ARCHIVES OF TRANSPORT
Volume 41, Issue 1, 2017

ISSN (print): *0866-9546*
e-ISSN (online): *2300-8830*
DOI: *10.5604/01.3001.0009.7388*

TECHNOLOGICAL CONDITIONS OF INTERMODAL TRANSHIPMENT TERMINALS IN POLAND

Mirosław Nader[1], Arkadiusz Kostrzewski[2], Mariusz Kostrzewski[3]
[1,2,3] Warsaw University of Technology, Faculty of Transport, Warsaw, Poland
[1]e-mail: mna@wt.pw.edu.pl
[2]e-mail: a.kostrzewski@poczta.fm
[3]e-mail: markos@wt.pw.edu.pl

Abstract: *The following paper introduces comparison and evaluation of two intermodal transport technologies. The first of them is "rolling motorway" technology, better known as "Rollende Landstrasse" or "Ro–La", while the second one is called pocket wagons technology. We present general characteristics of chosen intermodal freight transport technologies in a form of a brief description of both intermodal technologies. Moreover, we describe initial processes, loading and operations in the case of the two mentioned technologies. The paper contains as well as computing example and the schemes of intermodal freight transhipments terminals for "rolling motorway" and pocket wagons technologies and inevitably means of transport to be used in the technologies. The chosen wagon types taken into consideration are as it follows. In case of "Rollende Landstrasse" technology we chose wagon types of 602S, Saadkkms and Saadkms and in case of the second technology the chosen types of wagons are: Sdggmrss, Sdgnss and Sdgmnss. Different kind of wagons in mentioned technologies are pictured and briefly described. Additionally, freight wagons – potentially used in the mentioned technologies – are evaluated with use of selected methods applicable in evaluation of alternatives. Wagons are evaluated under the specified conditions, especially with taking into consideration chosen operational parameters of them. In conclusion we relate to current condition of internal transhipment terminals in Poland and other aspects that concern them.*

Key words: *intermodal transport, intermodal transhipment terminal, "rolling motorway" system, Rollende Landstrasse, intermodal pocket wagons system.*

1. Introduction

Intermodal freight transport "*is the concept of utilizing two or more 'suitable' modes, in combination, to form an integrated transport chain aimed at achieving operationally efficient and cost–effective delivery of goods in an environmentally sustainable manner from their point of origin to their final destination. (...) a number of different transport modes, such as road, rail or inland waterway or either short– or deep–sea shipping, thus making them multimodal operations, in the majority of instances efficient movements are invariably achieved by the use of just two modes: most commonly road haulage collection and final delivery journeys combined with a rail–freight trunk–haul journey, what is known as a 'combined road–rail' operation*", Lowe (2005).

Intermodal Polish transport market of freight transport is limited almost entirely to the transport of containers. In 2011, transport of containers amounted to 97% of all intermodal transport while swap bodies constituted just over 2% of all intermodal transport, Central Statistical Office (2012). In 2012, within railway intermodal transport, there were carried by 32.5% containers (loaded and empty) more than in 2011, while above 73% of this transport was realised in international transport. The number of carried swap bodies was 13% less than last year, Central Statistical Office (2013). In 2013, within railway intermodal transport, there were carried by 7% containers (loaded and empty) more than in 2012, while above 73% – the same as a year ago – of this transport was realised in international transport. The number of carried swap bodies was 68.2% less than last year, Central Statistical Office (2014). Other units of intermodal transport, such as semi–trailers and road trains, constitute less than one per cent, each year. Nevertheless, this does not mean that no technology to transport these last two loading units exists. The strong competition between road transport and rail transport is an important barrier. Road transport users do not bear all the real costs of usage the road network infrastructure and negative effects on the environment and surroundings. Another barrier is inadequate administrative and financial support of the Polish Government, which seems to be uninterested in serious changes in the researched matters, Stokłosa (2011), Zielaskiewicz (2010). This is a strange way of thinking, especially that intermodal choice means less harmful emissions (primarily greenhouse gas emissions), less energy consumption, less traffic on the road. Reduced costs over road trucking is the key benefit for intercontinental use, as well as reduced. The results of the paper can be used as a decision support for government officials in the configuration of their specific transport policies as well as for logistics service providers to adjust their technology investment decisions based on the anticipated user demand in different situations.

The main aim and purpose of this paper is to present two intermodal transport technologies that can be applied in the present infrastructural and technological logistics facilities: intermodal terminals in Poland. The mentioned technologies are:

- rolling motorway" technology also known as "*Ro – La*", which is short name of German "*Rollende Landstrasse*" (sometimes "rolling highway", "*Rollende Autobahn*"),
- pocket wagons" technology.

Transport of semi–trailers, using pocket wagons, occurs on a small scale in Poland. In 2011 only 64 semi–trailers were transported using mentioned technology. We can say those were "accidental" cases. In the '90s of the previous century, the "rolling motorway" technology from Rzepin to Poznan was attempted to be run. However, due to the lack of interest this kind of transport was suspended, Zielaskiewicz (2010).

In the paper, some of the main design parameters are identified. These are length and utilisation of transhipment tracks, train and truck arrival behaviour, type and number of transhipment equipment, international transhipment terminal access procedures etc.

The culmination of the aim mentioned in the paper is evaluation of chosen freight wagons used in intermodal transport, especially in intermodal transhipment terminals. The research method used in the paper is comparative research, which is one of the scientific methods, next to method of induction and method of deduction. Herein, comparative analysis is given for two technologies that can be potentially used in intermodal transport in Poland.

2. General characteristics of chosen intermodal freight transport technologies

2.1. General description

One of the challenges with the semi–trailers and road trains transport in intermodal transport technologies is that the loading gauge must be maintained. The height of a rail vehicle along with an intermodal transport unit transported on a rail vehicle must not exceed 4.65 meters. The width of a unit loaded on a rail vehicle must not exceed 2.55 meters (in case of a refrigerator car it must not exceed 2.6 meters), whereas the length of a tractor–trailer train must not exceed 18.85 [m], Kwaśniowski et al. (2008).

A typical intermodal rail–road transhipment terminal includes elements, such as, :

- *"rail sidings for train/wagon storage, marshalling and inspection purposes,*
- *transhipment tracks (also termed loading tracks) for the train loading/unloading operations,*
- *storage or buffer lanes for ITUs* (Intermodal Transport Unit – added by the paper's authors),
- *loading and driving lanes for the trucks,*
- *gates, internal road network,"* Ballis and Golias (2002).

This is the main information before proceeding to characteristics of technologies. Finally, let us consider technologies themselves.

2.2. Rollende Landstrasse technology

Road trains transport in the "*Rollende Landstrasse*" technology is taking place on a specialised low–loader platform wagons. Transhipment of a load unit is realised in horizontal position, using its own power engine. This allows to realise loading and unloading of load units without any usage of loading equipment, also under railway electric traction. "*Ro – La*" technology belongs to the group of associated systems. This means a semi–trailer and a tractor are transported on a platform wagon together. This enables the onward journey of a unit load (here: a semi–trailer's tractor together with a semi–trailer) after unloading wagons composition.

