WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2021.137188

ARCHIVES OF CIVIL ENGINEERING

Vol. LXVII ISSUE 2 2021

s. 611–630

Research paper

Decision support for the intermodal terminal layout designing

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Abstract: The article presents the issue of container handling processes at a rail-road intermodal terminal. In the article, we have focused on the problem of a terminal layout design from the point of view of parking lots for external trucks. The main purpose of this article is the assessment of the necessary parking lots for the trucks considering daily turnover of containers and the trucks appointment time windows. We analyze how the length of the truck's appointment time windows as well as the difficulties in containers loading operations and a number of handling equipment influence the necessary parking lots for trucks in the intermodal terminal. The trucks planned for loading of import containers may arrive at the terminal before the loading moment that is specified in crane operations schedule. The container handling time is given by a probability distribution. The equations defining the most important elements of the considered problem were presented in the general form. The special case of this model has been developed in the FlexSim simulation software. Based on the simulation research and calculations we pointed out that right truck's appointment time windows can significantly reduce necessary parking lots at the yard. The literature analysis presented in the article indicates that most of the research in the field of intermodal terminal is focused on operations in container ports. There is lack of literature considering rail-road terminal layout planning in terms of the necessary parking lots and truck's appointment time windows.

Keywords: intermodal transport, intermodal terminal, containers, parking lot for trucks, trucks appointment time windows

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1. Introduction

Because of the growing threat resulting from the global warming resulting from CO_2 emissions to the atmosphere, international institutions such as the European Commission are increasingly undertaking debates on reducing the negative impact of transport on the environment [47]. One of the effects of this type of debate is the adoption in the EU White Book of provisions according to which by 2050 about 50% of freight transported by road must be transferred to rail transport. According to GUS (Polish Central Statistical Office) data, road transport in Poland in 2018 was used to transport as much as 85% of all loads. Such a large share of the road transport in the total mass of transported loads generates a threat not only to the environment. Other external costs generated by the road transport are also a problem, including noise, accidents or road congestion. The solution to the problem of shifting loads from road to rail transport is to use intermodal transport, which integrates, among others these two types of transport. The idea of intermodal transport has been known for a long time, nevertheless, the development of this type of transport is due to containerization, which began to develop quite quickly in the mid-twentieth century. Currently, the vast majority of cargo (so-called general cargo), especially in international and overseas relations, is transported in containers. This unit, due to its standardized construction, can easily be transported by road and rail, and of course by sea.

Intermodal transport involves the transportation of freight in an intermodal container or a vehicle, using multiple modes of transportation (e.g., rail, ship, truck), without any handling of the freight itself when changing modes. It allows to combine the strengths of various modes of transport and thus achieve a synergy effect in the form of increased transport efficiency and reduction of its external costs. All these features cause that the intermodal transport is an increasingly important part of the logistics sector. The main element of the intermodal transport in the land area is rail transport, predestined for long-distance transport. Unfortunately, rail transport in most cases does not allow supplying the final recipient. That is why this type of transport must be supplemented with road transport in intermodal transport for door-to-door transport. Reloading of an intermodal unit from rail to truck requires appropriate infrastructure. This type of place can be an intermodal terminal or a properly equipped railway siding.

The basic function of the transshipment terminal (intermodal terminal) is to allow the intermodal transport units loading and unloading as well as to change the mode of transport. As reported in [3], such terminals are usually located close to large industrial centers, ensuring the loading services of these areas. According to the definition presented in [23] authors assume that the intermodal terminal is a spatial facility with its proper organization and infrastructure enabling the transshipment of intermodal transport units: containers, swap bodies and semi-trailers between means of transport belonging to the different modes of transport as well as enabling operations to be performed on these units (operations regarding, e.g. storage, loading, unloading, technical service). Terminals can be located on the railway network with access to road infrastructure as well as in seaports and are part of the port. A characteristic type of intermodal terminal is an inland terminal, which have an access to both rail and road transport infrastructure, and in some cases, inland waterway infrastructure. It is located outside the areas with sea access.

The general task of an intermodal terminal is to handle imported and exported containers. After the train arrival at the intermodal terminal, the container rail cars are unloaded. Containers (import containers) are transferred directly to road vehicles (container semitrailers) or to the storage yard. It means that some transshipments are direct (rail car - truck), called as a 'direct moves' and some of them are indirect (rail car – storage yard - truck), called as a 'split moves'. Road transport is then used to transport import containers to the final customers. Container export operations are usually performed after the import operations are completed. These operations involve train loading, which means that road vehicles must deliver loaded containers (export containers) from customers to the terminal [24].

