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THE INTERMODAL TRANSPORTATION OF SEMITRAILERS

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Abstract *The paper focuses on intermodal transportation systems for semitrailers in Europe. Transportation of semitrailers by rail is a good alternative to direct road transport. In the paper, individual systems are presented and their characteristics are explained. The characteristics of individual transportation systems are the inputs into the WSA and the TOPSIS methods. The results of the methods answers the question which semitrailer transportation system is the most suitable (beneficial) for trucking companies today. The paper may be a source of information for state authorities, trucking companies, intermodal transportation operators and terminal operators.*

Keywords *intermodal transportation, multiple criteria decision making, WSA method, TOPSIS method, standard semitrailer, intermodal semitrailer*

1 INTRODUCTION

Intermodal transportation is an important measure for sustainable development and – more specifically – for sustainable logistics/transport. It is beneficial regarding environmental protection and has potential for *modal-shift from road transport to rail (and water) transport*. Current situation of modal-split on European freight transport market is: 75.3% road transport, 18.7% rail transport and 6% inland waterway transport (Eurostat, 2020). The data are for the year 2018. The share of transport modes is counted according to transport performance (in tonne-kilometres, *tkm*) There is an effort to use *modal-shift tools* to improve the modal-split – i.e. to encourage greater use of ecological and safer transport modes (rail and water transport) and decrease the share of road transport. **Among hereinbefore mentioned modal-shift tools, the intermodal transportation belong.**

Intermodal transportation has two main ranges – *accompanied* and *unaccompanied*. Accompanied intermodal transportation systems are transporting whole road vehicles (usually vehicle combinations) and their drivers. Among these systems belong: RO-LA (German: Rollende Landstrasse; Rolling Road), LeShuttle-Freight (operated in Eurotunnel) and ferries. Unaccompanied intermodal transportation systems are transporting only intermodal loading units (**ILU**; also called intermodal transport units – **ITU**) like containers (ISO/maritime, ACTS, AWILOG etc.), swap-bodies and semitrailers.

In the intermodal transportation, three types of semitrailers are used – standard (*non-cranable*), intermodal (*cranable*) and bimodal. **This paper is focused on systems related to road/rail transportation of standard and intermodal semitrailers.** Bimodal semitrailers' transportation systems

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are currently not in operation in Europe. Although in the past, the BTZ system (Bayerischer Trailer-Zug) was in operation between Germany and Italy (Barnard, 1995).

Key concepts from the field of intermodal transportation are defined by company UIRR – *International Union for Road-Rail Combined Transport* (UIRR, 2020), (UIRR, n.d.). As well as in other sources like legislative documents and norms (e.g. ČSN 26 9375 Terminology of combined transport (1995)) and literature – e.g. Široký et al. (2012), Novák et al. (2013), Rathouský et al. (2016) or Novák et al. (2018). For the purpose of this paper, **intermodal transportation** is defined as a transportation during which two or more transport modes are used, and a cargo remains in one loading unit (ILU/ITU) during the whole transport process. In the case the longest part of transport process in intermodal transportation is done by rail/water transport (and the first-mile and/or last-mile transport is done by road and is as short as possible), the transportation is called **combined transportation**.

This paper includes characteristics of available semitrailer transportation systems (in sections 3.2 and 3.3) so it may be used as **a source of information for professionals, trucking-companies and state authorities**.

The **application of Multiple-criteria decision making (MCDM) methods** to identify the most suitable system is included (in section 4).

The paper is focused on segment of semitrailers because these days it seems to be the most promising. The share of semitrailers on the intermodal transportation market is continuously growing. According to *UIRR Annual Report for the years 2019-2020* the share of semitrailers on intermodal transportation market (regarding transport volume) has been increasing since 2007 and currently is almost 15% (UIRR, 2020). Despite the "corona-crisis", the number of consignments transported in intermodal semitrailers has grown 4.89% in 2019. For trucking-companies the operation of standard semitrailers doesn't involve any further (higher) investments into their vehicle-fleet. As well as, **higher usage of semitrailers' transportation systems will help to achieve target of moving 30% of current road cargo transport** (with transport distance over 300 km) **to rail and water transport until 2030** – as stated e.g. in Ministerstvo dopravy (2018) and CargoBeamer (2020a).

2 METHODOLOGY

2.1 Literature review

The paper is Europe-oriented and **it focuses exclusively on currently running systems**. The scope of our research (literature review) corresponds with it. The analysed systems are: **Modalohr**, **CargoBeamer**, **pocket wagons**, **NiKraSa** and **ISU**. In sections 3.2 and 3.3, the details regarding these systems are presented. All hereinbefore mentioned systems will be considered as variants in the MCDM methods – see section 4.

