulation model in the FlexSim environment and their results indicate the need for a structured planning of the intermodal train loading process. The presented characteristics of the crane's operation indicate that the prior knowledge of the pin configuration on container wagons that are to arrive at the intermodal terminal is of great importance for the train loading planning process. The knowledge of this arrangement simulated in variants 1-3 allows the terminal operator to properly prepare the containers for loading onto the train. As shown in particular by the characteristics of the distance traveled by the crane, the knowledge of the pin configuration on the wagons or the change of their configuration just after the arrival of an empty intermodal train allows to reduce the distance covered by the loading device several times. This does not significantly reduce the train loading time. However, taking into account the operation of the gantry and the associated costs, minimizing the distances covered by the gantry can successfully increase the economic efficiency of the transshipment terminal. As a result, it also improves the economic efficiency of the entire intermodal transport process.

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References

[1] AMBROSINO, D., BRAMARDI, A., PUCCIANO, M., SACONE, S., SIRI, S., 2011. *Modeling and solving the train load planning problem in seaport container terminals*. In: 2011 IEEE International Conference on Automation Science and Engineering, (1)1, 208-213. DOI: 10.1109/CASE.2011.6042439.

[2] AMBROSINO, D., SIRI, S., 2014. *Models for train load planning problems in a container terminal.* In: Computer-based Modelling and optimization in transportation, 262, 15-25. DOI: 10.1007/978-3-319-04630-3.

[3] AMBROSINO, D., BERNOCCHI, L., SIRI, S., 2016. *Multi-objective optimization for the train load planning problem with two cranes in seaport terminals.* In: 14th IFAC Symposium on Control in Transportation Systems, 49(3), 383-388. DOI: :10.1016/j.ifacol.2016.07.064.

[4] ANGHINOLFI, D., FOTI, L., MARATEA, M., PAOLUCCI, M., SIRI, S., 2012. *Optimal loading plan for multiple trains in container terminals*. In: Odysseus 2012, 5th International Workshop on Freight Transportation and Logistics, 1-4.

[5] BOYSEN, N. FLIEDNER, M. JAEHN, F., PESCH, E., 2012. *A Survey on Container Processing in Railway Yards. Transportation Science*. Transportation Science, 47(3), 294–454. DOI: 10.1287/trsc.1120.0415.

[6] BOYSEN, N., FLIEDNER, M., 2010. *Determining Crane Areas In intermodal transshpment yards: The yard partion problem*. European Journal of Operational Research, 204(2), 336-342. DOI: 10.1016/j.ejor.2009.10.031.

[7] BRUNS, F., KNUST, S., 2012. *Optimized load planning of trains in intermodal transportation*. OR Spectrum, 34(3), 511–533. DOI: 10.1007/s00291-010-0232-1.

[8] CARIS, A. MACHARIS, C., JANSSENS, G. K., 2008. *Planning Problems in Intermodal Freight Transport: Accomplishments and Prospects.* Transportation Planning and Technology, 31(3), 277-302. DOI: 10.1080/03081060802086397.

[9] CORRY, P., KOZAN, E., 2006. *An assignment model for dynamic load planning of intermodal trains.* Computers Information Research, 33(1), 1-17. DOI: 10.1016/j.cor.2004.05.013.

[10] CORRY, P., KOZAN, E., 2008. *Optimised loading patterns for intermodal trains*. OR Spectrum, 30(1), 721-750. DOI: 10.1007/s00291-007-0112-5.

[11] CRAINIC, T.G. PERBOLI, G., ROSANO, M., 2018. *Simulation of intermodal freight transportation systems: a taxonomy*. European Journal of Operational Research, 270(1), 401-418. DOI: 10.1016/j.ejor.2017.11.061.

[12] DOTOLI, M., EPICOCO, N., 2015. *An improved technique for train load planning at intermodal rail-road terminals.* In: IEEE 20th Conference on Emerging Technologies Factory Automation, 1-4. DOI: 10.1109/ETFA.2015.7301580.

[13] DOTOLIA, M., EPICOCOA, N., FALAGARIOB, M., PALMA, D., TURCHIANO, B., 2013. *A train load planning optimization model for intermodal freight transport terminals: a case study.* In: IEEE International Conference on Systems, Man, and Cybernetics, 3597-3602. DOI: 10.1109/SMC.2013.613.

[14] DUINKERKEN, M.B., OTTJES, J.A., 2000. *A simulation model for automated container terminals.* In: Proceedings of the Business and Industry Simulation Symposium, 10, 134-139.

[15] FROYLAND, G. KOCH, T, MEGOW, N. DUANE, E., WREN, H., 2008. *Operations research at container terminals: a literature update*. OR Spectrum, 30(1), 55–75. DOI: 10.1007/s00291-007-0082-7.

[16] HEGGEN, H. BREAKERS, K., CARIS A., 2018. *Multi-objective approach for intermodal train load planning.* OR Spectrum, 40(2), 341–366. DOI: 10.1007/s00291-017-0503-1.

[17] JACHIMOWSKI, R., SZCZEPAŃSKI, E., KŁODAWSKI, M., MARKOWSKA, K., DĄBROWSKI, J., 2018. *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 CO2 Emissions*. Annual Set The Environment Protection, 20(2), 965-988. ISSN 1506-218X.

[18] JACYNA, M., JACHIMOWSKI, R., SZCZEPAŃSKI, E., IZDEBSKI, M., 2020. *Road vehicle sequencing problem in a railroad intermodal terminal–simulation research*. Bulletin of the Polish Academy of Sciences. Technical Sciences, 68(5), 1135-1148. DOI: 10.24425/bpasts.2020.134643.