In order to ensure efficient operation on the road vehicles in the terminal and at the same time maximizing the handling equipment working time and minimizing train service time, the terminal should provide an appropriate number of parking spaces for trucks waiting for loading / unloading. The number of the parking lots will depend on the volume of daily terminal turnover (including the number of loading / unloading operations), the number of handling devices used and the strategy of truck appointment. Too few parking lots for trucks in the intermodal terminal will cause delays in the implementation of loading operations and thus will reduce the efficiency of handling equipment. The lack of presence of a road vehicle at the terminal when the crane operator undertakes to service a given container may result in the extended service time, or the abandonment of such service and the transition to the next container service. On the other hand, too many parking lots for road vehicles will be associated with excessive expenditure on the construction of the surface of these parking lots as well as irrational use of the yard.

In connection with the above, the main purpose of the article is to determine the number of parking lots in the terminals depending on the number of handling devices, the volume of daily terminal turnover and the trucks appointment strategy. Trucks appointment strategy includes the necessity of

scheduling container deliveries / arrivals to / from the terminal. The research carried out in this article is a continuation of research on the service of trucks in terminals that are available at work [25].
For the purposes of the research, a literature review was carried out in the area of the intermodal terminal layout design as well as trucks service processes at intermodal terminals. In addition, the equations defining the most important elements of the considered problem were presented in the general form. The simulation model of the analyzed situation based on the real observations was developed and examined in the section 4. The final section covers the conclusion

2. Literature review

Because of the negative influence of road transport on the environment, the intermodal transport has been largely studied in the recent literature. Analysis of this literature allows distinguishing four main areas of research related to intermodal transport [2], [12]: intermodal network design, intermodal terminal layout design, intermodal terminal location, intermodal terminal operations and intermodal transportation routes optimization. According to the information above the functional areas of terminals and the processes implemented in them were considered. Those areas has been described in the latest publications which consider intermodal transport from many perspectives, such as supply chain on an international scale [17]. In this article we focus on the terminal layout design considering road vehicles handling operations performed at intermodal terminals.
Most literature dealing with the intermodal terminals concerns the optimization of container handling processes in the terminals. A detailed review of the literature in this area was made, among others at work [42]. This literature is focused mainly on the area of marine intermodal terminals. In the case of land-based intermodal terminals, literature is not as rich. The literature on operation optimization of rail–road intermodal terminal is relatively scarce. Although rail–road and marine terminals operating with containers, have similar equipment. Only the specific operational procedures and functioning rules are not the same. The main difference is related to quay crane operations in the marine terminal and gantry crane in the inland terminals. Research achievements in container terminals in the marine ports cannot be directly applied in the intermodal rail–road terminals. Less attention than to the container handling processes in the literature is devoted to planning the layout of intermodal terminals. In fact, most of the research in the area of shaping terminal layout comes down to simulation researches. These studies usually have the character of simulation models aimed at solving the problem of forming the layout of a terminal. Part of this research relates not only to the layout but also to the shaping of the intermodal terminal network and container transport between

terminals. When analyzing the current literature on problems related to the functioning of intermodal terminals, one can refer to [23]. Author has analyzed many aspects of terminal functioning and decision making problem connected with its functioning. This problem is also crucial for the issue discussed in this article.

An example of such research is publication [35], where the author analyzed the number and location of necessary intermodal terminals in Korea. In turn, a holistic (i.e. considering many factors) approach to simulation research on the intermodal transport was made in [40]. The authors considered the issue of container transport between terminals as well as their handling at terminals. It was assumed, that train arrivals are defined in a train timetable, while the patterns of truck arrivals for ITU (Intermodal Transport Unit) delivery and pick-up can be either statistically modelled or given as a deterministic input. The presented simulator was able to simulate both a single terminal and a rail network. A similar simulation model was described in [32]. Simulation models presenting processes implemented in a single terminal depending on the transshipment devices used were presented in the elaboration [6]. The layout of the terminal was the input to the simulation model. Simulation tests were carried out for various input data parameters. Some authors has focused directly on the narrow area of analysis e.g. simulation based procedures related to the intermodal terminal functioning [18]. However, this issue requires development and updating.

Extensive work related to shaping the layout of the intermodal terminal was carried out in the other two publications: [4], [5]. Authors tested the micro model for different terminal layouts. The differences between layouts refer to numbers of tracks and cranes. Ideal terminal layouts for a given transshipment volume are determined by calculating the total cost per container. Publications take into account dependencies between processes occurring in the terminal. New intermodal technologies and solutions were considered as well as the already well known. Similar approach to the described above was presented in work [1].

Other literature positions addressed the issue of comparing the use of gantry cranes and reach stackers [33] as well as comparing the use of straddle carriers and automatic yard cranes at the sea terminal. In both cases, the terminal layout was significantly different depending on the handling equipment used.

