MODELLING OF CONTAINER TRAIN HANDLING IN THE LAND INTERMODAL TERMINAL

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Abstract

The purpose of this study is to present an issue of a container train handling in the land intermodal terminal. The two main processes performed during the train handling are considered and analyzed. First one is train unloading. Second process is train loading. All the important factors affecting handling time and cost efficiency are featured. Its influence is described and justified. An article is opened by an introduction and the literature review. Crucial factors for choosing a research area are presented. Second part of the study presents intro to a future modelling process. Problem is formulated and assumptions are made. The main purpose of this study part is to create substructure and assumptions for mathematical model that will be a result of the study. This study results shall enable planned survey in the field of intermodal train handling. Multi-criteria mathematical model developed for an analyzed issue include chosen important factors such as container mounting pin configuration, empty wagons number minimization and others. Listed factors and other are occurring while train handling and got an impact on the whole process realization. The study is ended by conclusion to the considered intermodal train handling subprocess.

Keywords: Intermodal transport, container train, process modelling, intermodal terminal, logistics

1. INTRODUCTION

Nowadays more and more attention is given to the intermodal transport. There are a few factors which determinates this occurrence. One of them is intermodal transport possibilities. With well-organized transport system it is possible to deliver goods more efficiently and faster. Especially thanks to combined transport using train at the main road and trucks on the initial and final shorter route section distances (allowing for door-to-door transport). Intermodal transport allows to handle large amount of cargo in shorter time [1,10]. It enables to reduce needed handling work amount. Some service operations are limited (less repacking, document handling, moving small transport units). Only one transport unit is used during the transport process [9]. This type of transportation is very effective in terms of the middle and long transport distances. This type of transport is perfectly fitted to the European roads network and other conditions (average transport distance, land size, countries layout). Goods delivered to the sea transshipment point can be easily forwarded to the trains and trucks. Further operations can be carried out in the land intermodal transshipment points. In the last time transport ecological aspect has been considered [1,10]. Intermodal transport leads to carbon dioxide emission reduction. It has less impact on the environment and allows to reduce road traffic. The average road infrastructure exploitation period can be overlong [1,10]. Besides, there are a lot of other benefits (the whole transport process time reduction, better cost efficiency or development of the new technologies. The European Union emphasizes the importance of intermodal transport for over fifty years. Thanks to this approach intermodal transport is still developing. It is proved in rapports and statistics. A combined rail-road and rail-rail intermodal transport seems to have a huge potential [1,10]. Despite many benefits still not all optimization areas have been widely considered and presented in the scientific elaborations. Especially in case of land container and ITUs (Intermodal Transport Unit) transshipment terminal (**Figure 1**).

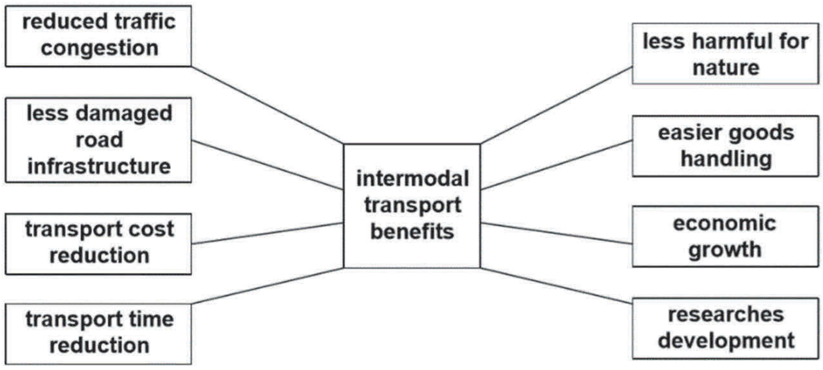
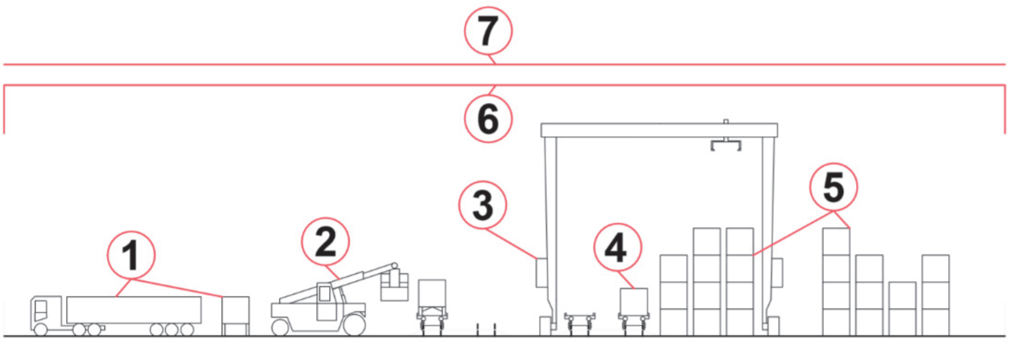