[19] JACYNA, M., PYZA, D., JACHIMOWSKI, R., 2017. *Transport intermodalny: projektowanie terminali przeładunkowych*. Wydawnictwo Naukowe PWN. ISBN 978-83-01-19680-6.

[20] JACYNA, M., SEMENOV. I., 2020. *Models of vehicle service system supply under information uncertainty.* Eksploatacja I Niezawodnosc, 22(4), 694-704. DOI: 10.17531/EIN.2020.4.13.

[21] JACYNA, M., WASIAK, M., LEWCZUK, K., KŁODAWSKI, M., 2014. *Simulation model of transport system of Poland as a tool for developing sustainable transport*. Archives of Transport, 31(3), 23-35. DOI: 10.5604/08669546.1146982.

[22] JACYNA-GOŁDA, I., ŻAK, J., GOŁĘBIOWSKI, P., 2014. *Models of traffic flow distribution for various scenarios of the development of proecological transport system*. Archives of transport, 32(4), 17-28. DOI: 10.5604/08669546.1146994.

[23] KLODAWSKI, M., JACHIMOWSKI, R., JACYNA-GOLDA, I., IZDEBSKI, M., 2018. *Simulation analysis of order picking efficiency with congestion situations*. International Journal of Simulation Modelling, 17(3), 431-443. DOI: 10.2507/IJSIMM17(3)438.

[24] KOSTRZEWSKI, A., NADER, M., KOSTRZEWSKI, M., 2018. *Racjonalizacja rozłożenia wybranych jednostek transportu intermodalnego na długości ładunkowej pociągu*. Prace Naukowe Politechniki Warszawskiej. Transport, 120, 201-208.

[25] KUZMICZ, K.A., PESCH, E., 2018. *Approaches to empty container repositioning problems in the context of Eurasian intermodal transportation*. Omega 85, 83(1), 194-213. DOI: 10.1016/j.omega.2018.06.004.

[26] LAI, Y-C., BARKAN, CH.P.L., ÖNAL, H., 2008. *Optimizing the aerodynamic efficiency of intermodal freight trains*. Transportation Research Part E: Logistics and Transportation Review, 44(5), 820-834. DOI: 10.1016/j.tre.2007.05.011.

[27] LEWCZUK, K., 2015. *The concept of genetic programming in organizing internal transport processes*. Archives of Transport, 34(2), 61-74. DOI: 10.5604/08669546.1169213.

[28] LI, C., BURTON, D., KOST, M., SHERIDA, J., THOMPSON M.C., 2017. *Flow topology of a container train wagon subjected to varying local loading configurations*. Journal of Winde Engineering and Industrial Aerodynamics, 169, 12-29. DOI: 10.1016/j.jweia.2017.06.011.

[29] LI, X., OTTO, A., PESCH, E., 2019. *Solving the single crane scheduling problem at rail transshipment yards.* Discrete Applied Mathematics, 264, 134-147. DOI: 10.1016/j.dam.2018.07.021.

[30] MANTOVANI, S., MORGANTI, G., UMANGA, N., CRAINIC, T.G., FREJINGER, E., LARSEN, E., 2017. *The load planning problem for double-stack intermodal trains*. European Journal of Operational Research, 267(1), 107-119. DOI: 10.1016/j.ejor.2017.11.016.

[31] NEHRING, K., JACHIMOWSKI, R., 2020. *Modelling of container train handling in the land intermodal terminal*. In: 9th Carpathian Logistics Congress - Conference Proceedings, 242-249. ISBN 978-80-87294-96-3.

[32] PAP, E., BOJANIC, G., RALEVIC, N., GEORGIJEVIC, M., BOJANIC, V., 2012. *Crane scheduling method for train reloading at inland intermodal container terminal*. In: 2012 IEEE 10th Jubilee International Symposium on Intelligent Systems and Informatic, 189-192. DOI: 10.1109/SISY.2012.6339512.

[33] PN ISO 668-1999 – *Kontenery ładunkowe serii 1 – Klasyfikacja, wymiary i maksymalne masy brutto*.

[34] POWELL, W.B., CARVALHO, T.A., 1998. *Real-Time Optimization of Containers and Flatcars for Intermodal Operations*. Transportation Science, 32(2), 90-203. DOI: 10.1287/trsc.32.2.110.

[35] STAHLBOCK, R., VOß, S., 2008. *Operations research at container terminals: a literature update.* OR Spectrum, 30(1), 1–52. DOI: 10.1007/s00291-007-0100-9.

[36] SZCZEPAŃSKI, E., JACYNA, M., JACHIMOWSKI, R., VAŠEK, R., NEHRING, K., 2021. *Decision support for the intermodal terminal layout designing*. Archives of Civil Engineering, 67(2), 611-630. DOI: 10.24425/ace.2021.137188.

[37] UIC, 2018. *UIC International Union of Railways. 2018 Report on combined transport in Europe. Version 1, Last updated: January 2019*. Paris: UIC International Union of Railways. Available: https://uic.org/IMG/pdf/2018_report_on_combined_transport_in_europe.pdf

[38] VEEKE, H. P., OTTJES, J. A., 1999. *Detailed simulation of the container flows for the IPSI concept.* In: Proceedings of the 11th European Simulation Symposium, 1-4. ISBN 1-56555-177-x.