Despite the fact that many intermodal transport optimization issues has been considered, none of the analyzed literature described the issue of the necessary number of the parking lots for trucks. This issue is crucial for minimizing the dwell time of handling devices waiting for trucks to start container's loading operations. In the terminals, where it is common to carry out direct transshipments in a rail car -truck relationship, the arrival plan for trucks is set up for the arrival / departure plan of the train. In terminals where direct transshipments are rare, this strategy does not apply. In the second case, the time in which trucks should wait for the service at the terminal follows directly from the crane operating schedule.

Crane scheduling is one of the important issues of the intermodal terminal operational planning. Again the majority part of the attention for this issue is devoted in literature to marine intermodal terminals. One of the publications which considers mainly seaports terminals gantry scheduling, but can be also used in the case of land terminals is [38]. The problem of crane scheduling in the rail-road terminals has not been widely considered in the literature so far. In the rail-road terminal this problem becomes more complex and difficult than in other types terminals because cranes operations have to include road vehicles service. Unfortunately, road vehicles may be late for the loading / unloading planned in the crane schedule. This results in the necessity to take up servicing of the next container / intermodal unit on which the road vehicle awaits loading / unloading at the terminal. Therefore, the crane's handling sequence may change over time. In the rail-road terminal this problem was investigated in publication such as [21], [41]. Some similar investigations were made by other authors [46], who has decided to even narrow the area of the study to the use of a specific equipment e.g. RMG (Rail Mounted Gantry) crane. Even some developed mathematical models has been presented for the discussed problem. In [15] authors decided to compile three stage mathematical model, which considered many terminal (e.g. set of hours, set of containers handling) and gantry (e.g. number of movements, number of operations) functioning parameters and variables. Unfortunately, the issue of the parking spaces has not been further analyzed.

Part of the literature on the operation of intermodal terminals by road vehicles concerns the issues of vehicle queuing at the entrance gate and the resulting problems. These problems include long waiting times at the gate and in the internal parking lots of the intermodal terminals, and thus increased emissions of harmful exhaust compounds in these areas and the lack of effective usage of the crane operating time.

The above problems are usually solved using queue theory. The phenomenon of congestion at the entrance gate to the terminal appears every time a larger number of containers are to be delivered to / from the terminal in connection with the arrival / departure of the container train. Outside the rush hour determined by train arrival / departure, the phenomenon of congestion at the entrance gate is kept to a minimum. The scale of this phenomenon depends strongly on the size of the intermodal terminal. By far the largest queues at the entry gate to the terminal occur at sea terminals, where the time of unloading / loading a container ship is a crucial factor for optimizing the operation of the terminal. Therefore, most of the publications in this area focuses on maritime intermodal terminals and minimizing the waiting time of a road vehicle in the queue to enter the terminal. Works [8], [9] can be considered as the ones to describe presented above problem occurring in the terminals. Authors of both publications decided to use genetic algorithms and other specialized tools (including computer analysis) in order to develop the knowledge on the terminal scheduling issues. The trucks managing problem has been also a part of the study. Some authors decided to develop more chosen area focused case study concerning this topic. Perfect example can be [16] which presents the situation of the two chosen ports on the west coast of the United States. In publication [10] an attempt was made to solve the problem of truck scheduling too. This time authors decided to use time-varying tools. Study includes developed theoretical study, mathematical model and computer analysis visible in the results of the study. However, the study continues to focus only on the process of trucks queuing at the gates. Very similar approach is presented in [48]. The minimization of trucks waiting time at the terminal gate was based on the optimization of tucks appointment system as well as the vehicle time windows change. Authors of [16] analyze the possibility of the reduction of the pollution emission coming from trucks waiting at the intermodal terminal gate. They propose the legislation permitting terminals to adopt either gate appointments system or off-peak operating hours as a means of reducing truck queues at gates.

Some of the authors of the cited above publications ([8], [9]) noticed a common problem: long truck queues at gates often limit the efficiency of a container terminal and generate serious air pollution. One of the solution to this problem can be a proposed method called 'vessel dependent time windows (VDTWs)'. Its aim is to control truck arrivals, which involves partitioning truck entries into groups and assigning different time windows to the groups. Part of this issue is also discussed in [10]. A hybrid algorithm using GA and Simulated Annealing are used to solve the optimization problem. In turn, author of [48] developed a model for optimizing a truck appointment system with the objective of decreasing external trucks' waiting times, at the gate and yard, and internal trucks' waiting times at the yard.

Other publications in the area of the length of the queue at the terminal gate minimization went in the direction of planning the shape of the gate area and examining the strategy of queuing trucks at the terminal gate. For example in work [19] authors developed a model to measure costs of congestion at the gates, provided alternatives to improve gate operation and investigated ways to reduce gate congestion at the Port of New York. Trucks waiting costs and the queue length were estimated based on the multi-server queuing model. Work [20] presents similar approach to the problem and its possible solution.