Low–loader platform wagons are mounted on multiple axis bogie with a complex structure. Diameters of wheel, depending on the type of a wagon, are from 360 to 450 [mm]. It is reduced in relation to the nominal value, which is 920 [mm] for freight wagons. This also involves a reduced allowable axle load, which is from 75 to 97.5 [kN] (it depends on wagon type). Therefore, due to the need of transport a 40–tons truck combination on platform wagon, more axles must be used (a minimum quantity of axels is eight). The reduced wheel's diameter makes it necessary to reduce velocity limit of a railway vehicle, especially when junctions and railway curves are overcome. Obviously, it is associated with increased probability of derailment. Lowering a wagon floor causes limitations connected to wheelset bearings and brake discs as well. In addition, it is necessary to carry out brakes on side frames of a wagon, because lowered floor of a vehicle does not allow the inclusion of a braking system under a floor. The mentioned factors entail insufficiency of life–cycles of a wheel, an axle bearing and a brake discs are not sufficient taking into account normalised freight wagons repair cycles. The need of frequent wheelset's parts replacement results in higher operating costs.

Examples of low–loader platform "*Ro – La*" wagons are shown in figures 1. – 3. Meanwhile table 1. specifies the basic parameters of wagons used in the "*Rollende Landstrasse*" technology, Kwaśniowski et al. (2008), Stokłosa (2011), Zielaskiewicz (2010).

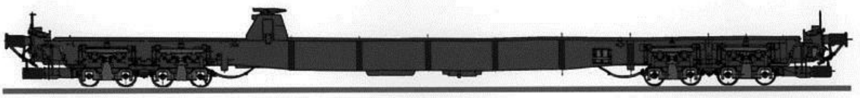


Fig. 1. Low–loader platform "Ro – La" wagon, series 602S
Sources: http://archiwum.wiz.pl/images/duze/1997/11/97112307.JPG (access: March 7th, 2015).

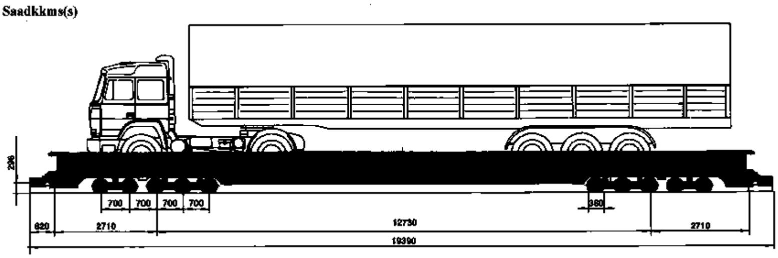


Figure 2. Low–loader platform "Ro – La" wagon, series Saadkkms
Sources: Kwaśniowski et al. (2008), http://spz.logout.cz/gif6/vagon.jpg (access: August, 12th 2013).

Table 1. Specification of basic parameters of platform wagons used in "Rollende Landstrasse" technology

Technical data	**Unit**	**Wagon type**		
		602S	**Saadkkms**	**Saadkms**
Railway vehicle gauge	[–]	UIC 505 – 1		
Total length	[mm]	20 400	19 390	19 390
Length of the cargo area	[mm]	18 260	18 890	18 600
The height of the cargo area above rail head	[mm]	600	480	450
Tare weight of wagon	[kg]	20 400	21 000	17 150
Wagon capacity	[t]	48	54	42
Allowable axle load	[t/axle]	9.75	7.5	7.5
Wheel diameter	[mm]	450	380	360
Quantity of axles	[–]	8	10	8
Maximum permissible speed	[km/h]	100	120	100

Source: own work based on Zielaskiewicz (2010), http://www.ekk–wagon.pl/ (access: June 1st, 2013) UIC 505 – 3, http://www.fuvarozas–szallitmanyozas.com/szallitas/vasuti+kontener+tipus (access: March 7th, 2015).

2.3. Pocket wagons technology

Semi–trailers transport in the “pocket wagon” technology is taking place on a specialised wagons fitted with so–called “cargo pocket”. “Cargo pocket” is used to place there an axle of load unit. Transhipment of a semi–trailer is realised in the vertical position, which requires the use of loading equipment such as a gantry crane (a bridge crane, an overhead cranes) or a knuckle boom crane trucks. Loading equipment must be equipped with a pincer clutch end to take a load unit. Due to the vertical form of transhipment, it cannot be realised under railway electric traction. A semi–trailer must have adequate structural strengthening, especially at joints with a pincer clutch end. In Poland, according to various sources, about 5–7% of semi–trailers have adequate structural strengthening.

Equipping a wagon with “cargo pocket” allows using the nominal diameter of rolling wheels, which means that a diameter is 920 [mm]. The maximum permissible axle load is 22.5 [t/axle]. Pocket wagons, depending on the type, have from 4 to 6 axles. Parts of a brake system are located under the vehicle body. Let us present examples of pocket wagons. A pocket wagon of series Sdgnss is shown in figure 4. A pocket wagon of series Sdggmrss is shown in figure 5. A pocket wagon of series Sdgmnss 434S is shown in figure 6., whereas table 2. specifies the basic parameters of wagons used in the “pocket wagon” technology, Kwaśniowski et al. (2008), Stokłosa (2011), Zielaskiewicz (2010).

Table 2. Specification of basic parameters of wagons used in “pocket wagon” technology

Technical data	***Unit***	**Wagon type**		
		Sdggmrss	**Sdgnss**	**Sdgmnss**
Railway vehicle gauge	[–]	UIC 505 – 1		
Total length	[mm]	34 200 34 030*	19 740 4–axled: 19 480** 6–axled: 34 030**	18 340
Length of the cargo area	[mm]	2 x 16 230 10 710 + 11 985*	14 200 4–axled: 14 750** 6–axled: 2 x 14 200**	16 300
The height of the cargo area above rail head	[mm]	270	272 4–axled: 270** 6–axled: 270**	255
Tare weight of wagon	[t]	34,8 35*	– 4–axled: 23.8** 6–axled: 38.0**	21,3
Wagon capacity	[t]	100	– 4–axled: 66.2** 6–axled: 97.0**	59
Allowable axle load	[t/axle]	22,5	22,5	22,5
Wheel diameter	[mm]	920	920	920
Quantity of axles	[–]	6	4/4**/6**	4
Maximum permissible speed	[km/h]	100 120*	100 4–axled: 120** 6–axled: 120**	100

*Source: own work based on Zielaskiewicz (2010), http://www.ekk–wagon.pl/ (access: June 1st, 2013), Lowe (2005), UIC 505 – 3 and *http://www.astrarail.com/products/intermodal–wagons/sdggmrss–twin/ (access: March 7th, 2015), **https://www.yumpu.com/no/document/view/11887682/sdgnss–swingable–megatrailer–pocket–wagon–kockumsindustrierse (access: March 7th, 2015).*