Besides studying characteristics of individual semitrailer transportation systems, the researched area (European market) has been analysed from wider environmental point of view – particularly how freight transport negatively influence environment and what are the measures suitable to be taken to mitigate these impacts. Göçmen and Erol (2018) are solving environmental consequences of transport but even considering social factors (accidents and deaths) and risks associated with transportation of dangerous goods. In addition, the **problem of non-cranable semitrailers' transportation by rail is often discussed**. According to (van Leijen, 2020) and (Bíró, 2019) current share of intermodal semitrailers on European transport market is estimated to ca. 3-10%. In other words, 90-97% of all semitrailers are standard (non-cranable). **This creates a huge potential for modal-shift** from road to rail through implementation of intermodal transportation systems for standard semitrailers. Van Leijen (2020) describes a project for standard semitrailers with potential of moving 50,000 semitrailers on rail (on a route between Netherlands and Poland) in the next 2-3 years. The benefits of modal shift from road to rail in countries Austria, Germany, Liechtenstein and Switzerland is solved by UIC (2020). According to den Boer at al. (2011) it is estimated that **maximum potential share of rail freight transport is in the range of 31-36% -** i.e. the performance of rail transport can potentially double (compared to the current state).

2.2 The target of the paper and methods used

Besides the analysis of semitrailer transportation systems, the target of this paper is to apply **MCDM** methods **WSA** (*Weighted Sum Approach*) and **TOPSIS** (*Technique for Order Preference by Similarity to Ideal Solution*) for the **selection of the most appropriate system of transportation of semitrailers by rail** – see section 4. The authors have used two MCDM methods to verify the results. For determination of criteria weightings, the **Fuller triangle method** has been used. For details regarding chosen methods see section 2.5.

2.3 Research question and hypothesis

The paper answers the **research question (RQ)**: "*Which semitrailer transportation system to expand throughout Europe to support modal-shift from road to rail?*"

Hypothesis: based on the research, the authors expect the most suitable semitrailer transportation system to be one of the horizontal ones – either *Modalohr* or *CargoBeamer*.

2.4 Determining variants and criteria and their weightings

As mentioned hereinbefore, **the systems that will be considered as variants** in the MCDM methods will be:

1. Modalohr (LorryRail),
2. CargoBeamer,
3. pocket wagons,
4. NiKraSa,
5. ISU.

The authors decided to use **following criteria for evaluation of variants** (systems of semitrailer transportation):

1. railway track (siding) electrification possibility,
2. need of investment into intermodal (cranable) semitrailer,
3. number of personnel needed for transhipment in a terminal,
4. the degree of risk of damage to the semitrailer during transhipment,
5. transhipment costs.

Considering hereinbefore specified criteria, it is clear the authors have chosen **criteria relevant for "both sides" of intermodal transportation** – i.e. the intermodal transportation operators (terminal operators respectively) and trucking companies.

The **criterion number 1** has been included to consider possibility of railway track electrification in a terminal. In the case the transhipment is vertical, the electrification of railway track (siding) in a terminal is not possible. In the case the transhipment is horizontal, the electrification is possible. **Criterion number 2** represents need of higher investments into intermodal semitrailers for trucking companies. Intermodal semitrailers are more expensive and heavier (ca. 300-500 kilograms) in comparison with standard ones. **Criterion number 3** considers the impact on labour costs. The data used in this criterion are obtained from Klemenčič and Burg (2018). **Criterion number 4** takes into account potential additional costs (resulting from damage to a semitrailer during transhipment) for trucking companies. In this criterion, the authors considered individual transhipment principles and evaluated the level of risk.

Criterion number 5 compares individual systems according to transhipment costs (in Euro, excl. VAT) as analysed by Klemenčič and Burg (2018).

The criteria matrix (also called **decision matrix**) is shown in Tab. 1. This matrix is the input into both methods considered – the WSA and the TOPSIS (see sections 4.1 and 4.2 respectively).

Tab. 1 The criteria matrix; source: Authors.

Semitrailer transportation system	rail electrification possibility	investment into cranable semitrailer	number of personnel needed	potential risk of damage to semitrailer	transhipment costs [€]
pocket wagons	0	1	2	1	15
NiKraSa	0	0	2	2	15
ISU	0	0	3	3	30
Modalohr	1	0	2	1	80
CargoBeamer	1	0	1	1	75
criterion type	MAX	MIN	MIN	MIN	MIN

The values in **criterion "rail electrification possibility"** have this meaning: if certain system requires vertical transhipment, it means the railway track (siding) can't be electrified – therefore value "zero" means electrification is not possible, value "1" means electrification is possible as the particular system belongs to horizontal ones.

Only the first criterion has maximizing character (see the last line in Tab. 1), the values of other criteria will be converted to maximization (see further in section 4.1 Tab. 4 and 4.2 Tab. 10). The principle of conversion of minimization to maximization is described e.g. by Stopka et al. (2019).

The values in **criterion "investment into cranable semitrailer"** have the same meaning as the first criterion – i.e. "zero" in the case the trucking companies needn't invest into intermodal (cranable) semitrailer, and "1" in the case the trucking companies have to invest into intermodal semitrailer.

The values in **criterion "number of personnel needed"** are self-explaining.

The values in **criterion "potential risk of damage to semitrailer"** has been determined by authors according to the literature review and the study of characteristics of individual systems. The higher the value of the criterion is, the higher the risk of damage to the semitrailer is.