Other publication such as [14] was checking the queuing strategy at the gate. The pooled queue and non-pooled queues were investigated. In order check which strategy is better the agent-based simulation model was developed. With the use of the simulation model, queuing strategies under various operational conditions were analyzed. A tool for gate operations planning including gate layout planning was developed by authors of [37]. Their work enables to determine the average truck queuing time for a given gate configuration or determine how many service gates and queuing lanes are needed in order to achieve a desired level of the service for a given truck arrival rate and truck service rate.

One of the problems observed during the literature analysis of the issue is the fact that there is a deficit of new publications that would take into account new approaches to the issue or modern technologies. Most of the base models and major studies have been presented a few years ago and before. The market is still dynamically growing and researches shall fallow this trend. New approaches to solving logistic problems can be derived indirectly from sources relating to logistics issues other than the functioning of intermodal terminals. Some dependencies are similar to each other and algorithms and models, after appropriate modification, can be efficiently used in the analyzed problem. An example of this is [28], [29]. Both publications focuses on the vehicle assignment to the tasks. Work [28] uses genetic algorithm to solve the assignment problem. Some part of the algorithm logic or presented in the publication mathematical model can be transferred in order to be used during the discussed intermodal transport issue. As the publication concerns production company case some changes need to be made (type of tasks, vehicles or the transport units) but other aspects as the chosen criteria and logic can be used easily. A similar approach, this time using an ant algorithm, was used in [29].

When trying to create a holistic approach to a selected problem, the key is to take into account many factors and the most real representation of the process being carried out. A key factor in the construction of a mathematical model or subsequent simulations is to consider the necessity to make decisions when managing vehicles in the terminal despite the lack of information. Problem of information uncertainty has been widely discussed in [30] where authors described task of vehicles service problems. The elaboration consider mainly supply-chain issues but again, elements of the presented algorithms and approaches can be used indirectly. In addition to the selection of algorithms and the model, the decision method which will consider many factors may also be very important. Among many publications dealing with this issue for different areas of logistics a comprehensive approach to the multi-criteria decisions has been recently presented in [11], [22]. Another work that describes the issue of multi-objective decision making process in terms of logistics tasks is [44].

Despite examining by authors a slightly different issue than the handling of the containers themselves in the terminal, numerous helpful analogies can be found.

The above literature review indicates that most of the research in the field of intermodal terminal layout design focuses on the optimization of a number of handling equipment or rail trucks. More over most of the literature in the field of trucks operations at the terminal gate refer to queue minimization as well as the trucks turn round time. The vast majority of literature has been devoted to the seaport terminals. Literature analysis shows that there is no papers concerning the number of necessary parking lots for road vehicles in terms of handling equipment working time utilization.

3. Problem description

In this paper, we consider the truck intermodal terminal layout designing problem together with truck appointment issue. We focus on the influence of the trucks appointment schedule (also the appointment time windows) on the number of necessary parking lots for trucks at the intermodal terminal yard. Number of necessary parking lots is also determined by the yard crane utilization.

All the containers moved through the terminal can be divided into imported and exported containers. Export containers are sent from the terminal by rail transport. Import containers are delivered to the terminal by rail transport and then transshipped to their destination by road transport (road vehicles usually belonging to road transport carriers). In this paper, we focus on the operations performed on import containers. As road vehicles assigned by consignees arrive to the terminal to pick up specific containers, they might wait for loading / unloading. This delay depends on the truck arrival time and the crane operations efficiency. To make sure that trucks do not wait too long, the booking system for picking up import containers is usually used to collect information in advance. In the literature such booking system is called the ‘truck appointment system’. It means that trucks should arrive at the terminal at a given time window. The time window is supposed to allow the truck to wait for loading / unloading, so the crane efficiency is as high as possible. Usually the crane operator prepared for container loading calls the truck driver and gives him information about the specific place of loading in the truck operations line. Unfortunately, despite the prepared loading plan, which determine the trucks time windows in a trucks appointment schedule, there might occur some irregularities and resulting from the possibility that some trucks are not present at the terminal yard because a lack of space for parking. It is also possible that the crane operations outrun the schedule (e.g. due to some disturbances) and truck appointed at the give time period is simply not there. In order to provide an efficient trucks service, the appropriate number of parking lots is required. On the other hand, too many parking spaces require additional space and expenditure on their construction. The idea of the considered problem is presented in the figure 1.