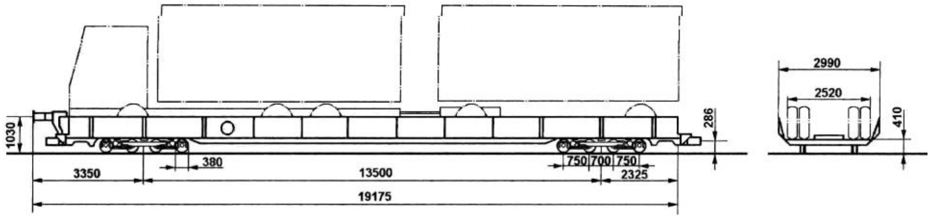
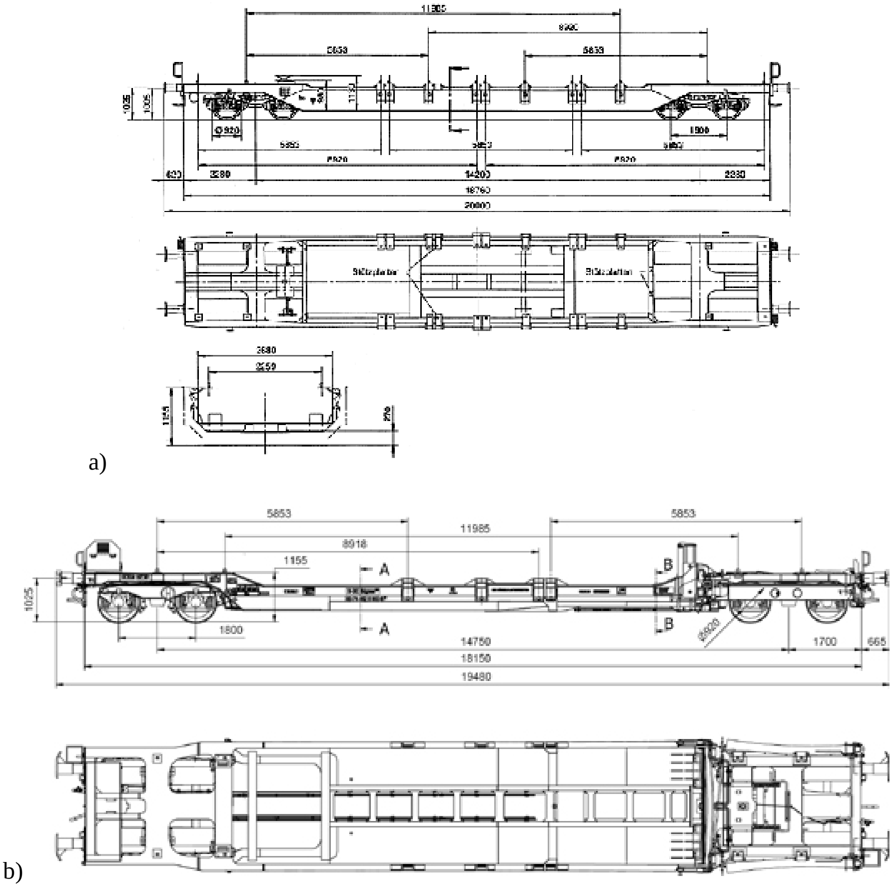


Fig. 3. Low–loader platform “Ro – La” wagon, series Saadkms
Source: http://trainz.uv.ro/draw/vagm/images/saadkms.jpg (access: August 12th, 2013), www.fuvarozas–szallitmanyozas.com/content/vasuti_kontener/saadkms_498_20.jpg (access: March 7th, 2015).



a)

b)

Fig. 4. Pocket wagon, series Sdgnss a) four axles, b) four axles
Source: a) http://www.intermodale24–rail.net/speciali/IMMAGINI/T4–T5/Sdgnss–T4–2_Zeichnung_kl.gif (access: August 12th, 2013), b) https://www.yumpu.com/no/document/view/11887682/sdgnss–swingable–megatrailer–pocket–wagon–kockumsindustrierse (access: March 7th, 2015).

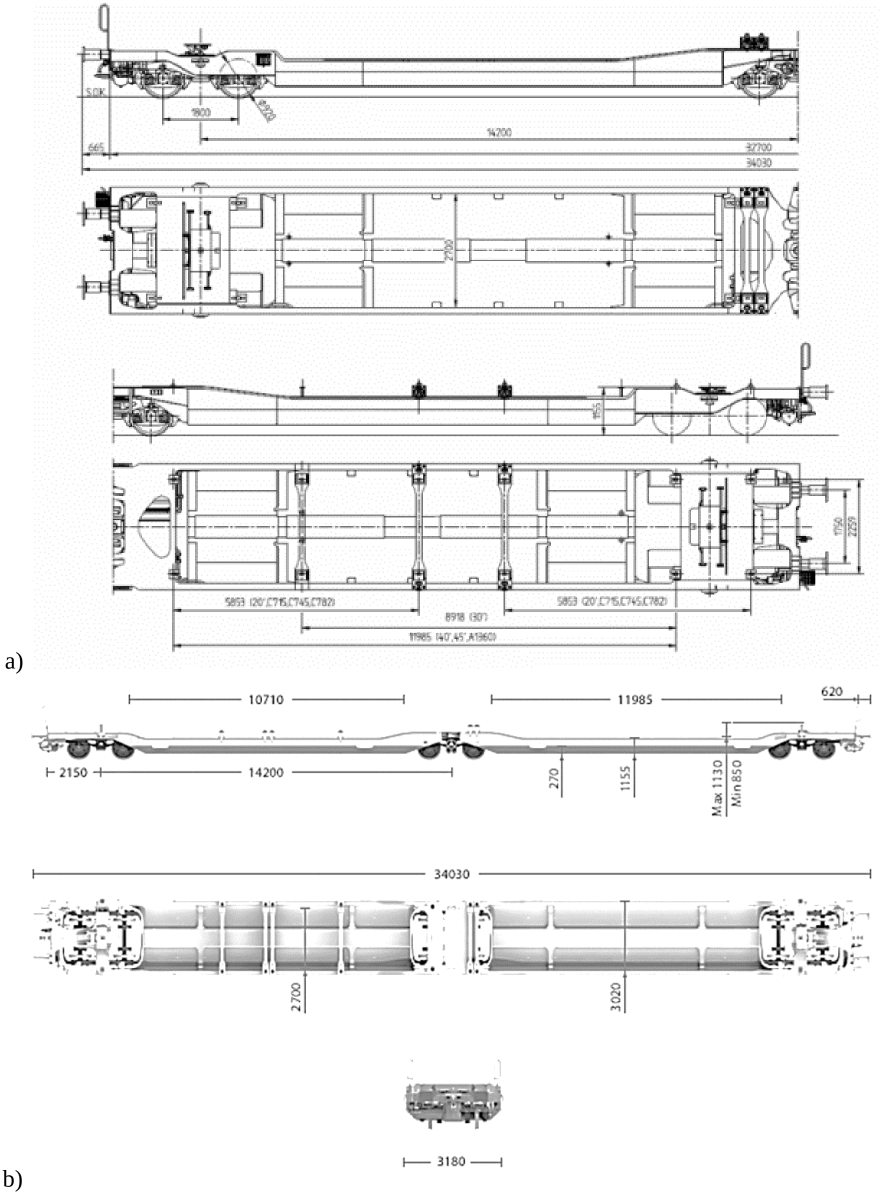


Fig. 5. Pocket wagon, series Sdggmrss

Source: a) *http://www.greencargo.com/Global/Godsvagnshandboken/Oppna_vagnar/S/Sdggmrss%20mega-trailer%20blid3.gif (access: August 12th, 2013), b) http://www.astrarail.com/products/intermodal–wagons/sdggmrss–twin/ (access: March 7th, 2015).*