The values in **criterion "transhipment costs"** are self-explaining. The values represents the costs (in Euro, excl. VAT) of semitrailer transhipment in a terminal.

As already mentioned above, we will use the Fuller triangle method for **determination of criteria weightings** – see Fig. 1.

1	1	1	**1**
2	**3**	**4**	5
	2	2	**2**
	3	**4**	5
		3	3
		4	**5**
			4
			5

Fig. 1 The Fuller triangle; source: Authors.

The criteria which are more important compared to the others are highlighted with yellow colour and bold font. **The application of Fuller triangle method is presented in Tab. 2.**

Tab. 2 The preferences and weightings of criteria; source: Authors.

Criterion	Number of preferences	Weightings of criteria
1	1	0.1
2	3	0.3
3	1	0.1
4	4	0.4
5	1	0.1

From the results in Tab. 2, it is clear the criteria relevant for trucking companies have significantly higher weightings. This ensures **the best suitable system of semitrailer transportation** (identified by the MCDM methods) **will be "user friendly" for trucking companies**.

As the social target is to make modal-shift from road to rail, in the end **the trucking companies will be the ones who will make final decision** whether to drive door to door "on their own wheels" or whether they will use more ecological and safer intermodal transportation.

2.5 The MCDM methods

2.5.1 The selection of MCDM methods

The WSA method has been chosen due to the speed of determination of results – and is highly recommended by Stopka et al. (2014). **The TOPSIS method** (more sophisticated compared to the WSA) is widely used in MCDM problems (it is often mentioned and used in scientific papers) in logistics and transport – e.g. Bottani and Rizzi (2006) are using TOPSIS in the field of outsourcing of logistics services, Perçin, S. (2009) evaluates third party logistics providers, Li et al. (2011) are using TOPSIS for location of a logistics centre – similar to Stopka et al. (2014) who are solving allocation problems of logistics objects, presenting MCDM methods (e.g. ORESTE, TOPSIS, AHP and WSA) as well as methods for determining criteria weightings (e.g. method of ranking, Fuller triangle method and Scoring method). Velasquez and Hester (2013) states that **areas of the TOPSIS method application** are "*supply chain management and logistics, design, engineering and manufacturing systems, business and marketing management, environmental management, human resources management, and water resources management*".

The Fuller triangle method has been chosen because for the purpose of this paper, it is possible and sufficient to decide whether one criterion is more important than the other. It is not necessary to use – for instance – Saaty method which is using 9 point scale (Stopka et al., 2014).

Principle of the methods used will not be described here – only the application will be presented (see section 4). The theoretical background of the MCDM methods can be found e.g. in: Chýna et al. (2012) or Spackman et al. (2009).

2.5.2 Application of MCDM methods

The general procedure (sequence of steps) in the MCDM process is as follows:

1. **identification of variants** – in our case: the list of semitrailer transportation systems to be compared (the list of variants is above in section 2.4),
2. **identification of criteria** – in our case: relevant characteristics of systems considered (the list of criteria and their explanation is above in section 2.4),

3. **determination of criteria weightings** – in our case: the application of Fuller triangle method (the results are above in Tab. 2 in section 2.4),
4. **application of specific MCDM method** – in our case: application of the WSA and the TOPSIS method (see further in sections 4.1 and 4.2),
5. **interpretation of results** – identification of the most suitable variant and discussion (see further in the last paragraphs of sections 4.1 and 4.2, and the discussion in section 5).

3 SYSTEMS FOR TRANSPORTATION OF SEMITRAILERS

As mentioned hereinbefore, there are three types of semitrailers on intermodal transportation market – standard semitrailers, intermodal semitrailers and bimodal semitrailers. **Each of these types has specific construction defining possibilities of their manipulation** (transloading techniques) in intermodal transportation terminals. The type of semitrailer regarding cargo it is designed to transport is irrelevant – i.e. it doesn't matter whether the semitrailer is a platform vehicle (with canvas, curtainsider), box-body, refrigerated, tanker, silo etc.

All transportation systems analysed in sections 3.2 and 3.3 allow transportation of **semitrailers with height of 4 meters, width of 2.6 meters and length of 13.6 meters** – i.e. if a semitrailer meets requirements for road traffic (given by *Directive 2015/719*, amending *Directive 96/53/ES*), it can be transported by rail.

Some types of railway wagons enables transportation of **semitrailers with length upto 15 meters** – i.e. for example *Kögel EuroTrailer*.

During rail transport, maximum permissible weight of loaded semitrailer slightly varies according to individual system (type of railway wagon respectively) – it can reach **ca. 33-38 tons**. Trains usually reach maximum speeds either **100 kmph** or **120 kmph**.

3.1 Transloading techniques

Generally, there are two principles of manipulation with semitrailers – *horizontal* and *vertical*. Horizontal systems are usually called **Ro-Ro** (Roll-on / Roll-off) and vertical systems called **Lo-Lo** (Lift-on / Lift Off). In the case the **Ro-Ro systems** are used, *it is possible to transload any type of semitrailer* – this is, of course, beneficial. The **Lo-Lo systems** either *require intermodal (cranable) semitrailers or usage of specially designed transhipment systems for standard semitrailers*. These systems are solved hereinafter.