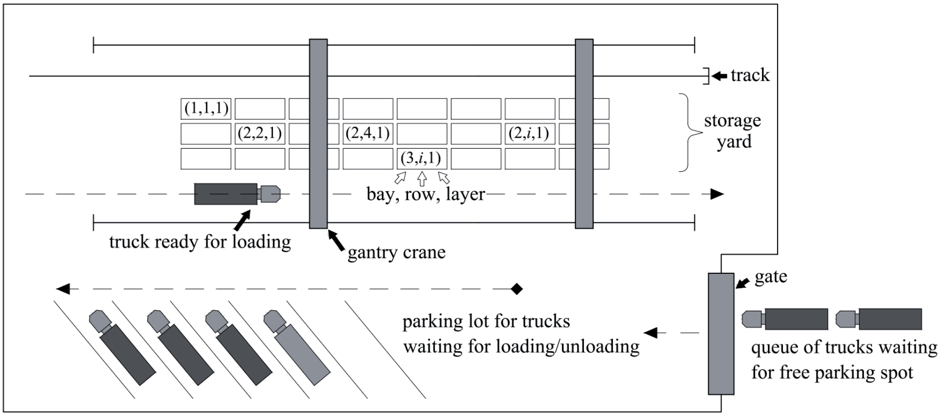

Fig. 1. Rail-road terminal layout considered in the article

The considered problem is primarily characterized by the trucks service time understood as the time period from the truck's arrival at the crane operating area until the final truck departure. This time includes container loading of course. It was assumed that the trucks service time is a random variable described by the beta distribution with the density function as follows:

$$\forall k \in K \quad f(\alpha,\beta,x) = \begin{cases} \dfrac{1}{B(\alpha,\beta)} x^{\alpha-1}(1-x)^{\beta-1} & \mathrm{T1}_k \le x \le \mathrm{T2}_k \\ 0 & x \notin (\mathrm{T1}_k, \mathrm{T2}_k) \end{cases} \tag{3.1}$$

This function specifies the pickup time interval for each container ($k = 1, 2, ..., K$) where the lower and upper limits are defined as $\mathrm{T1}_k$ and $\mathrm{T2}_k$, respectively. Whereas α and β are shape parameters, and B is a beta function. The time value taken by the random variable T described by the beta distribution for a single implementation will be recorded as t_k. It takes a value from the range and can be different for each container. These ranges are conditioned by the container pick up difficulty.
The moment of an arrival of truck s ($s = 1, 2, ... S$) results from its order in the container loading schedule. It was assumed that the truck's arrival time will be determined based on the average truck's service time ($t0$) and the value (ca) determining how much earlier the vehicle should arrive:

$$\forall s \in S \quad ta_s = s \cdot t0 - ca \tag{3.2}$$

The moment of truck's arrival cannot be a negative value, therefore it was assumed that if the moment of arrival of the first truck is 0, then the moment of loading of the first container onto the first truck will be *ca*. The actual moment of the beginning of a *s* truck's service (container *k* loading) is given by the following formula:

$$\forall s \in S \quad th_s = ca + \sum_{k=1}^{s-1} t_k \quad \text{for } s \geq 2 \tag{3.3}$$

The above characteristics allow formulation of the characteristics of interpretation of the maximum number of trucks waiting in the parking lot for service (*CAP*):

$$CAP = \max_{s \in S} \left(\left\lfloor \frac{ca + \sum_{k=1}^{s-1} t_k}{t0} \right\rfloor - s \right) \tag{3.4}$$

The presented equations are the main elements of the model of a situation considered in this article. These elements are necessary to be considered in order to efficiently use the terminal space as well as the handling equipment. The next part of the article presents a specific problem based on a real example in the form of a simulation model in the Flexsim environment.

4. Simulation model

The literature review presented in chapter 2 shows that logistics processes can be very improved and carefully analyzed with the usage of the dedicated simulation tools [31] and advanced algorithms such as genetic algorithms (e.g. see [26], [27], [36]) and neural networks [43]. Another study including logistics processes simulation and complex algorithms usage, is published recently [26]. Despite the fact that not all the studies are strictly focused on the intermodal terminal issues, they prove how important and helpful simulation of the logistics processes can be. As it was mentioned in the part 3. publications [8], [9], which considered intermodal transport terminals, included genetic algorithms too. Helpful clues can be found also in publication such as [28], [29], [34].

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 of the handling equipment assessment. The simulation is used to test optimization methods and algorithms before they are implemented during the intermodal transport units flow management and control systems in the terminal. Simulation models of the selected processes performed in the intermodal terminal were formulated in [13], [45].

Some authors decided to consider even more specified problem of the robotized intermodal terminals [39]. Literature research on this topic (i.e. terminal work scheduling) and its description can be found in publication [7]. Most of the literature regarding simulation research focuses on processes automation in the marine intermodal terminals.