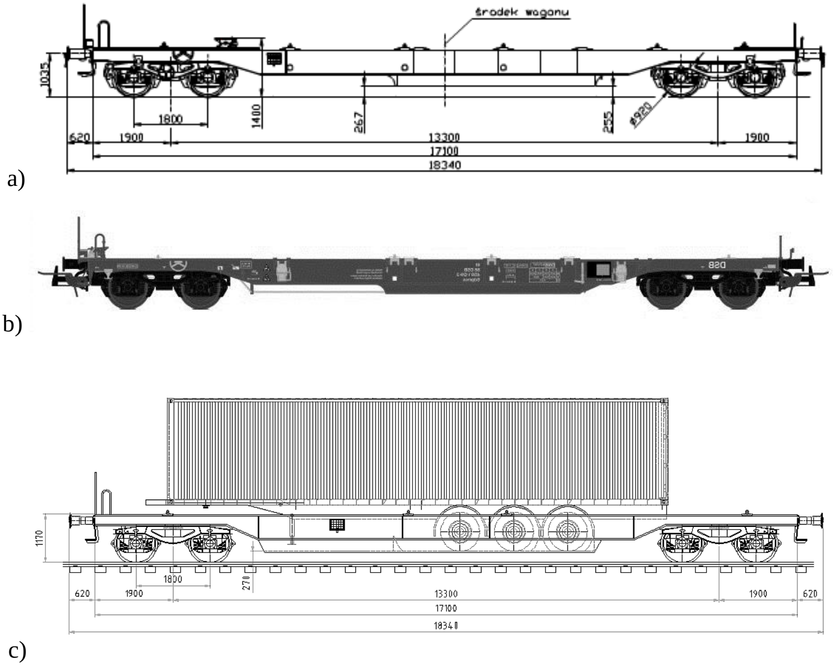


Fig. 6. Pocket wagon, series Sdgmnss

Source: a) http://www.gniewczyna.pl (on–line access: June 1st, 2013), b) www.danskmodel.dk/NYT%20-i%20forretningerne/2010/HT–Sdgmnss–big.jpg (access: August 12th, 2013), c) http://de.academic.ru-/pictures/dewiki/83/Sdgmns743_sketch.png (access: August 12th, 2013).

3. Loading process of intermodal transport units

In this section we present activities associated with a process of intermodal transport units loading on a wagon. The process is considered to last from the moment of a load unit entry into an intermodal transhipment terminal to the moment of a train departing from a terminal.

Preparatory activities for semi–trailers and tractor–trailer loading on specialised railway wagons

Each of semi–trailers and tractor–trailers must be subjected to administrative and measurement control before realising of the loading process. The control consists of:

1) The registration of an intermodal transport unit and validating documents.
2) Checking the permissible total weight and basic technical condition of an intermodal transport unit. In case of a negative result an intermodal transport unit ought to be returned.
3) Making the measurement of technical parameters in terms of the permitted loading gauge. If any doubt exists, an intermodal transport unit goes to a loading gauge control gate.
4) Admission of a semi–trailer or a tractor–trailer into transporting as a subject of "rolling motorway" or "pocket wagon" technology.
5) Preparation of rail forwarding transport documentation known as: a shipping list, a packing list, a waybill, a packing slip (also known as a bill of parcel, an unpacking note, a packaging slip, a delivery docket, a delivery list, a manifest or a customer receipt) based on such as *UIRR* (International Union of combined Road–

Rail transport companies) list, the *TIR* (Transport International Routier) carnets etc.

6) A driver receives an adequate documentation, which instructs him about time of loading, loading place (a wagon number, which is loaded with an intermodal transport unit is indicated to a driver by a terminal's employee on a terminal front).
7) Placement of the intermodal terminal unit to a loading front to wait for loading onto a railway wagon.

After intermodal transport units are loaded, a proper terminal employee stamps a shipping list. If there are no objections concerning condition of freight or transport process, the intermodal transport unit can leave the intermodal transhipment terminal.

The description of the process of releasing semi–trailers and tractor–trailers for loading on specialised railway wagon was based on actual service process, which are realised on the terminal in Wels, Austria, according to Stokłosa (2011), Zielaskiewicz (2010).

Tractor–trailers loading process in case of a low–loader platform wagon in Rollende Landstrasse technology

Loading activities in case of "*Rollende Landstrasse*" technology are realised according to the FIFO strategy. This means that the first of a tractor–trailer sets that was first loaded on a train, is also unloaded in the first place. As far as implementation of loading activities in case of "*Ro – La*" technology is concerned, only straight loading rail track and a direct loading ramp are necessary/required. Loading on low–loader platform wagons is realised according to a few points, as follows:

1) Parking a solid moulded composition consisting of low–loader platform wagons on a loading track.
2) Removing a headstock of the last low–loader platform wagons and providing a direct loading ramp.
3) Driving the first tractor–trailer on a railway wagon, driving through along unloaded wagons until the desired position in a cargo area of a specialised wagon located just behind the sleeper (suitable for drivers and transport operators employees).
4) Driving the next tractor–trailer on a railway wagon in a sequence designated by the employee in terminal gate, occupying a designated position of successive wagons.
5) Securing loading units (carried by a driver) with skids to lock the rear wheels by blocking minimum two wheels on both sides of the tractor–trailer, in order to immobilise it while the train departs and moves.
6) Driver going to a sleeper wagon.
7) Validating by an auditor that tractor–trailers are loaded correctly.
8) Disconnecting a direct loading ramp, closing headstocks.
9) Accessing a locomotive with a sleeper wagon to a composition consisting of low–loader platform wagons on loading track, making engagement and basic brake tests and technical inspection of railway wagons. After loading of the wagon and necessary inspections and brake tests, the train is ready to depart.

The process of unloading runs in reverse. After disconnecting and departing of a locomotive with a sleeper wagon, intermodal transport units leave the train. In order to achieve the implementation of unloading activities, "*Ro–La*" technology needs only straight loading rail track, Kwaśniowski et al. (2008), Stokłosa (2011), Zielaskiewicz (2010).

The minimum length of a loading track for a composition consisting of 20 wagons of 602S type, was calculated by using the formula (1), according to Towpik (2009), Zelaskiewicz (2010).

$$L_{Ro-La} = (n_w \cdot l_w) + l_l + l_s + l_p \tag{1}$$

where:

L_{Ro-La} – length of a loading track in a loading front in case of low–loader platform wagons for "*Ro – La*" technology, [m],
n_w – quantity of a low–loader platform wagons, [–],
l_w – length of a low–loader platform wagon, [m],
l_l – length of an electric locomotive (for above calculations an electric locomotive class ET22 was assumed, [m],
l_s – length of a sleeper wagon (type 134Ab), [m],
l_p – safety protection length (10 – 15 [m]), [m].

Basing on formula (1), we assume the minimum loading track length in case of a train consisting of 20 wagons of 602S type is 470 [m]:

$$L_{Ro-La} = (20 \cdot 20.40m) + 19.24m + 26,40m + 15.00m = $$
$$= 468.64m \cong 470.00m$$

Semi–trailers loading process in case of a pocket wagon

Loading process of semi–trailers on pocket wagons is realised as follows:

1) Parking a solid moulded composition consisting of pocket wagons on a loading track.
2) Placement of a tractor–trailer to the place designated by a terminal employee on the loading front.
3) Disconnecting the tractor and the semi–trailer by the driver.
4) Approaching a gantry crane (a bridge cranes, an overhead cranes) or a knuckle boom crane trucks, locating a pincer clutch end under a semi–trailer and taking up a semi–trailer.
5) Moving (transporting) a pincer clutch with the load unit and leaving the semi–trailer in a loading area of a pocket wagon.
6) Raising a pincer clutch and returning to the starting position for the purpose of loading another semi–trailer on the pocket wagon.
7) Securing loading units carried by a terminal employee.
8) Accessing a locomotive to a composition consisting of pocket wagons on the loading track, making engagement and basic brake tests and technical inspection of railway wagons.