3.2 Systems of horizontal transhipment

3.2.1 Modalohr (LorryRail)

Modalohr is a French system for transportation either semitrailers or semitrailer-combinations (including drivers travelling in a couchette wagon coupled in a train). It has been in operation since 2003. The system is universal in its **use in unaccompanied and accompanied intermodal transportation**. Primarily, it is operated in unaccompanied version.

Central part of Modalohr wagons (loading-deck) is rotary (ca. 45 degrees to the side). The turning process is done via electric motors mounted in the railway track in a terminal. A semitrailer is pulled on a wagon by a tractor (or terminal-tractor) and uncoupled from it. After this, the centre part of a wagon is turned back to the driving position.

The advantage is that each wagon is loaded individually, all the wagons in a train may be loaded simultaneously. The transloading time is very short – the whole train may be loaded with semitrailers in **ca. 30-40 minutes** (LOHR, 2016a), (LOHR, 2016b). The principle of transhipment in Modalohr system is shown in Fig. 2.

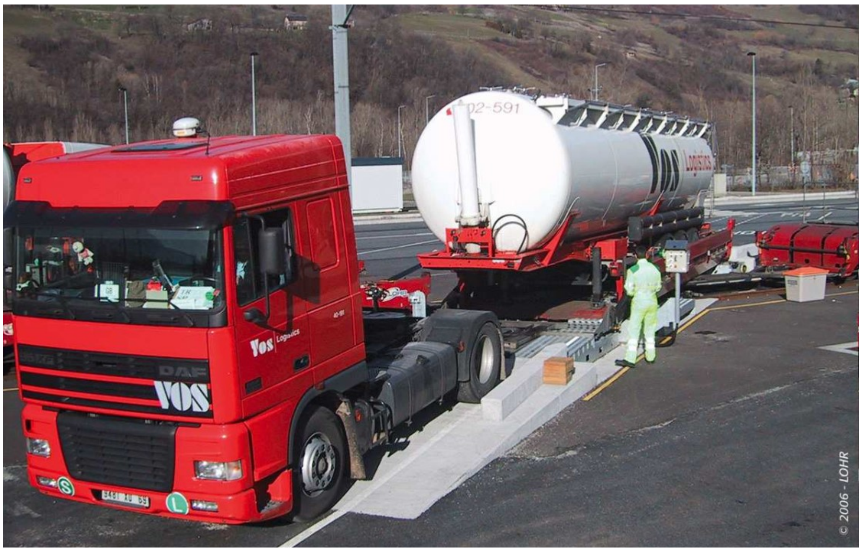

Fig. 2 The Modalohr system – horizontal transhipment of standard semitrailer; source: LOHR.

Currently, these are the lines of Modalohr system (VIIA, n.d.):

1. Aiton (F) – Orbassano (I),
2. Bettembourg (L) – Le Boulou (F),
3. Calais (F) – Le Boulou (F),
4. Calais (F) – Orbassano (I),
5. Séte (F) – Paris (F) – Zeebrugge (B),
6. Barcelona (E) – Bettembourg (L),
7. Macon (F) – Calais (F),
8. Macon (F) – Le Boulou (F).

On the line *Barcelona – Bettembourg*, it is estimated to save over 22,000 trucks/year on the road, representing a **reduction in CO_2 emissions of 23,070 tonnes/year** (Todd, 2019).

3.2.2 CargoBeamer

The project originally started in 1998. The pilot project took place in Leipzig (D) – a terminal for three CargoBeamer wagons has been built. First tests of CargoBeamer system were on the route between Spain and Germany – semitrailers have been loaded with cargo for automotive industry (Volkswagen AG). Since 2015, the line between *Kaldenkirchen (D) and Domodossola (I)* has been in operation. Since opening, **more than 70,000 semitrailers has been moved from road to rail** (CargoBeamer, 2020b).

On May 14th 2020, new line connecting *Kaldenkirchen (D) and Sestokai (LT)* has been opened. The target is to implement CargoBeamer system in its horizontal transhipment form (for explanation see the next paragraph). But if necessary (due to lack of special transloading equipment in a terminal), **vertical transhipment of semitrailers is possible**. The principle of standard semitrailers' transhipment is then the same as in the case of NiKraSa system (see further in section 3.3.2), or direct vertical transhipment of intermodal semitrailers takes place.

For horizontal transhipment of a semitrailer onto CargoBeamer wagon, the detachable central part (loading platform, also called a "*pallet*") of a wagon is positioned radially next to a wagon. On the platform a semitrailer is pulled by a tractor (or a terminal tractor) and dropped there. Then the platform is moved back onto a wagon. The loading process of the whole train takes **15-20 minutes** (CargoBeamer, 2020c). The transhipment process in CargoBeamer is shown in Fig. 3.

