EVALUATION OF SEMI-TRAILER RAIL TRANSPORT TECHNOLOGIES BY USING MULTI-CRITERIA ANALYSIS

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Abstract. The subject of this study are four types of semi-trailer rail transport technologies: Modalohr Horizontal, CargoBeamer, Cargospeed and Megaswing. In this study the methodology to evaluate semi-trailer rail transport technologies has been developed. The methodology is based on multi-criteria analysis and consists of three steps. In the first step quantitative and qualitative criteria for assessment of the studied technologies have been defined. The criteria have been grouped into three main groups - technical, technological and economic. The sub-criteria for each main group have been defined. The technical group of criteria studies six sub-criteria related to the technical parameters of the rolling stock and the load units. The technological group of criteria consists of six sub-criteria related to the technological possibilities of manipulation by using different technologies and periods for manipulation of the loading units. The economic group of criteria includes three sub-criteria related to the investment costs and the equipment costs of each technology. The Shannon Entropy method has been applied in the second step to assess the weights of criteria and sub-criteria. Prioritization of the technologies has been performed in the third step. The PROMETHEE (Preference ranking organization method for enrichment evaluation) method has been applied. The results show that the economic (50%) and technological criteria (45%) have the greatest impact. The technical criteria have little impact (5%). It was found that the Modalohr horizontal is the best variant of semi-trailer rail transport technologies.

Keywords: intermodal transport, semi-trailers, Shannon entropy, PROMETHEE, railway transport, multi-criteria analysis methods.

Introduction

Intermodal transport has grown significantly worldwide over the last decade. According to the International Union for Road-Rail Combined Transport (UIRR), the number of consignments – containers and swap bodies, craneable semi-trailers and complete trucks (Ro-La) delivered by combined transport [1] has increased by more than 50.3% in the recent 10 years. The total number of intermodal consignments transported in 2020 was 4.56 million against 3.03 million in 2010. Transport performance of the intermodal transport during the same period more than doubled from 42.4 billion tkm in 2010 to 89.6 billion tkm in 2020. Transportation of semi-trailers by train occupies a significant part of unaccompanied combined transport. The number of craneable semi-trailers increased by over 127% from 2010 to 2020 - from 300867 units transported in 2010 to 683282 units in 2020. Craneable semi-trailers transported in 2010 accounted for 9.9% of total intermodal consignments. In 2020, craneable semi-trailers accounted for 14.9% of combined transport.

There are two types of transshipment technologies applied for handling of semi-trailers – vertical and horizontal [2]. The vertical technologies are used to manipulate craneable semi-trailers that are loaded onto wagons by means of gantries or mobile cranes equipped with pincers. The specialized for intermodal transport craneable semi-trailers are equipped with two handling zones located on each side of the vehicle. An additional equipment is necessary for vertical handling of non craneable semi-trailers.

The growing interest in the intermodal transport of craneable semi-trailers raises the question of the existing possibilities and technologies for railway transportation of non-specialized for vertical handling conventional semi-trailers. Various technologies have been developed for unaccompanied combined transport of semi-trailers, which are not intended for vertical transshipment. These technologies are based on the use of specialized railway rolling stock and terminal equipment for reloading semi-trailers on wagons. Modalohr Horizontal (Lohr), CargoBeamer, Cargospeed and Megaswing are some of the technologies that offer the ability to load, unload and transportation of non-craneable semi-trailers by train [3]. These technologies are applied for horizontal handling of both types of semi-trailers - craneable and non-craneable, when loading and unloading on wagons. The advantages, disadvantages and opportunities offered by these technologies raise the question of selecting the appropriate technology.

A description and a comparative analysis of the technologies Modalohr Horizontal, CargoBeamer, Cargospeed and Megaswing have been performed in various literature sources [3-7]. The various possibilities by using accompanied and unaccompanied combined transport are discussed in [3]. An analysis of the technologies for unaccompanied combined transport of semi-trailers has been performed in the study. The advantages and disadvantages of the individual technologies are considered.