The minimum length of a loading track for a composition consisting of 20 wagons of type 434S series Sdgmnss, was calculated by using the formula (2), Towpik (2009), Zelaskiewicz (2010).

$$L_{pock} = \left(n_w \cdot l_w\right) + l_l + l_p \qquad (2)$$

where:

L_{pock} – length of a loading track in a loading front in case of pocket wagons technology, [m],
n_w – quantity of a low–loader platform wagons, [–],
l_w – length of a low–loader platform wagon, [m],
l_l – length of a shunting locomotive (for above calculations a shunting locomotive class SM42 was assumed, [m],
l_p – safety protection length (10 – 15 [m]), [m].

Basing on formula (2), we assume the minimum loading track length in case of a train consisting of 20 wagons of type 434S series Sdgmnss is 400 [m]:

$$L_{pock} = \left(20 \cdot 18.34m\right) + 14.24m + 15.00m =$$
$$= 396.04m \cong 400.00m$$

It must be mentioned that both in case of "*Rollende Landstrasse*" technology and "pocket wagons" technology loading track length may differ from the calculated values. "*Real–world considerations impose limitations on train length according to specific operating conditions (e.g. safety against derailment). Limitations may also be imposed by mountainous landscape or the length of passing tracks (e.g. for trains to and from Italy). The 'long' European trains have a length of 600–750 [m]*", Ballis and Golias (2002). It should be noted as well that there are still many 400–500 [m] long trains running, while it is technically possible on many transportation corridors that 600–700 m long trains would be run, Kreutzberger and Konings (2016). Therefore, it is believed that safety against derailment seems to be maintained.

4. Total transport cycle time

Total transport cycle time in case of "*Rollende Landstrasse*" technology and "pocket wagons" technology was calculated by using formulas (3) and (4). Total transport cycle time takes into account time from arrival of an intermodal transport unit to a terminal until a train composition departs.

Total loading cycle time in case of *Rollende Landstrasse* technology

Total loading operation time in case of "*Rollende landstrasse*" technology is calculated by formula (3), Kwaśniowski (2008).

$$T_{CRo-La} = t_p + \left(n-1\right) \cdot t_{op} + t_k \qquad (3)$$

where:

T_{CRo-La} – total loading operation cycle time in case of "*Rollende Landstrasse*" technology, [min],
t_p – intermodal transport unit loading set–up time (administrative and measurement activities), [min],
t_{op} – intermodal transport unit loading time, [min],
t_k – ending time, which includes: validating by an auditor that tractor–trailers are loaded correctly, accessing a locomotive with a sleeper wagon to a composition consisting of low–loader platform wagons on loading track, making engagement and basic brake tests and technical inspection of railway wagons, [min].

Total time of 20 tractor–trailers operating in case of "*Rollende landstrasse*" technology comes to circa

1.5 hours. It contains time of tractor–trailer loading on low–loader platform wagons and comes to about 40 minutes.

Total loading cycle time in case of *pocket wagons* technology

Total loading operation cycle time in case of "pocket wagons" technology is done by formula (4), Kwaśniowski (2008).

$$T_{Cpock} = t_p + n \cdot t_{op} + t_k \tag{4}$$

where:

T_{Cpock} – total loading operation cycle time in case of "pocket wagons" technology, [min],
t_p – intermodal transport unit loading set–up time (administrative and measurement activities), [min],
t_{op} – intermodal transport unit loading time, [min],
t_k – ending time, which includes: securing loading units carried by a terminal employee, accessing a locomotive to a composition consisting of pocket wagons on loading track, making engagement and basic brake tests and technical inspection of railway wagons, [min].

Total loading operation cycle time in case of "pocket wagons" technology depends on means of transport which is used for loading operations (transhipment). Total time of 20 semi–trailers operating in case of "pocket wagons" technology amounts to:

- gantry crane RMG (*Rail Mounted Gantry)* – circa 100 minutes,
- truck mounted crane of type Reachstacker – circa 75 minutes,
- truck mounted crane of type Reachstacker and gantry crane RMG – circa 55 minutes.

The total duration of intermodal transport units operating can have different values depending on the adopted factors, which are:

- type and capacity of transhipment equipment, which is used,
- velocity limit of road vehicles,
- operability of intermodal transhipment terminal employees and drivers, Zielaskiewicz (2005).

Total loading cycle time in case of *pocket wagons* technology

Organisational and functional conceptual layouts of an intermodal transhipment terminal for "Rollende Landstrasse" technology and "pocket wagons" technology are given in figures 7. and 8. They include the loading tracks length, which were calculated in sections 3. Load units' storage places are marked there. And moving ways (directions) of external means of transport (a tractor plus a semi–trailer) and internal (a truck mounted crane, a gantry crane RMG) means of transport are also marked. In addition, a minimum turning radius for a tractor, 15 meters on a single arc is marked. The given layouts are of type one–way circular system, Ližbetin and Caha (2016).

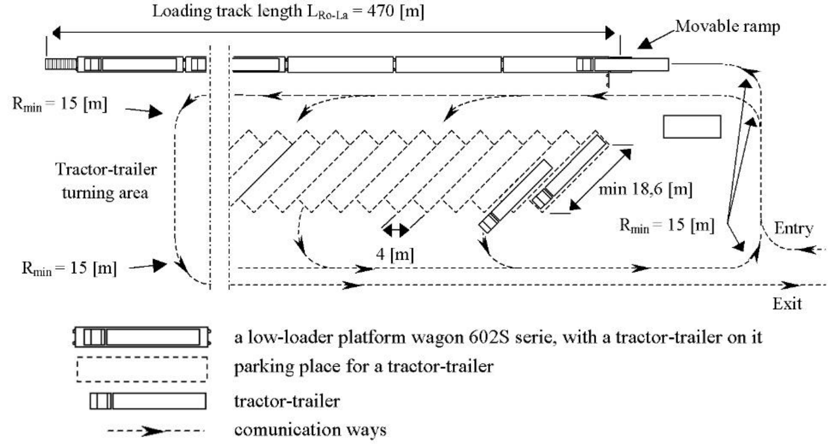


Fig. 7. Conceptual layout of an intermodal transhipment terminal for "*Rollende Landstrasse*" technology
Source: own work based on Stokłosa (2011), Jałocha–Kocha (1998).