The problem of necessary parking lots for trucks in the intermodal terminal is an important but unfortunately not an easy to solve issue. Difficulties in the parking lot layout planning arise from the disturbances in handling equipment operations duration determining the vehicles arrival moments at the intermodal terminal. Well-designed and planned time windows for trucks arrival seems to be a solution to such a problem. Unfortunately, it is hard to estimate the time windows length. Too wide time windows for trucks arriving at the terminal, cause that many trucks arrive in the same time, which may cause a lack of parking space for trucks waiting for the loading process. Too short time windows may cause long cranes idle time.

The idea of the parking lot layout planning is to minimize the cost associated with necessary parking lots for trucks. In theory, based on the list of intermodal transport units meant to be delivered to the final customers it is possible to plan the road vehicles loading in such a way, that the intermodal transport units loading sequence is based on the distance between them in the storage yard. Such an approach to road vehicles loading is possible assuming that the road vehicles are waiting in the terminal and can be called for loading any moment. In such a case the handling device distance is easy to be minimized. If the road vehicle is not ready for loading (did not reach the terminal or there is no parking lot for the truck), the handling device operator must proceed to the next unit (i+1). After all the crane must also perform unscheduled move to load the container on the late truck.

In the article for the given number of containers that must be loaded on road vehicle we examined different variants of truck appointment time windows in order to determine the parking lot layout (necessary parking lots for tucks). The variants also included a different number of cranes operating at the terminal, as well as different time of operations depending on the difficulty in container's loading.

Based on that we specified 3 variants regarding number of cranes operating in the terminal at the same time. The following variants of cranes included:

- Variant 1 – 1 crane;
- Variant 2 – 2 cranes;
- Variant 3 – 3 cranes.

Moreover we consider 3 variants of truck appointment time windows. The following variants of time windows for trucks appointment included:

- Variant 1 – truck arrive at the moment of loading planned in the crane operations (loading) schedule;
- Variant 2 – truck arrive 20 minutes before the moment of loading planned in the crane operations (loading) schedule;
- Variant 3 – truck arrive 60 minutes before the moment of loading planned in the crane operations (loading) schedule.

In order to model the different location of the container as well as the difficulties connected with containers pick up and lie down, we assumed, the loading time will differ depending on 3 categories of difficulty. These categories include:

- Category 0 – there is no difficulty in container loading. The loading time varies from 90 to 240 seconds and is given by Beta probability distribution. The same is with other categories;
- Category 1 – loading time varies from 90 to 240 seconds;
- Category 2 – loading time varies from 240 to 480 seconds;
- Category 3 – loading time varies from 240 to 960 seconds.

Moreover it was assumed that 60% of all containers has a difficulty category 1. 35% of all containers has a difficulty category 2. The rest of containers (15%) has a difficulty category 3. In our study we consider either there is a difficulty or no.

Based on the above variants (3 variants of cranes, 3 variants of truck appointment time windows and 3 variant of container loading difficulty) we achieved a compilation of 18 possible research variants. These variants are presented in the table 1.

With the usage of FlexSim simulation software the maximum and the average number of trucks waiting for loading were calculated. The maximum and average trucks waiting time were calculated as well. Statistics regarding the maximum number of trucks waiting for loading are understood as the necessary number of parking lots for trucks. For the purpose of a research additional assumption were made:

- ISO 1A, containers are handled;
- There are 720 containers have to be loaded on trucks;
- The loading operation duration depend on the difficulty of containers pick up and lie down. This time is given by the Beta probability distribution;
- The loading moment of a given truck is a result of the loading schedule calculated based on the loading time duration (including difficulty in variants V10-V18). It means that in case of two

cranes operating, more containers will be loaded in a given time period on trucks than in the case with a single crane. This give us more necessary parking lots in variants with 2 or 3 cranes that in the variants with a single crane.

Table 1. Simulation variants

Variant		V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
Cranes number variant	1 crane	1	1	1	1	1	1	1	1	1	1
	2 cranes	0	1	1	0	1	1	0	1	1	0
	3 cranes	0	0	1	0	0	1	0	0	1	0
Appointment time window	At the moment in schedule	1	1	1	0	0	0	0	0	0	1
	20 minutes before schedule	0	0	0	1	1	1	0	0	0	0
	60 minutes before schedule	0	0	0	0	0	0	1	1	1	0
Difficulty	0-no difficulty; 1 - difficulty	0	0	0	0	0	0	0	0	0	1
Variant		V10	V11	V12	V13	V14	V15	V16	V17	V18	V10
Cranes number variant	1 crane	1	1	1	1	1	1	1	1	1	1
	2 cranes	1	1	0	1	1	0	1	1	1	0
	3 cranes	0	1	0	0	1	0	0	1	1	0
Appointment time window	At the moment in schedule	1	1	0	0	0	0	0	0	0	1
	20 minutes before schedule	0	0	1	1	1	0	0	0	0	0
	60 minutes before schedule	0	0	0	0	0	1	1	1	1	0
Difficulty	0-no difficulty; 1 - difficulty	1	1	1	1	1	1	1	1	0	1

A fragment of the analyzed FlexSim simulation model is presented in the figure 3. The simulation model was run 15 times (there were 15 replications for the given sample).