The technologies for unaccompanied combined transport of non-craneable semi-trailers are compared by the authors through different qualitative and quantitative technical, technological and economic indicators [3; 4; 7-10]. A comparison of selected intermodal transport systems Modalohr Horizontal, CargoBeamer, Cargospeed, Megaswing, etc. is presented in [7; 8]. A comparative analysis of technologies through application of technological, technical and economic criteria has been performed by the authors. An analysis of combined transport terminal operations and an overview of the combined transport in the Baltic Sea Region are presented in [9; 11]. In the reports combined transport terminals, infrastructure elements and equipment, terminal processes, transshipment and organizational characteristics of combined transport terminals are described. An overview of the main characteristics of organization and technology in multimodal and intermodal transport is presented by the authors in [12].

Application of multiple-criteria decision making methods on determination of the best suitable semitrailer transportation system in Europe is presented in [4]. The Weighted Sum Approach and the TOPSIS methods are used by the authors for comparison of some technologies and selection of the appropriate transportation system.

A study of technical trends related to intermodal automated freight transport systems is presented by the authors in [10]. In the paper is given a comparative analysis and review of automated freight transport technologies as Modalohr, Cargospeed, Flexiwagon, etc. Data base and comparative analysis of transshipment technologies for accompanied and unaccompanied combined transport are described in [3]. A review of combined transport technologies and transshipment technologies for the different loading units – containers, semi-trailers and swap bodies has been made by the authors. The most important advantages and disadvantages of combined transport technologies are presented in the research.

The application of different technologies for transportation of semi-trailers is presented in [3; 4; 13]. Currently the Modalohr system is used on lines in France, Luxembourg, Italy, Belgium and Spain. The Cargospeed system was tested in 2006 in Sweden and it is no currently in operation. The CargoBeamer is in operation in Italy, Germany, France and the United Kingdom. Until today there are not realized intermodal relations by using the Megaswing system. It was tested in Germany and Sweden.

The purpose of this paper is to assess semi-trailer rail transport technologies based on the multi-criteria analysis.

Materials and methods

The methodology for assessment of the semi-trailer rail transport technologies consists of the following steps:

- Step 1: Defining quantitative and qualitative criteria for assessment the semi-trailer rail transport technologies. Determination of the alternative semi-trailer rail transport technologies.
- Step 2: Determination of the weights of criteria. In this step the Shannon entropy method is used.
- Step 3: Prioritization of the alternative transport technologies. For this purpose, the PROMETHEE method for ranking the semi-trailer rail transport technologies is applied.

In this study the following groups of criteria including quantitative and qualitative sub-criteria are proposed:

- Technical criteria (TN). This group studies six sub-criteria related to the technical parameters of the rolling stock and the load units (LU).
- Technological criteria (TL). This group consists of six sub-criteria related to the technological possibilities of manipulation by using different technologies and periods for manipulation of the loading units.
- Economic criteria (E). This group includes three sub-criteria related to the investment costs and the equipment costs of each technology.

The sub-criteria for each main group criteria are presented in Table 1.

Table 1

Initial decision matrix

Main groups of criteria	**Sub-criteria**	
Technical criteria (TN)	TN1	Maximum load per LU, t
	TN2	Wagon tare, t
	TN3	Maximum length of LU, m
	TN4	Tare of wagon per one LU, t/LU
	TN5	Area per one module, m^2/module
	TN6	Load limit of one wagon/tare ratio, coef.
Technological criteria (TL)	TL1	Handling time of transshipment process per LU (Unloading and Loading), s
	TL2	Parallel loading and unloading
	TL3	Restrictions - Special terminal requirements
	TL4	Staff per LU/module
	TL5	Transportation of other loading units (containers and Swap bodies)
	TL6	Number of locations of operation lines
Economic criteria (E)	E1	Investment costs/Manipulating area, EUR /m^2
	E2	Cost of transshipment infrastructure (per one transshipment module), EUR /module
	E3	Cost of wagon/Number of LU per wagon, EUR /LU

The sub-criteria TL2, TL3 and TL5 are qualitative, the others are quantitative. The qualitative sub-criteria can take values of 0 or 1. If the answer is "yes", the value of the indicator is "1"; otherwise, the value is "0".