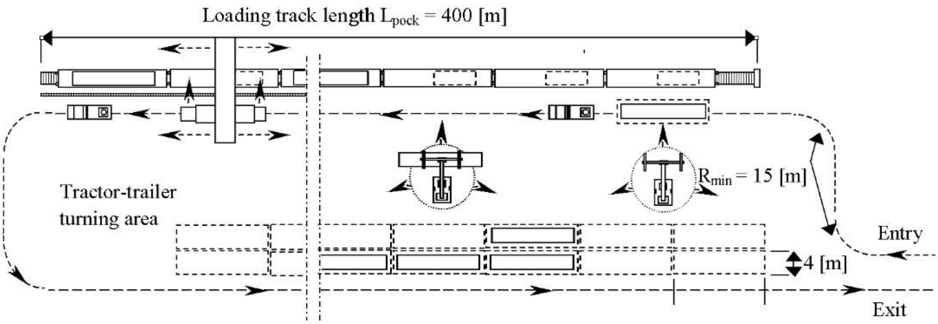


Fig. 8. Conceptual layout of an intermodal transhipment terminal for “pocket wagons” technology (a) direct transhipment realised by a gantry crane RMG; b) indirect transhipment realised by a truck mounted crane of type Reachstacker; c) direct transhipment realised by a truck mounted crane of type Reachstacker)

Source: own work based on Stokłosa (2011), Jałocha–Kocha (1998).

5. Evaluation of chosen freight wagons

To determine potentially the most advantageous wagon in case of usage of intermodal technology, the point method with assigned weights (Brzeziński, 2006 cited in Nowakowski and Werbińska–Wojciechowska, 2012: 952) is used. This method consists of determining the selection criteria, and then assigning them to appropriate weights. The final result is to choose a wagon with the highest assessment, which is the sum of the products of weights and granted ratings for every single criterion.

Using point method begins by identifying the subjects of assessment that in this case are the wagons. It consists of the nine–pieces set $\boldsymbol{W} = \{w\colon w = \{1, \ldots, 9\}, w \in \mathrm{N}\}$, where $w = 1$ stands for wagon 602S, $w = 2$ stands for wagon Saadkkms, $w = 3$ stands for wagon Saadkms, $w = 4$ stands for wagon Sdggmrss variant *a* (the total length 34 200 [mm], the length of the cargo 2 x 16 230 [mm], the tare weight of wagon 34.8 [t], the maximum permissible speed 100 [km/h]), $w = 5$ stands for wagon Sdggmrss – variant *b* (the total length 34 030 [mm], the length of the cargo 10 710 + 11 985 [mm], the tare weight of wagon 35 [t], the maximum permissible speed 120 [km/h]), $w = 6$ stands for wagon Sdgnss – variant *a* (the total length 19 740 [mm], the length of the cargo area 14 200 [mm], the height of the cargo area above rail head 272 [mm], the allowable axle load 22.5 [t/axle], the maximum permissible speed 100 [km/h]), $w = 7$ stands for wagon Sdgnss – variant *b* (the total length 19 480 [mm], the length of the cargo area 14 750 [mm], the height of the cargo area above rail head 270 [mm], the tare weight of wagon 23.8 [t], the wagon capacity 66.2 [t], the allowable axle load 22.5 [t/axle], the maximum permissible speed 120 [km/h]), $w = 8$ stands for wagon Sdgnss – variant *c* (the total length 34 030 [mm], the length of the cargo area 14 200 [mm], the height of the cargo area above rail head 270 [mm], the tare weight of wagon 38 [t], the wagon capacity 97 [t], the allowable axle load 22.5 [t/axle], the maximum permissible speed 120 [km/h]) and $w = 9$ stands for wagon Sdgmnss.

The next step of point method using is to choose the proper selection criteria. Herein, it consists of the eight–pieces set $\boldsymbol{K} = \{k\colon k = \{1, 2, 3, 4, 5, 6, 7, 8\}, k \in \mathrm{N}\}$ described in table 3.

Table 3. Summary of evaluation criteria used in the point method (column 2) and summary of weights of criteria used in the point method (column 3)

k	**Criteria**	***p*(*k*)**
1	*2*	*3*
1	Railway vehicle gauge	0.05
2	Total length	0.10
3	Length of the cargo area	0.05
4	The height of the cargo area above rail head	0.20
5	Tare weight of wagon	0.30
6	Wagon capacity	0.15
7	Quantity of axles	0.05
8	Maximum permissible speed	0.10

Then to each criterion its weight is given. The weights *p*(*k*) are assigned subjectively, according to the judgement of the decision–maker (the weights proposed by paper authors are given in table 3., column 3). It is worth noting that the sum of the weights do not exceed unity (or 100%; which is expressed in formula (5)).

$$\sum_{k=1}^{K} p(k) = \sum_{k=1}^{k=8} p(k) = \sum_{k=1}^{k=8} p(w,k) = 1, \quad w = \{1,...,9\} \quad (5)$$

The next step is standardising assessments of wagon selection. Each wagon variant is evaluated in terms of criterion *k* (table 3.).

Measurable criteria obtain values that are results of the analysis given in tables 1. and 2. In the opinion of the decision–maker the criteria *k* = {2, 5, 6, 7, 8} should be maximised, and the criteria *k*= {1, 3, 4} should be minimised. For all these reasons (minimising or maximising of some criteria), assessment of various criteria are shown in a simplified manner (table 4.). Due to the comparison of nine variants, it is sufficient to introduce nine points scale *s*(*w*,*k*). The application of this operation enables the standardisation of evaluation criteria, in this case it is maximising of rates. Each variant is evaluated in terms of criterion *k*. Standardising criteria of *k* = {2, 5, 6, 7, 8} is about to allot *s*(*w*,*k*). The higher the value of *k* criterion (*c*(*w*,*k*) is the value of criterion for *w*-wagon and *k*-criterion, given in tables 1 and 2.), the higher the value *s*(*w*,*k*) is given. Effects of using this kind of expert method is given in table 4. Differently, standardising of criteria *k* = {1, 3, 4} is about to allot *s*(*w*,*k*) in following way. The lower the value of *k* criterion (*c*(*w*,*k*)), the lower the value *s*(*w*,*k*) is given. Effects of using this kind of expert method is given in table 4.

Then the values *q*(*w*, *k*) are generated. Those are products of multiplying weights of criteria and their assessments (table 5.). It is expressed in formula (6).

$$q(w,k) = p(w,k)\cdot s(w,k), \quad k\in \boldsymbol{K}, \quad w\in \boldsymbol{W} \qquad (6)$$

Table 4. Standardising of criteria, allotting values of parameter *s*(*w*,*k*)

Wagon type	**602S**	**Saadkkms**	**Saadkms**	**Sdggmrss**		**Sdgnss**			**Sdgmnss**
w / ***k***	1	2	3	4	5	6	7	8	9
1	4	7	7	1	2	5	6	2	9
2	4	6	5	9	7	1	2	8	3
3	1	2	3	5	5	4	5	5	9
4	8	7	9	4	3	0	5	2	6
5	2	3	1	9	9	0	5	8	4
6	3	1	1	9	9	9	9	9	9
7	6	9	6	3	3	1	1	3	1
8	4	5	4	4	5	4	5	5	4

Table 5. Multiplying product of ratings and weights, *q*(*w*,*k*)

Wagon type	**602S**	**Saadkkms**	**Saadkms**	**Sdggmrss**		**Sdgnss**			**Sdgmnss**
w / ***k***	1	2	3	4	5	6	7	8	9
1	0.20	0.35	0.35	0.05	0.10	0.25	0.30	0.10	0.45
2	0.40	0.60	0.50	0.90	0.70	0.10	0.20	0.80	0.30
3	0.05	0.10	0.15	0.25	0.25	0.20	0.25	0.25	0.45
4	1.60	1.40	1.80	0.80	0.60	0.00	1.00	0.40	1.20
5	0.60	0.90	0.30	2.70	2.70	0.00	1.50	2.40	1.20
6	0.45	0.15	0.15	1.35	1.35	1.35	1.35	1.35	1.35
7	0.30	0.45	0.30	0.15	0.15	0.05	0.05	0.15	0.05
8	0.40	0.50	0.40	0.40	0.50	0.40	0.50	0.50	0.40