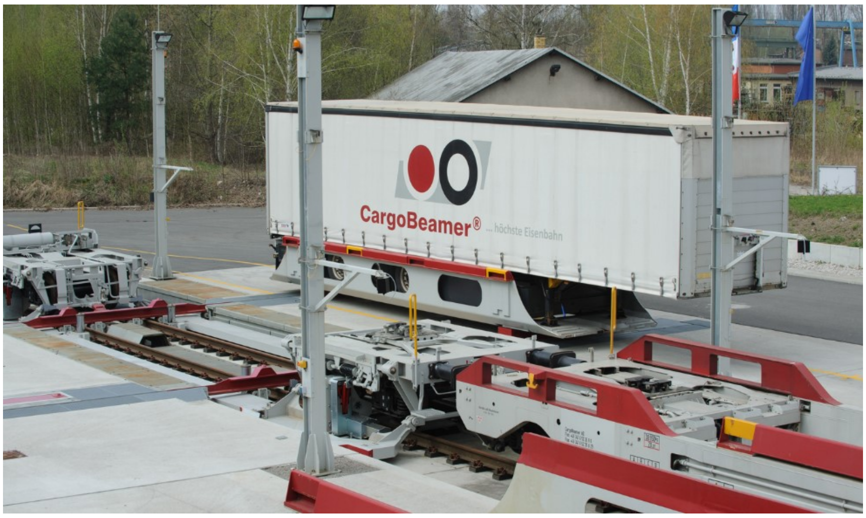

Fig. 3 The CargoBeamer system – horizontal transhipment of standard semitrailer; source: CargoBeamer.

According to CargoBeamer (2020b), a new terminal is under construction in Calais (F). The terminal will be able to unload and load trains with up to 36 semitrailers, in a fully automated process within 20 minutes. The opening of the Calais terminal is scheduled for spring 2021. Routes **from Calais to Great Britain** (via Eurotunnel and ferries) are planned.

CargoBeamer system enables very **quick transhipment of semitrailers between two trains**, as well. This is beneficial primarily in terminals situated at the area where **different rail-gauges meet** (typically "normal" and "wide"). It is relevant at France-Spain border, Slovakia-Ukraine border etc. Complete transloading process between two trains takes **ca. 1 hour**, compared to 2-3 days "standard practice" when vertical transhipment is used (CargoBeamer, 2010). CargoBeamer system eliminates competitive disadvantage for rail transport compared with road transport.

3.3 Systems of vertical transhipment

3.3.1 Pocket wagons

System of pocket wagons is still the most important system in unaccompanied intermodal transportation. Pocket wagons are suitable for transportation of semitrailers, swap-bodies and ISO (maritime) containers – i.e. they are **highly universal**. Unfortunately, transloading of hereinbefore named ILUs **is always vertical**. In perspective of this paper, solving transportation of semitrailers, it is **a disadvantage for trucking companies** as they need to invest into specially designed **intermodal (cranable) semitrailers**. Intermodal semitrailers are (in comparison with standard ones) more expensive and ca. 300-500 kilograms heavier – i.e. have lower payload. The other possibility is use of NiKraSa or ISU systems, developed for **vertical transhipment of standard semitrailers** (details are further in 3.3.2 and 3.3.3).

The transhipment of semitrailers onto wagons is usually done **vertically by reach-stackers or gantry cranes** (depends on size of a terminal and thus on its equipment). The principle of transhipment (using a gantry crane) is shown in Fig. 4. In the figure, the **yellow rectangles on semitrailers are shown**. On intermodal (cranable) semitrailers they mark places at which a gantry crane or a reach-stacker can grab the semitrailer and lift it.

Fig. 4 The system of pocket wagons – vertical transhipment of intermodal semitrailer; source: LKW WALTER.

The necessity of vertical transloading brings a disadvantage related to railway traffic as well. **The railway track** (railway siding) **can't be electrified.** Transloading procedure in a terminal takes **2-3 hours**, depending especially on the length of a train (number of ILUs transloaded) and on type and number of transloading equipment in a terminal.

3.3.2 NiKraSa

The name comes from German "*Nicht-kranbare Sattelauflieger*" – i.e. "*non-cranable semitrailer*" in English. The system enables vertical transhipment of standard (non-cranable) semitrailers using special platform – a type of trough, similar to the "pallet" used in CargoBeamer system (see section 3.2.2). The whole principle of NiKraSa system is similar to CargoBeamer system but with the difference that **transloading of the platform with semitrailer is always vertical** – see Fig. 5.