Fig. 2. Part of the Flexsim simulation model

As a result of simulation research, the following figures presents:

— Maximum number of trucks waiting for loading (figure 3);

— Maximum stay time of trucks waiting for loading (figure 4).

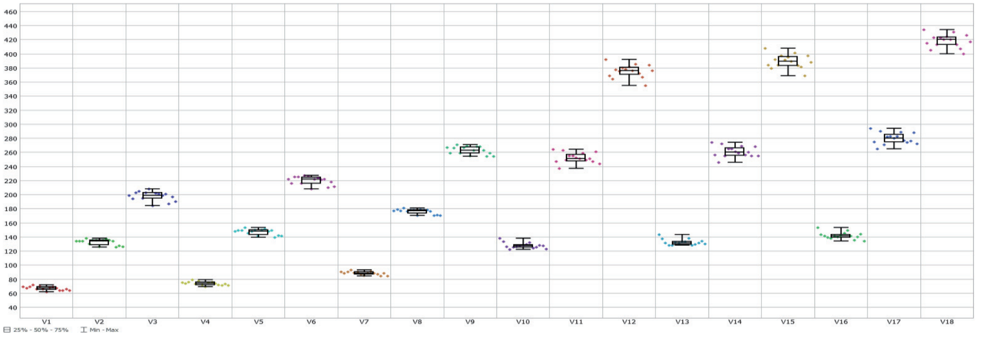

Fig. 3. Maximum number of trucks waiting for loading in variants V1-V18

Table 2. Simulation results for maximum number of trucks waiting for loading in variants V1-V18

	V1	V2	V3	V4	V5	V6	V7	V8	V9
min	62.0	125.0	184.0	69.0	139.0	208.0	84.0	170.0	254.0
max	72.0	138.0	208.0	79.0	153.0	227.0	93.0	181.0	271.0
	V10	V11	V12	V13	V14	V15	V16	V17	V18
min	122.0	237.0	355.0	128.0	246.0	369.0	134.0	265.0	400.0
max	138.0	264.0	392.0	143.0	274.0	408.0	153.0	294.0	434.0

The results presented in the figure 3 and the table 2 show the necessary number of the parking lots for tucks that arrived at the intermodal terminal and wait for loading. As it is shown in the figure 3 and presented in the table 3 depending on the number of the simulation model replication, the necessary number of parking lots for trucks in a given variant varied. The differences between results within a given variant were caused by the Beta probability distribution of the loading difficulty.

The comparison of the obtained above results must be analyzed from the point of view of number of cranes as well as the loading operation difficulty. It means that it is reasonable to compare variants containing either one or two or three cranes. Variants containing the given number of cranes can be investigated based on the truck's appointment time windows and the loading operations difficulty. As it was mentioned before, the variants with 2 or 3 cranes will need more parking lots than in the variant with one crane.

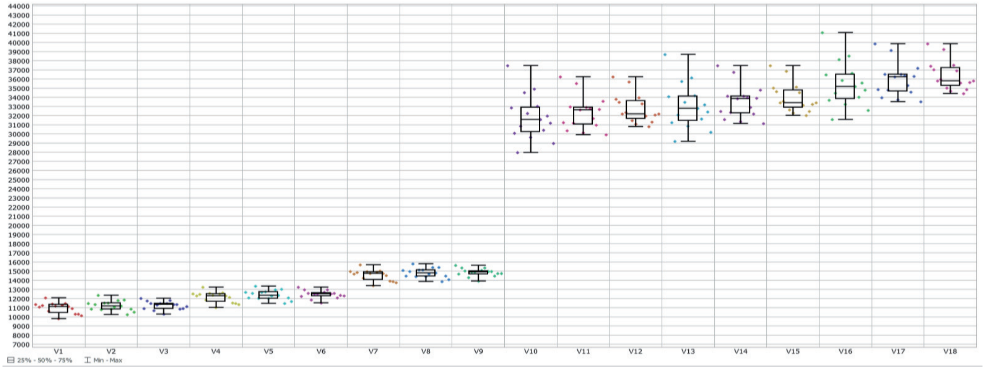

Fig. 4. Maximum stay time of trucks waiting for loading in variants V1-V18

The number of variants with the single crane and no loading difficulty are V1, V4, V7. The number of variants with the single crane and the loading difficulty are V10, V13, V16. Variants V1, V4, V7 differ from each other by the length of the time windows. The same is with variants V10, V13, V16. The necessary number of parking lots in the variant 1 are 72, where the trucks arrived at the terminal just at the loading moment from the schedule. In the case of truck arrival at the moment from schedule, the large number of a necessary parking lots results from the different loading time duration. The necessary parking lots in the variants V4 and V7 are: 79 and 93. In the variant V4 trucks arrived 20 minutes before schedule. In the variant V7 it was 60 minutes before schedule. These results show, that the 20 minutes of truck appointment time window is a better option than 60 minutes time window. Indeed, the smallest number of necessary parking lots was calculated in the variant V1, but if we take into account possible crane dwell time, the variant V4 seems to be a better solution. Similar comparison can be made for the rest of the variants.