Based on table 5., the aggregated indicators for the evaluation of each option are designated according to formula (7). The results in the case of each *w* variants are given as formulas (8)-(16).

$$f(w) = \sum_{k=1}^{k=8} q(w,k), \quad k \in \boldsymbol{K}, \quad w \in \boldsymbol{W} \tag{7}$$

$$f(1) = 4.00 \tag{8}$$

$$f(2) = 4.45 \tag{9}$$

$$f(3) = 3.95 \tag{10}$$

$$f(4) = 6.60 \tag{11}$$

$$f(5) = 6.35 \tag{12}$$

$$f(6) = 2.35 \tag{13}$$

$$f(7) = 5.15 \tag{14}$$

$$f(8) = 5.95 \tag{15}$$

$$f(9) = 5.40 \tag{16}$$

Based on the results of the assessments, the wagon *w* = 4 was chosen as favourable at the moment, because:

$$f(w^*) = \max\{f(1), \ ..., \ f(w)\}, \quad w \in \boldsymbol{W} \tag{17}$$

and:

$$\begin{gathered} f(4) > f(5) > f(8) > f(9) > f(7) > ... \\ ... > f(2) > f(1) > f(3) > f(6) \end{gathered} \tag{18}$$

According to the calculation, the best opted wagon would be *w* = 4 stands for wagon Sdggmrss – variant *a* (the total length 34 200 [mm], the length of the cargo 2 x 16 230 [mm], the tare weight of wagon 34.8 [t], the maximum permissible speed 100 [km/h]). Obviously, the chosen variant is computed in case of predefined weights of evaluation criteria used in the point method, based on expert knowledge. In the rapidly changing environment of railway organisations, it is not excluded that the investors would considers the different option because it would be adapted to its current expectations and would be more profitable. Another likely scenario is to change the weights of individual criteria used in determining the assessment of variants, for example due to changes in the mission and vision of the railway company or its long–distance goals. This ultimately means the evaluation is unequivocal.

6. Conclusion

In spite of adequate infrastructural and technological conditions of Polish transhipment terminals and availability of proper transport technology, transport of semi–trailers and tractor–trailers on railway wagons is not to be expected in the Polish transport system, whereas the intermodal transport in Europe has registered a high rate of growth for many years since the beginning of its services. Promoting this type of transport has many obvious advantages, which include e.g.: environmental protection and less strain on the road transport infrastructure by heavy vehicle traffic. The consideration of environmental issues, pollution prevention and safety aspects in the planning of intermodal transhipment terminals may present substantial constraints and may lead to noticeable alterations to the plans. Nevertheless, even in so–called Western European countries due to achieve the modal shift projected by public transport policies, intermodal rail transport needs to improve its performance in order to become more attractive. The challenge and proposed solutions to improve intermodal rail transport that were formulated in the 1990s are – with some modifications – still relevant, according to Kreutzberger and Konings (2016). In opinion of authors, adequate method of designing of these kind of intermodal terminals is needed, with taking into account the multi-criteria optimisation.

To continue, evaluation of means of transport in case of intermodal transport technology is given in the paper. It is only one of many aspects, which should be taken into consideration. Other of them is specified bellow in a very briefly way.

Many researcher are currently interested in new technologies in intermodal transport. Other technologies than "*Ro-La*" and pocket wagon technologies, not described intermodal technologies, are bimodal technology Abroll Container Transportation System, Modalohr, CargoBeamer, Flexiwaggon, Tiphook, Magaswing, Automatic Loading System (CargoRoo) not to mention many others. What is more important, the evaluation of freight wagons used for these technologies would became broader for example because last years' new patents occurred in Polish Patent Office and European Patent Office, such as patent No. 214797 (Nader and Sala, 2010) and EU Patent EP 2 532 562 A1 (Krasoń et al., 2016, Niezgoda et al., 2012).

Designing of intermodal transhipment terminal is not a part of the paper (notwithstanding, this might become the aim of future research), however we would like to highlight that the following basic design parameters are distinguished:

- length of transhipment tracks,
- utilisation of transhipment tracks,
- train and truck arrival behaviour/patterns,
- type and number of handling equipment,
- mean stacking height in the storage area,
- terminal access system (mainly rail side) and procedures,
- manpower planning e.g. as in Di Francisco (2016),
- additionally, the problem of empty containers runs should be mention, which is still to be discussed in the literature based on e.g. Xie et al. (2017),
- it should also be borne in mind dynamic transport demands and traffic conditions in the network for intermodal freight transport planning problems, such as e.g. in Le et al. (2015).

Description of these parameters can be found in the literature. The first six are briefly described for example in Ballis and Golias (2002). Besides, European Union regulation such as European Comission–Dg (1995), European Comission–Dg (1997a), European Comission–Dg (1997b), European Comission–Dg (1999a), European Comission–Dg (1999b), European Comission–Dg (2000) should be considered. You can also find interesting – and still current in some aspects – analysis and evaluation of the White Paper, which concerns the Polish transport policy. It is given in Taylor (1998).

For future development an expert system for the evaluation of conventional and potential innovative technologies in the intermodal transport area should be used. The existed one, given in the literature, can be used. Authors of Abacoumkin and Ballis (2004) propose to use an expert system based modelling tool which can be done in simulation mode. In this expert system, they take into consideration all necessary land for handling, storage and transport operations. In case of the equipment computing they provide two steps: the selection of handling equipment type and its supporting technologies and then computing of adequate number of equipment. Other findings in that matter are presented analytically in Ballis and Golias (2000), Ballis and Golias (2002) and in Xie et al. (2017), where the modelling approach to intermodal terminal designing with using expert system and simulation model is described and precisely analysed in cost aspect.

The idea standing behind the use of "*Rollende Landstrasse*" technology and "pocket wagons" technology to run sustained railway connections, which are more profitable than road transport in terms of the duration time of transport process and total costs related to this. They would be likely to succeed there, where large stream of heavy vehicles traffic occurs or even especially in protected area, such as the Rospuda Valley. It is also worth mentioning that, in accordance to relevant law regulations, the time of transport can be a necessary pause for the driver. This would help to reduce the transport process duration. In the future, the socio–economic conditions should appear, which will encourage road transport freighters to use on a larger scale semi–trailers and track–trailers transport with using intermodal transport technologies.

At the end of the paper we ascertain that regardless of technology, terminals must serve the demands of shippers, road transport operators, rail transport operators, as well as those of terminal operators themselves. It should be underlined that, finding similar after authors of Bontekoening et al. (2004): "*we did not find studies which touch upon this subject. Finally, we want to mention the need to obtain more insight in the impact of standardisation or the lack thereof on terminal costs and performances*."

Acknowledgment

Research and publication of the paper is financed with funds under: the statutory work of Department of Fundamentals in Means of Transport (Faculty of Transport, Warsaw University of Technology) No. 504P/1160/3484, the statutory work of Educational and Scientific Team of Modelling and Diagnostics of Technical Means of Transport (Faculty of Transport, Warsaw University of Technology) No. 504P/1160/3884, Grant of Transport Faculty Dean No. 504M/1160/1613 assigned to Arkadiusz Kostrzewski.