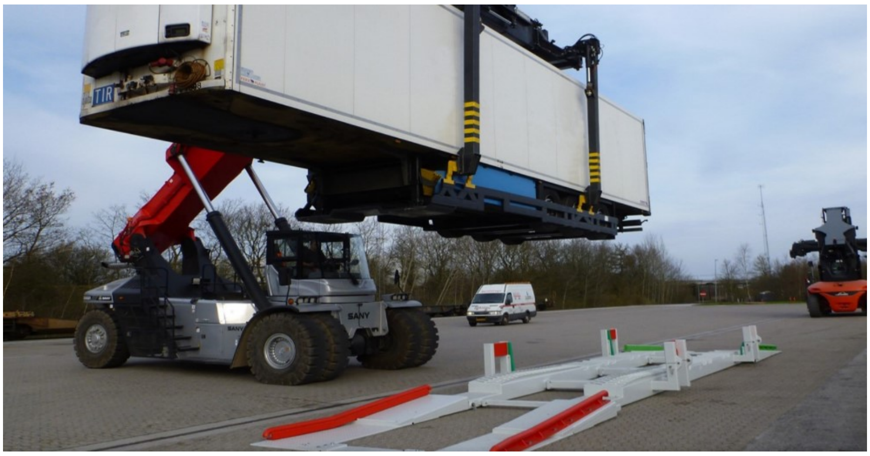

Fig. 5 The NiKraSa system – vertical transhipment of standard semitrailer; source: LKW WALTER.

The platform is positioned next to a train on terminal handling area by a reach-stacker or a gantry crane. Next, a semitrailer is pulled onto the platform using a tractor or a terminal-tractor. The last step is vertical transhipment of the platform with semitrailer into the railway wagon (Nagel-Group, n.d.), (IRJ, 2018). The system was officially launched in 2014.

Currently **these lines are running** (TX Logistik, n.d.), (Klemenčič and Burg, 2018):

1. Padborg (DK) – Verona (I),
2. Herne (D) – Verona (I),

3. Herne (D) – Budapest (H),
4. Bettembourg (L) – Trieste (I),
5. Lübeck (D) – Verona (I),
6. Herne (D) – Lübeck (D).

NiKraSa system is using **standard pocket wagons** (e.g. type *Sdggmrss*) and it **doesn't involve any additional investments into terminals infrastructure**. The utilization of terminals can even be improved implementing NiKraSa system. On the other hand, positioning a semitrailer onto the platform brings potential risk of damage to the semitrailer (Cempírek, 2018).

3.3.3 ISU

The name comes from German "*Innovativer Sattelauflieger Umschlag*" – i.e. "*Innovative semitrailer transhipment*". History of the system goes back to the year 2006. The principle of ISU is **based on special ramp which is placed in a terminal** – and on which a semitrailer is towed by a tractor (or a terminal-tractor). Then, a semitrailer is uncoupled from a tractor. Chain hinges (or textile-straps) are connected to semitrailer's king-pin (via traverse) and to 1st and 3rd axle (via wheel-grippers). Vertical transhipment into a wagon is then done via reach-stacker or gantry-crane (Hafner, 2019), (Possegger, 2012). **Potential risk of damage to semitrailer structure** (mainly to axle aggregate and tyres during lifting) **is disadvantage** of ISU system. Fig. 6 shows positioning of chain hinges at the semitrailer's kingpin and axles (on the left) and vertical transhipment into a railway wagon (on the right).

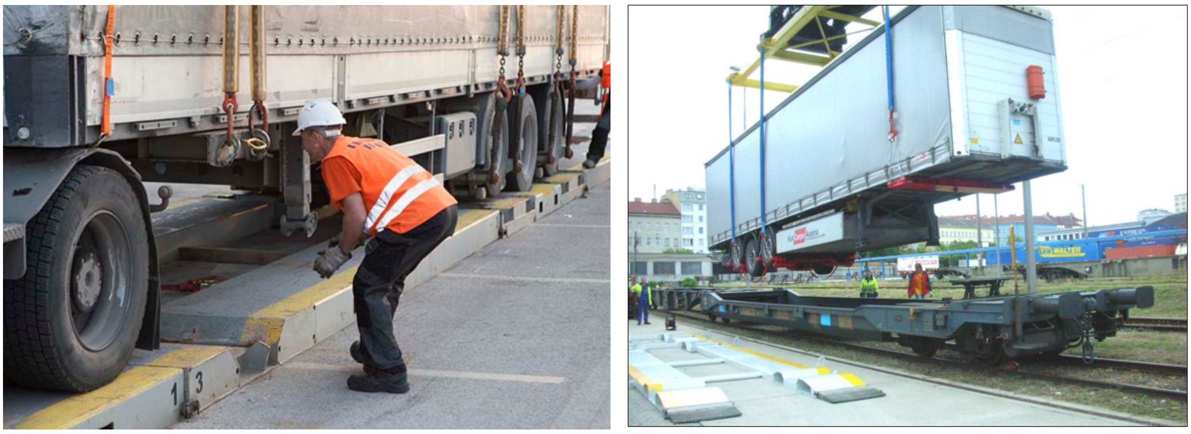

Fig. 6 The ISU system – positioning of chain hinges (left) and vertical transhipment of standard semitrailer (right); source: Intermodale24-rail; Bravo-project.

Pilot routes of ISU system were between *Wels (A) and Istanbul (TR)* and between *Wels (A) and Stara Zagora (RO)* – opened in 2009 and 2010 respectively. Deiterding et al. (2012) says that commercial demonstration is running between *Wels (A) and Curtici (RO)* since 2010. According to Hafner (2019), the line between *Wels (A) and Trieste (I)* is in the run, as well.