Figure 1 Intermodal and combine transport usage benefits [1,9,10]

Also, some mathematical models have been formulated [2]. Many models are based on assumptions and restrictions such as considering only limited number of types of ITU (e.g. only three ITU size types) or limiting other parameters range (pin configurations, stacking possibilities and others) [2,7,17]. It allows to consider factors that have not been discussed yet. Still there is lack of holistic approach which would consider more factors [2]. Example possible optimization areas in the intermodal land yard are presented in the **Figure 2**. To each area many factors can be assigned and considered in the further researches.



1	Trucks and trailers management (e.g. parking places assignment and movement)
2	Intermodal means of transport (e.g. reach stacker working algorithm, working areas approach)
3	Gantry management and scheduling (e.g. working place assignment, priorities, queuing))
4	Train layout forming (e.g. loading and unloading, length and weight restrictions, aerodynamic)
5	Intermodal units storing (e.g. storage places choice, units movement, stocking restrictions)
6	Terminal layout (e.g. needed rails length, storage field capacity)
7	Whole terminal work scheduling (where, how and when the process needs to be made?)

Figure 2 Chosen optimization areas in the intermodal rail-road land terminal [1,9,10]

In this study attention is focused on the rail-road land terminal functioning as it has been diagnosed that not enough studies have been developed in this area. Holistic approach is needed. In order to obtain more usable results study concerns only the specific functional area of intermodal terminal. It allows to consider more crucial factors for the chosen task execution. Authors' aim is to maximize possible results apply and to make them reliable. One of the main factors while choosing the area of research was diagnosed problem at the market. Researchers have studied Polish intermodal transport market. It can be diagnosed that intermodal transport in Poland is still underestimated [1,10,15,16]. Intermodal transport in Poland is developing and researches need to be done in order achieve progress. Especially combined transport can be beneficial. It can help to reduce pollution and congestion. It can be crucial for the train market restructuration [1,10]. The authors' intention is improving processes by the applying results of the study.

Further a brief literature review is presented and the optimization problem is formulated. Crucial information and the intro to mathematical model is presented in chapter 3. and 4. In this study mathematical model is also included (5. General mathematical problem formulation). The article is ended with a summary.

2. LITERATURE REVIEW AND EXISTING APPROACHES

There are researches made on land intermodal terminal. Mathematical models have been formulated. In order to narrow the research area, the focus is set on one problem: intermodal train handling in the rail-road land yard. Literature is analyzed so as to indicate what has already been described in the research area.

Many useful information can be found in the literature researches made on the intermodal transport. Study that has focused on the discussed factors is the one made by BOYSEN, FLIENDER, JAEHN and PESCH [2]. Authors has compiled detailed intermodal market and literature research. In their research the lack of holistic approach is highlighted. The survey shows that there were studies made e.g. on the aerodynamic efficiency. Other researches mentioned in the study considered more aspects of train formation and handling. Still many of factors need to be included in holistic model in order to build complex survey on the intermodal train handling. Presumptions for the intermodal train handling are also presented and described.

Another literature study has been made by STAHLBOCK and VOß [13]. Authors say that study is meant to present intermodal transport condition and perspectives. Authors find intermodal transport market as a fast-developing branch of economy. The study is comprehensive: it considers many more land intermodal yard functioning areas then only train processes. Even if it does not focus strictly on the train handling some useful materials and information can be found in them. Often new approaches, technologies or models can be found. STAHLBOCK and VOß [13] presented functional areas such as container handling equipment, human resources, assisting systems or optimization methods. To each area possible optimization methods are added. It has also given overall look at the possible optimization methods (also to the train handling).

Another wide literature research has been presented by CARIS, MACHARIS and JANSSENS [4]. Their article has been analyzed similarly to the previously described researches [2,13]. 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.

One of the studies focusing on the considered problem is the one made by BRUNS and KNUST [2]. In their article they focused on load planning trains. The authors' aim was to indicate best practices. 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 below (**Table 1**). 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 similarly.