The analysis of the trucks stay time at the parking lot shows that the biggest influent on that has the difficulty in container loading operation. Variants V1-V9, where the loading duration was from 90 to 240 seconds, have much lower trucks waiting time than variants V10-V18 where the loading duration was changing from 90 to 960 seconds. Time in the variants ranges vary depending on the given container operation difficulty. The number of the necessary parking lots for trucks in variants V10-V18 was much bigger than in variants V1-V9.

5. Conclusions

The aim of the research conducted in this paper was to indicate the necessary number of the parking lots for trucks at the inland rail - road intermodal terminal yard taking into account several factors. The analysis of the impact of trucks appointment time windows length on the necessary parking lots at the yard of the intermodal terminal was carried out. The study was extended by number of handling devices operating with containers as well as the possible difficulty in containers loading operations.
The analysis of characteristics presented in the figure 3 and the figure 4 shows that the length of the trucks appointment time windows has a significant influence of the number of necessary parking lots at the intermodal terminal yard. The time windows for trucks arriving to the terminal examined in the paper indicate, that too wide time windows (e.g. such as 60 minutes and more) may cause unnecessary trucks waiting time and the necessity to provide a right number of parking lots for these trucks. This is associated with the need of allocating a larger area for this car park. As the result costs growth can be observed (connected with the expenditure on its construction and maintenance).
Based on the simulation research, the hypothesis can be formulated: too wide time windows of trucks appointment can increase the intermodal terminal costs. Alternatively, too short time windows of trucks appointment can increase handling equipment waiting time because of the truck's absence at the terminal parking lot. Spatial constraints may also be the key factor.
Further research will include verification of the hypothesis for various variants of trucks service and handling equipment operations strategies. However, based on the preformed simulation research, it should be stated that during the work planning of the intermodal terminal, it is important to include the possibility of some irregularity occurrence and to schedule vehicles for loading properly.

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Wspomaganie decyzji w projektowaniu infrastruktury terminala intermodalnego

Słowa kluczowe: transport intermodalny, terminal intermodalny, kontenery, parking dla pojazdów ciężarowych, okna czasowe awizacji pojazdów ciężarowych

Streszczenie:

W artykule przedstawiono zagadnienie procesów obsługi kontenerów w kolejowo-drogowym terminalu intermodalnym. W artykule skupiono się na problemie projektowania układu terminali z punktu widzenia niezbędnych parkingów dla pojazdów ciężarowych dowożących/odwożących kontenery do/z terminala. Głównym celem artykułu jest wyznaczenie niezbędnej liczby miejsc parkingowych dla ciężarówek, biorąc pod uwagę dzienny obrót kontenerów, a także okna czasowe awizacji pojazdów ciężarowych. Analizowano, w jaki sposób szerokość okien czasowych awizacji pojazdów ciężarowych a także trudności w operacjach załadunku kontenerów i liczba urządzeń przeładunkowych wpłyną na niezbędną liczbę miejsc parkingowych dla pojazdów ciężarowych na placu terminala intermodalnego. Założono, że ciężarówki planowane do załadunku kontenerów importowych mogą przybyć do terminalu przed momentem załadunku określonym w harmonogramie pracy suwnicy. Założono również, że czas przeładunku kontenera wynika z rozkładu prawdopodobieństwa. Równania definiujące najważniejsze elementy rozważanego problemu zostały przedstawione w formie ogólnej. Badane problem zamodelowano w narzędziu symulacyjnym FlexSim. Na podstawie badań symulacyjnych i przedstawionych obliczeń wskazano, że właściwe ustalenie okien czasowych awizacji pojazdów ciężarowych może znacznie zmniejszyć liczbę potrzebnych miejsc parkingowych na terminalu. Analiza literatury przedstawiona w artykule wskazuje, że większość badań w obszarze terminali intermodalnych koncentruje się na optymalizacji operacji w portach kontenerowych. Brakuje literatury na temat układu terminali intermodalnych z punktu widzenia liczby niezbędnych miejsc parkingowych dla pojazdów ciężarowych.

Received: 15.01.2021, Revised: 04.02.2021