4 APPLICATION OF THE MCDM TO IDENTIFY THE MOST SUITABLE SEMITRAILER TRANSPORTATION SYSTEM

In this section we will present **individual steps of the WSA and the TOPSIS methods** and **determine their results**. The comparison of results of both methods and the discussion is presented further in section 5.

4.1 The WSA method

Individual matrixes, corresponding with individual steps, of the WSA method are presented in **Tab. 3** to **Tab. 8**.

Tab. 3 The criteria matrix; source: Authors.

Semitrailer transportation system	rail electrification possibility	investment into cranable semitrailer	number of personnel needed	potential risk of damage to semitrailer	transhipment costs [€]
pocket wagons	0	1	2	1	15
NiKraSa	0	0	2	2	15
ISU	0	0	3	3	30
Modalohr	1	0	2	1	80
CargoBeamer	1	0	1	1	75
criterion type	MAX	MIN	MIN	MIN	MIN

Tab. 4 The matrix of conversion of minimization values to maximization values; source: Authors.

Semitrailer transportation system	rail electrification possibility	investment into cranable semitrailer	number of personnel needed	potential risk of damage to semitrailer	transhipment costs [€]
pocket wagons	0	0	1	2	65
NiKraSa	0	1	1	1	65
ISU	0	1	0	0	50
Modalohr	1	1	1	2	0
CargoBeamer	1	1	2	2	5
criterion type	MAX	MAX	MAX	MAX	MAX

Tab. 5 The matrix of ideal and basal variants; source: Authors.

	rail electrification possibility	investment into cranable semitrailer	number of personnel needed	potential risk of damage to semitrailer	transhipment costs [€]
ideal variant	1	1	2	2	65
basal variant	0	0	0	0	0

Tab. 6 The normalized criterion matrix; source: Authors.

Semitrailer transportation system	rail electrification possibility	investment into cranable semitrailer	number of personnel needed	potential risk of damage to semitrailer	transhipment costs [€]
pocket wagons	0	0	0.50	1.00	1.00
NiKraSa	0	1.00	0.50	0.50	1.00
ISU	0	1.00	0	0	0.77
Modalohr	1.00	1.00	0.50	1.00	0
CargoBeamer	1.00	1.00	1.00	1.00	0.08

Tab. 7 The matrix of criteria weightings; source: Authors.

	rail electrification possibility	investment into cranable semitrailer	number of personnel needed	potential risk of damage to semitrailer	transhipment costs [€]
criteria weightings	0.1	0.3	0.1	0.4	0.1

Tab. 8 The aggregate utility and ranking of variants; source: Authors.

Semitrailer transportation system	the utility of individual variants	the rank of variants
pocket wagons	0.55	4
NiKraSa	0.65	3
ISU	0.38	5
Modalohr	0.85	2
CargoBeamer	0.91	1

The result: according to the WSA method, the best suitable system is **CargoBeamer**. The resulting *aggregate utility* of this variant is **0.91**.

4.2 The TOPSIS method

Individual matrixes, corresponding with individual steps, of the TOPSIS method are presented in **Tab. 9** to **Tab. 16**.

Tab. 9 The criterion matrix; source: Authors.

Semitrailer transportation system	rail electrification possibility	investment into cranable semitrailer	number of personnel needed	potential risk of damage to semitrailer	transhipment costs [€]
pocket wagons	0	1	2	1	15
NiKraSa	0	0	2	2	15
ISU	0	0	3	3	30
Modalohr	1	0	2	1	80
CargoBeamer	1	0	1	1	75
criterion type	MAX	MIN	MIN	MIN	MIN

Tab. 10 The matrix of conversion of minimization values to maximization values; source: Authors.

Semitrailer transportation system	rail electrification possibility	investment into cranable semitrailer	number of personnel needed	potential risk of damage to semitrailer	transhipment costs [€]
pocket wagons	0	0	1	2	65
NiKraSa	0	1	1	1	65
ISU	0	1	0	0	50
Modalohr	1	1	1	2	0
CargoBeamer	1	1	2	2	5
criterion type	MAX	MAX	MAX	MAX	MAX

Tab. 11 The normalized criterion matrix; source: Authors.

Semitrailer transportation system	rail electrification possibility	investment into cranable semitrailer	number of personnel needed	potential risk of damage to semitrailer	transhipment costs [€]
pocket wagons	0	0	0.1429	0.1538	0.0059
NiKraSa	0	0.2500	0.1429	0.0769	0.0059
ISU	0	0.2500	0	0	0.0046
Modalohr	0.5000	0.2500	0.1429	0.1538	0
CargoBeamer	0.5000	0.2500	0.2857	0.1538	0.0005

Tab. 12 The matrix of criteria weightings; source: Authors.

	rail electrification possibility	investment into cranable semitrailer	number of personnel needed	potential risk of damage to semitrailer	transhipment costs [€]
criteria weightings	0.1	0.3	0.1	0.4	0.1

Tab. 13 The weighted criteria matrix; source: Authors.