Table 1 Factors included in BRUNs and KNUST research [2]

Nr.	Factor/ assumption	Nr.	Factor/ assumption
1	place of train handling	5	intermodal load units' number
2	number of handling wagons	6	intermodal load units' types
3	type of wagon	7	storage area
4	train weight limit	8	ITUs main types

Another approach has been presented by CORRY and COZAN [5]. The focus of research also has been devoted to the ITUs flow between road and rail transport. It is emphasized how many factors influence processes in a terminal logistic system. In this study, main factors concerning are: types of equipment, terminal layout, storage capacity. Operating strategies are included in the analytical model. Authors claim that the aim of presented model is to deal with the uncertainty existing in the other studies. This mathematical model assigns ‘1’ to a container if it is matched to a wagon slot in a specific time or ‘0’ if not. Every container mass is identified. However, this mathematical model does not include pin configuration or aerodynamical aspect. Still this approach cannot be described as ‘the holistic’ one.

POWELL and CARVALHO [11] is more specialistic one than the others presented. The study takes into account only intermodal flatcars. Their study again indicates equipment used in the terminal and operating rules as the crucial factors. The presented math model is dynamic. The authors’ aim is to help intermodal operators to improve their performance. This model concerns many ITUs possible layouts on the intermodal wagon: double stacking, mixing trailers and containers on wagon or placing many units on wagon. Wagons parameters (length, capacity and number of axes) can also vary. The model tries to adjust train loading plan to the task. Operation movements are concerned too. This model can be useful, but it is still not holistic. It varies from two models presented previously as it focusses on a dynamic units’ assignment and queuing.

Research made in 2018 by HEGGEN, BREAKERS and CARIS [8] considers multi-objective approach for the intermodal train planning. The aim of this research is to utilize the train loading space, capacity, length and weight and handling load units. Intermodal work scheduling is also included. Model is static and multi-objective. Study leads to establishment of the most suitable work schedule. Analyzed parameters are presented below in **Table 2**. This study is based on analyzed before BRUNS and KNUST [2] research. It differs from BRUNS and KNUST’s approach as the main factor is not the fixation type but the unit size. Five main containers lengths are taken into account. In order to guarantee wagon stability, right weight distribution is considered (recommended is axle/center boogie/rear axle weight distribudtion 25 %/50 %/25 %).

Table 2 Factors included in HEGGEN, BREAKERS and CARIS research [8]

Nr.	Factor/ assumption	Nr.	Factor/ assumption
1	intermodal units’ types	6	units’ weight
2	wagon types	7	units’ dimensions
3	number of wagons	8	wagon tare weight
4	wagon capacity	9	payload for the wagon boogie
5	weight restrictions	10	distance between wagon boogies and center load

LAI, BARKAN and ÖNAL [14] carried out studies on the narrowed topic range. Their study concerns aerodynamical aspects of forming intermodal train. The argumentation of this study is supported by achieving energy savings, fuel efficiency and cost reduction thanks to smart train layout planning. Study uses integer-programing in order to support terminal operators. Similarly, to CORRY and COZAN’s [5] mathematical approach, this model assigns values ‘1’ or ‘0’ depending on the considered unit and wagon state. Aerodynamic force has a huge influence especially in the high-speed trains). A dense unit layout on the intermodal train can lower the aerodynamic force. The model’s aim is to reduce the unneeded empty spaces between ITUs. It is a guaranty of better stability of the train.

FROYLAND, KOCH, MEGOW, DUENE and WREN’S [7] research can be useful too. 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.

More theoretical approach has been presented by CRAINIC, PERBOLI and ROSANO [6]. 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 analyzed in order to expand knowledge on the intermodal transport functioning and it can have an indirect influence the survey [2,4,13].

The factor that hinders the study is the lack of current researches made on the intermodal fleet condition. The 2018 report states that the last wide research in this area has been made over nine years ago in 2009 [17]. Due to this fact it is hard to estimate which kinds of intermodal wagons are in current usage.

3. PROBLEM DESCRIPTION

Many factors have an impact on the efficiency of the container train handling process in the land terminal. Chosen process is only one among many other intermodal processes. In order to build a useful and well fitted model attention needs to be drawn only on the narrowly chosen subprocess. A model considering many processes could be too much expanded. There is a risk of skipping important factors. Whole train, trucks and intermodal units handling optimization can be achieved by modelling and experimenting in the specific work area. There is also a possibility that this optimization algorithm will be more effective.