References:

[1] ABACOUMKIN, C., & BALLIS, A., 2004. Development of an expert system for the evaluation of conventional and innovative technologies in the intermodal transport area. *European Journal of Operational Research*, 152(2), 410–419.

[2] BALLIS, A., & GOLIAS, J., 2000. Investigation of innovative intermodal pilot plants using macro and micro modelling tools. In 13th National Conference of Hellenic Operational Research Society on Transport and New Technologies, Piraeus/Greece: University of Piraeus.

[3] BALLIS, A., & GOLIAS, J., 2002. Comparative evaluation of existing and innovative rail–road freight transport terminals. *Transportation Research Part A: Policy and Practice*, 36(7), 593–611.

[4] BONTEKOENING, Y.M., MACHARIS, C., & TRIP J. J., 2004. Is a new applied transportation research field emerging?—A review of intermodal rail–truck freight transport literature. *Transportation Research Part A: Policy and Practice*, 38(1), 1–34.

[5] BRZEZIŃSKI, M., 2006. *Logistyka w przedsiębiorstwie (Logistics in enterprise)*. Warszawa: Bellona, in Polish.

[6] DI FRANCISCO, M., DÍAZ–MAROTO LLORETE, N., ZANDA, S., & ZUDDAS P., 2016. An optimization model for the short–term manpower planning problem in transhipment container terminals. *Computers & Industrial Engineering*, 97, 183–190.

[7] EUROPEAN COMISSION–DG TREN, 2000. Innovative technologies for intermodal transfer points, ITIP ongoing project, Brussels.

[8] EUROPEAN COMISSION–DG VII, 1995. Future optimum terminals for intermodal transport doc, SIMET project, Euret/411/95, Brussels.

[9] EUROPEAN COMISSION–DG Transport, 1999a. Cost effectiveness of intermodal transport, Deliverable D13/14, IMPULSE research project, Brussels.

[10] EUROPEAN COMISSION–DG Transport, 1999b. Design and organisational aspects of intermodal transport terminals, Deliverable D11, IMPULSE research project, Brussels.

[11] EUROPEAN COMISSION–DG Transport, 1997a. Market of intermodal transport, Deliverable D2, IMPULSE research project, Brussels.

[12] EUROPEAN COMISSION–DG Transport, 1997b. New generation terminal and terminal–node concepts in Europe, Deliverable D2, TERMINET project, Brussels.

[13] GŁÓWNY URZĄD STATYSTYCZNY (CENTRAL STATISTICAL OFFICE), 2014. Transport – wyniki działalności w 2013 roku (Transport – efects of operation in 2013), Warszawa, in Polish.

[14] GŁÓWNY URZĄD STATYSTYCZNY (CENTRAL STATISTICAL OFFICE), 2013. Transport – wyniki działalności w 2012 roku (Transport – efects of operation in 2012), Warszawa, in Polish.

[15] GŁÓWNY URZĄD STATYSTYCZNY (CENTRAL STATISTICAL OFFICE), 2012. Transport – wyniki działalności w 2011 roku (Transport – efects of operation in 2011), Warszawa, in Polish.

[16] JAŁOCHA–KOCHA, H. (ed.), 1998. *Wytyczne projektowania punktów ładunkowych transport kombinowanego (Assumptions for design of combined tranport loading points)*, Warszawa: CNTK, in Polish.

[17] KOSTRZEWSKI, A., & NADER, M. 2016. Przewozy naczep oraz zestawów drogowych w ramach wybranych technologii intermodalnych z poziomym przeładunkiem (Semi – trailers and road sets transportation of the selected intermodal technology with horizontal transshipment). *Prace Naukowe Politechniki Warszawskiej. Transport*, 111, 287–299, in Polish.

[18] KOSTRZEWSKI, A., & NADER, M. 2013. Technologiczne uwarunkowania krajowych lądowych baz przeładunkowych pośredniczących w transporcie intermodalnym (Technological factors of national transhipment land–terminals intermediate of the intermodal transport). *Prace Naukowe Politechniki Warszawskiej. Transport*, 97, 389 – 398, in Polish.

[19] KRASOŃ, W., NIEZGODA, T., & STANKIEWICZ M., 2016. Innovative Project of Prototype Railway Wagon and Intermodal

Transport System. T*ransportation Research Procedia*, 14, 615–624.

[20] KREUTZBERGER, E., & KONINGS, R., 2016. The challenge of appropriate hub terminal and hub–and–spoke network development for seaports and intermodal rail transport in Europe. *Research in Transportation Business & Management*, 19, 83–96.

[21] KWAŚNIOWSKI, S., NOWAKOWSKI, T., & ZAJĄC, M., 2008. *Transport intermodalny w sieciach logistycznych (Intermodal transport in logistics networks)*. Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej, in Polish.

[22] LE, L., NEGENBORN, R. R., DE SCHUTTER, B., 2015. Intermodal freight transport planning – A receding horizon control approach. *Transportation Research Part C: Emerging Technologies*, 60, 77–95.

[23] LIŽBETIN, J. & CAHA, Z., 2016. Theoretical Criteria for The Evaluation of the Operational Performance of Intermodal Transport Terminals. *Procedia Engineering*, 161, 1197–1203.

[24] NADER M., SALA M., 2010. The rail coach. Warsaw University of Technology, patent No. 214797.

[25] NIEZGODA, T., KRASOŃ, W., BARNAT, W., GIELETA, R., DAMAZIAK, K., SYBILSKI, K., 2012. A railway wagon and a mechanism for rotating and blocking a loading floor of a railway wagon for combined transportation, Military University of Technology, EU Patent EP 2 532 562 A1.

[26] NOWAKOWSKI, T., & WERBIŃSKA–WOJCIECHOWSKA, S., 2012. *Przegląd metod oceny i wyboru dostawców w przedsiębiorstwie (Supplier selection methods used in enterprises – state of art)*. Logistyka, 2, 945–955, in Polish.

[27] STOKŁOSA, J., 2011. *Transport intermodalny. Technologia i organizacja (Intermodal transport. Technology and organization)*. Lublin: Wydawnictwo Naukowe Wyższej Szkoły Ekonomii i Innowacji, in Polish.

[28] TAYLOR, Z., 1998. Polish transport policy: An evaluation of the 1994/5 White Paper. *Journal of Transport Geography*, 6(3), 227–236.

[29] TOWPIK, K., 2009. *Infrastruktura transportu kolejowego (Infrastructure of railway transport)*. (2nd ed.). Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej, in Polish.

[30] UIC 505 – 1, Railway transport stock Rolling stock construction gauge (http://xa.yimg.com/kq/groups/22520649/738560679/name/e505x1.pdf, on–line access: August 12th 2013).

[31] XIE, Y., LIANG, X., MA, L., & YAN H., 2017. Empty container management and coordination in intermodal transport. *European Journal of Operational Research*, 257, 223–232.

[32] ZIELASKIEWICZ, H., 2010. *Transport intermodalny na rynku usług przewozowych (Intermodal transport in transportation services market)*. Radom: Wydawnictwo Naukowe Instytutu Technologii Eksploatacji – PIB, in Polish.