Semitrailer transportation system	rail electrification possibility	investment into cranable semitrailer	number of personnel needed	potential risk of damage to semitrailer	transhipment costs [€]
pocket wagons	0	0	0.0143	0.0615	0.0006
NiKraSa	0	0.0750	0.0143	0.0308	0.0006
ISU	0	0.0750	0	0	0.0005
Modalohr	0.0500	0.0750	0.0143	0.0615	0
CargoBeamer	0.0500	0.0750	0.0286	0.0615	0

Tab. 14 The matrix of ideal and basal variants; source: Authors.

	rail electrification possibility	investment into cranable semitrailer	number of personnel needed	potential risk of damage to semitrailer	transhipment costs [€]
$\mathbf{H_j}$	0.0500	0.0750	0.0286	0.0615	0.0006
$\mathbf{D_j}$	0	0	0	0	0

Tab. 15 The matrix of distances from ideal and basal variants; source: Authors.

Semitrailer transportation system	distance from ideal variant	distance from basal variant
pocket wagons	0.0913	0.0632
NiKraSa	0.0604	0.0823
ISU	0.0843	0.0750
Modalohr	0.0143	0.1101
CargoBeamer	0.0005	0.1128

Tab. 16 The indicators of relative distance from basal variant and ranking; source: Authors.

Semitrailer transportation system	the indicator of relative distance from basal variant	the rank of variants
pocket wagons	0.41	5
NiKraSa	0.58	3
ISU	0.47	4
Modalohr	0.89	2
CargoBeamer	1.00	1

The result: according to the TOPSIS method, the best suitable system is **CargoBeamer**. Its value of *indicator of relative distance from basal variant* is **1.00** (when considering three decimal numbers: **0.995**).

5 FINDINGS AND DISCUSSION

The authors demonstrated application of MCDM methods on determination of the best suitable semitrailer transportation system in Europe. According to results of both the WSA method and the TOPSIS method, the best suitable system of semitrailer transportation is the **CargoBeamer**. The CargoBeamer belongs to horizontal transhipment systems – i.e. **it is perfectly suitable for trucking companies operating standard (non-cranable) semitrailers**. The vast majority of trucking companies operate this type of semitrailers. At best, only 10% of semitrailers are intermodal (cranable) – i.e. enable vertical transhipment in intermodal transportation terminals.

The **Modalohr** system is the second best according to both methods. It has reached 0.85 (in the WSA method) and 0.89 (in the TOPSIS method). Similar to CargoBeamer, the good rank is caused by the criteria weightings. The system **NiKraSa** has reached the third place – again in both methods: 0.65 in the WSA method and 0.58 in the TOPSIS method. The last two systems (**ISU** and **pocket wagons**) have different positions. According to the WSA method, the fourth place has the system of pocket wagons and the fifth place has the ISU system – according to the TOPSIS method, the rank is vice versa.

In general, the implementation of horizontal transhipment systems for semitrailers will have positive impact on modal-split. Currently, the share of road transport on European transportation market is 75.3%, the share of rail transport is only 18.7%. But, potentially, the rail transport could reach the share of 31-36% (den Boer at al., 2011). At least part of this increase could be due to (thanks to) higher performance of intermodal transportation.

In this paper, the authors have been primarily oriented on suitability of individual systems for trucking companies. If the authors would have chosen different criteria and/or counted different weightings of the same criteria, the results could be different. In the next survey, different criteria and their weightings can be used. We can primarily consider these **cost-related criteria and technical criteria** as:

1. the investment costs into terminals (regarding their location, size and particular system(s) operated),
2. the investment/lease costs into railway wagons designed for individual systems,
3. the capacities of trains used in individual systems (number of ILUs they can transport),
4. the degree of versatility of railway wagons used (regarding transportation possibilities of different types of ILUs).

By implementing hereinbefore mentioned criteria into MCDM methods we will **increase the objectivity of choice** of the best suitable semitrailer transportation system.

6 CONCLUSIONS

The objective of this research study was to introduce functional systems of transportation of semitrailers by rail. After the necessary description of individual systems, the **application of MCDM methods** (the WSA and the TOPSIS) took place. The authors have analysed individual semitrailer transportation systems and their characteristics regarding:

1. **their technology**: possibility of railway-track electrification, number of terminal-personnel needed and transhipment costs,
2. **suitability for trucking-companies**: need of investment into intermodal semitrailer and risks of damage to a semitrailer during transhipment.

The paper provides results of MCDM methods. The results are presented in section 4 and gave the answer on **the research question** defined in section 2.3 – the most suitable system is *horizontal transhipment system* **CargoBeamer**. The WSA method gave result of 0.91 and the TOPSIS method 1.00.

The hypothesis specified in section 2.3 has been **confirmed** – the system identified as the most suitable belongs to horizontal ones.

Corresponding with the discussion in section 5, **further research** should include the survey among representatives of trucking-companies, intermodal transportation operators, terminal operators and authorities, to identify their **needs, possibilities and expectations** towards intermodal transportation. The discussion over **criteria, their values and their importance** should take place, as well.

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