While analyzing the intermodal yards functioning important evidences have appeared. They leaded to the final choice of the train handling process as the modelling one. The first factor was the geographical research area (Europe, Poland). This region's potential as a market for an intermodal transport is still not used. It also leads to obtaining benefits. Rail-road intermodal land yards are a main part of point infrastructure. It allows to accomplish handling and ITUs flow. It is a buffering place too. Intermodal is a possibility to reduce road congestion. It is estimated that intermodal freight volume in Poland is only 4 %. Road transport dominates. In 2018 about 74 % cargo has been moved by the road transport. In the intermodal transport mainly standard containers are used. In 2018 over 96 % of handled ITUs were containers [15]. Only 1,5 % of handling ITUs were truck intermodal trailers and swap bodies [9,15]. In 2017 in Poland 239,9mln tons has been transported with the usage of the intermodal transport. In 2018 it already was 250mln tons (5 % more). It is a proof that this market is still growing [16].

The authors decided to focus on the train handling. This decision was made mainly due to the information presented in the literature. Lack of holistic approach and the easiness to indicate factors occurring while ITUs moving on and from the railway [2]. Improving this process seems to be possible. The construction of the proper model has been chosen as a task. The main factors can be for example an intermodal train aerodynamic, pin configuration, train optimal length, reduction of empty wagons and others. The factors influence handling time, work effort etc. The research area still seems to be unexplored [2].

The train handling process can have a huge impact on the intermodal terminal functioning. Not optimized handling strategy leads to an occurrence of negative phenomena (e.g. delays). Finding an answer for the question 'when to change pin configuration?' seems to be vital. The key factor is the precise train load plan. Other included factor should be an aerodynamical aspect [2,14]. Another factor is also connected with a train mass and capacity. Intermodal trains schedules are developed much earlier than the real train load and movement process. The intermodal train operator needs to register planned train parameters. The transport cost calculation and fees are based on this information. Moving empty wagons is not economical. Empty spaces occurring in the intermodal train layout sometimes can be caused by some independent factors (e.g. road delays). Despite this, well organized load plan and arrivals schedule leads to minimization of empty spaces. Empty course number reduction savings can be achieved. Another aspect is the possible ITUs layouts [2,3]. In order to sum up this section all handling aspects and factors are presented below (**Figure 3**).

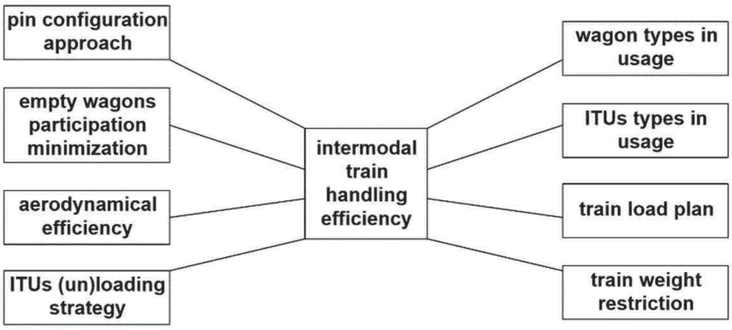


Figure 3 Considered in the study factors occurring while train handling in the rail-road yard [2,3]

In the next paragraph (4. General problem formulation) a brief 'summing up' problem formulation is presented. It includes the most important aspects of the analyzed task.

4. GENERAL PROBLEM FORMULATION

Using information from the previously presented data final problem can be defined. First step in the mathematical model creation can be done i.e. assumptions, restrictions formulation, varieties definition and systematization of markings. Model scientific description is planned to be done in the future research. research in the planned scientific project will also cover experimenting and optimization processes. The researchers target is to elaborate holistic intermodal train handling approach. In order to achieve this, multicriteria analysis is required. In such an approach all possible criteria can be considered with the differentiation of chosen factors importance for the process realization and efficiency. Multicriteria model is universal, gives many possibilities of analysis and allows to expand survey. According to the analyzed data in the next section (5. General mathematical problem formulation) example of mathematical model is formulated. It takes into account only one factor but presents logic of problem solving.

5. GENERAL MATHEMATICAL PROBLEM FORMULATION

In this part of the article the general mathematical model is presented. Presented below mathematical analysis focusses on the one factor i.e. intermodal container dimensions. Number of chosen criteria has been limited to only one factor as this is only example model. It allows to present logic of procedure possible to understand at the same time. The data necessary for the optimization task are as follows:

$\boldsymbol{I} = \{1, \ldots, i, \ldots, I\}$ - set of containers,
$\boldsymbol{J} = \{1, \ldots, j, \ldots, J\}$ - set of rail cars (wagons),
d_{ij} - distance between container i and rail car j,
l_i - i-th container length,
L_j - j-th rail car length,
q_i - i-th container mass,
Q_j - j-th rail car total mass,

Decision variables have an interpretation of the wagon's container allocation:

$$\mathbf{X} = [x_{ij}] \quad x_{ij} = \begin{cases} 1, \text{when container } i \text{ is allocated to rail car } j \\ 0, \text{in other case} \end{cases}$$

The criterion function (1) has the interpretation of minimizing the distance covered by the crane during train loading process:

$$\mathrm{F}(\mathbf{X}) = \sum_{i \in \boldsymbol{I}} \sum_{j \in \boldsymbol{J}} x_{ij} \, d_{ij} \longrightarrow min \qquad (1)$$

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

- Every container can be allocated to at most one rail car (wagon):

$$\forall i \in \boldsymbol{I} \quad \sum_{j \in \boldsymbol{J}} x_{ij} \leq 1 \tag{2}$$

- Total length of containers on the given rail car cannot excide the rail car length:

$$\forall j \in \boldsymbol{J} \quad \sum_{i \in \boldsymbol{I}} x_{ij}\, l_i \leq L_j \tag{3}$$

- Total mass of containers on the given rail car cannot excide the rail car maximum allowed mass:

$$\forall j \in \boldsymbol{J} \quad \sum_{i \in \boldsymbol{I}} x_{ij}\, q_i \leq Q_j \tag{4}$$

- Decision variables can have binary values:

$$\forall i \in \boldsymbol{I} \quad \forall j \in \boldsymbol{J} \quad x_{ij} = \{0,1\} \tag{5}$$

The model is an introduction to the further research. Variable x_{ij} specifies if container *i* can be allocated to rail car *j*. The aim of the optimization is to minimize the distance covered by the crane working in the terminal.

6. SUMMARY SECTION

Intermodal transport is a developing economy sector. This type of transport brings benefits such as generating less environmental pressure, reducing a traffic congestion, handling huge amount of goods etc. It has been diagnosed that this geographical region combined transport potential is not used. In order to obtain optimized intermodal terminal functioning optimization in narrowed areas needs to be done. Authors decided to focus on the intermodal train handling process. There is lack of the holistic approach.

Some reliable studies have been made in the research area. In order to find information about the specified optimization area three types of articles and survey can be useful. First of them is literature review. Information about studies made can be found in those sources. Second type of source are the articles and surveys that include mathematical models. They are especially precious because of the mathematical approaches presented in them Last type of helpful sources are all descriptive articles: reports etc.

Authors' main conclusion is that holistic approach is still needed in the chosen area. Some information needs to be update and more factors needs to be considered while constructing model. Mentioned factors are among the others: train aerodynamic, unit types and parameters, wagons types and parameters, fixation pins configuration, train layout, empty slots minimization, train weight etc.

This article is an introduction survey to the next more advanced one which will include holistic model. Presented mathematical model example reduces number of considered factors. Purpose of this assumption is to present logic of thinking in a simple way. Presented model considers only units dimensions aspect. In this study only preliminary assumptions and restrictions have been formulated. Possible parameters range and variables have been specified. This information will be fully used in practice at the next stage.

Formulated problem, assumptions made and described factors will be used in the future. Main general study task is to build model that would present a holistic approach to the train handling process. Versatile model can influence functioning of the considered functional terminal area. Main problem is the fact that considered problem is complexed. A lot of aspects need to be included. However, researchers will do their best to formulate complex model. It is believed that final surveys results will be helpful and will find practical usage.

REFERENCES

[1] BARTCZAK, K. Analiza barier rozwoju transportu intermodalnego w Polsce. *Autobusy*. 2016. vol. 4/2016, pp. 120-126.

[2] BOYSEN, N. FLIEDNER, M. JAEHN, F. and PESCH, E. A Survey on Container Processing in Railway Yards. *Transportation Science* [online]. 2012. vol. 47, iss. 3, pp. 294-454 [viewed 2019-10-01]. Available from: https://pubsonline.informs.org/doi/abs/10.1287/trsc.1120.0415;

[3] BRUNS, F. and KNUST, S. Optimized load planning of trains in intermodal transportation. *OR Spectrum* [online]. 2012. vol. 34, iss. 3, pp. 511-533 [viewed 2019-11-01]. Available from: https://doi.org/10.1007/s00291-010-0232-1.

[4] CARIS, A. MACHARIS, C. and JANSSENS, G. K. Planning Problems in Intermodal Freight Transport: Accomplishments and Prospects. *Transportation Planning and Technology* [online]. 2008. vol. 31, iss. 3, pp 277-302 [viewed 2019-11-13]. Available from: https://doi.org/10.1080/03081060802086397.

[5] CORRY, P. and KOZAN, E. An assignment model for dynamic load planning of intermodal trains. *Computers & Information Research* [online]. 2006. vol. 33, iss. 1, pp. 1-17 [viewed 2019-11-03]. Available from: https://doi.org/10.1016/j.cor.2004.05.013.

[6] CRAINIC, T.G. PERBOLI, G. and ROSANO, M. Simulation of intermodal freight transportation systems: a taxonomy. *European Journal of Operational Research* [online] 2018. vol. 270, iss. 1, pp. 401-418 [viewed 2019-10-09]. Available from: https://doi.org/10.1016/j.ejor.2017.11.061.

[7] FROYLAND, G. KOCH, T, MEGOW, N. DUANE, E. and WREN, H. Operations research at container terminals: a literature update. OR Spectrum [online]. 2008. vol. 30, iss. 1, pp. 55-75 [viewed 2019-11-17]. Available from: https://doi.org/10.1007/s00291-007-0082-7.

[8] HEGGEN, H. BREAKERS, K. and CARIS A. Multi-objective approach for intermodal train load planning. *OR Spectrum* [online]. 2018, vol. 40, iss. 2, pp. 341-366 [viewed 2019-10-19]. Available from: https://doi.org/10.1007/s00291-017-0503-1.

[9] JACYNA, M. PYZA, D. and JACHIMOWSKI, R. *Transport intermodalny: Projektowanie terminali przeładunkowych.* 1st ed. Warsaw: Wydawnictwo Naukowe PWN SA, 2017. p. 281

[10] KOZERSKA, M. Transport intermodalny w Polsce- szanse i bariery rozwoju. *Logistyka*. 2014. vol. 3/2014, pp. 3200-3205.

[11] POWELL, W.B. and CARVALHO, T.A. Real-Time Optimization of Containers and Flatcars for Intermodal Operations. *Transportation Science* [online]. 1998. vol. 32, iss. 2, pp. 90-203 [viewed 2019-10-23]. Available from: https://doi.org/10.1287/trsc.32.2.110.

[12] PYZA, D. and PIĄTEK, M. Wybrane aspekty projektowania terminali intermodalnych. *Prace naukowe Politechniki Warszawskiej*. 2017. vol. 119, pp. 389-399.

[13] STAHLBOCK, R. and VOß, S. Operations research at container terminals: a literature update. *OR Spectrum* [online]. 2008. vol. 30, iss. 1, pp. 1-52 [viewed 2019-11-01]. Available from: https://doi.org/10.1007/s00291-007-0100-9.

[14] YUNG-CHENG, L. BARKAN, CH.P.L. and ÖNAL, H. Optimizing the aerodynamic efficiency of intermodal freight trains. *Transportation Research Part E: Logistics and Transportation Review* [online]. 2008, vol. 44, iss. 5, pp. 820-834 [viewed 2019-10-29]. Available from: https://doi.org/10.1016/j.tre.2007.05.011.

[15] URZĄD TRANSPORTU KOLEJOWEGO. *Przewozy intermodalne w 2018r* [online]. Version 1, Last updated: June 2019. Warszawa: UTK. 1 p. [viewed 2019-10-26]. Available from: utk.gov.pl/pl/raporty-i-analizy/analizy-i-monitoring/statystyka-przewozow-to/dane-archiwalne/14817, Przewozy-intermodalne-w-2018-r.html.

[16] URZĄD STATYSTYCZNY W SZCZECINIE. *Transport- wyniki działalności w 2017 r.* [online]. Version 1, Last updated: September 2018. Szczecin: US w Szczecinie. 59 p. [viewed 2019-11-01]. Available from: stat.gov.pl/files/gfx/portalinformacyjny/pl/defaultaktualnosci/5511/9/17/1/transport_wyniki_dzialalnosci_w_2017.pdf.

[17] UIC International Union of Railways. *2018 Report on combined transport in Europe* [online]. Version 1, Last updated: January 2019. Paris: UIC International Union of Railways. 68 p. [viewed 2019-11-03] Available from: https://uic.org/IMG/pdf/2018_report_on_combined_transport_in_europe.pdf