In this research four semi-trailer rail transport technologies are studied:

- Alternative 1 (A1): Modalohr Horizontal (Lohr),
- Alternative 2 (A2): CargoBeamer,
- Alternative 3 (A3): Cargospeed,
- Alternative 4 (A4): Megaswing.

The values of all sub-criteria are placed in the initial decision matrix which rows show the alternatives and the columns correspond to the sub-criteria.

The Shannon Entropy method has been applied in the second step to assess the weights of criteria and sub-criteria. This method uses the data in the initial decision matrix to determine the weights of criteria based also on the information of the numbers. The determined weights are related only to specific data and do not depend on expert assessment. In this sense, this method is not subjective. This concept uses information entropy to determine the weights of the criteria. The information entropy for each sub-criterion is determined as follows, [14]:

$$E_i = -\frac{\sum_{i=1}^{n} p_{ij} ln p_{ij}}{ln n}, \tag{1}$$

where $i = 1, \dots, n$ number of criteria, $j = 1, \dots m$ is the number of alternatives;
E_i – information entropy for each i – th criterion;
p_{ij} – normalized values of initial decision matrix $(x_{ij})_{mxn}$;
n – number of criteria.

$$0 \leq E_i \leq 1 \tag{2}$$

The normalized values p_{ij} are determined as follows:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{3}$$

The weights of criteria are determined using the values of the parameter D_i.

$$w_i = \frac{D_i}{\sum_{i=1}^{n} D_i} \tag{4}$$

$$D_i = 1\text{-}E_i \quad (5)$$

The following conditions are valid:

$$0 \leq w_i \leq 1 , \sum_{i=1}^{n} w_i = 1 \quad (6)$$

The methodology of Shanon entropy is applied for all sub-criteria to determine the global weights. Once the global weights of all sub-criteria have been determined, it is necessary to determine the local weights of the sub-criteria in each main group of criteria.

The local weights of sub-criteria for each main group could be calculated as follows:

$$w_{lk} = \frac{w_{gk}}{\sum_{k=1}^{K} w_{gk}} \quad (7)$$

where w_{gk} – global weighs of sub-criteria in the main group g;
$g = 1, \dots, G$ is the number of the main group criteria;
$k = 1, \dots, K$ is the number of sub-criteria in the main group g;
w_{lk} – local weights of sub-criteria in the main group g.

The global weights of sub-criteria in each main group are these determined by Shannon entropy.

The weights of the main group of criteria are determined based on the pre-determined global weights of all sub-criteria as follows:

$$w_g = \frac{\overline{w_g}}{\sum_{g=1}^{G} \overline{w_g}} \quad (8)$$

$$\overline{w_g} = \frac{\sum_{k=1}^{K} w_{gk}}{K} \quad (9)$$

where w_g – weight of the main group g;
$\overline{w_g}$ – average weight for sub-criteria of the main group g.

The third step of the methodology includes application of the PROMETHEE method to prioritize the technologies. This method is outranking the method of multi-criteria analysis to evaluate the alternatives with respect to criteria, [15]. The type of optimization of criteria has to be set as minimum or maximum. The PROMETHEE method uses also a preference function. There are six types of the preference function - usual criterion; quasi criterion; criterion with linear preference; level criterion; criterion with linear preference and indifference area; Gaussian criterion. PROMETHEE method includes the following main steps: determination for each pair the possible decisions and for each criterion the value of the preference degree; determination of the global preference index for each pair of the possible decisions; determination of the outranking flows for each of the alternatives; determination of the ranking of the criteria for each of the alternatives. The alternatives are ranked according to the values of the net outranking flows. The net outranking flow $\varphi(a_j)$ for the alternative a_j is calculated as a difference between positive $\varphi^+(a_j)$ and negative $\varphi^-(a_j)$ outranking flows:

$$\varphi(a_j) = \varphi^+(a_j) - \varphi^-(a_j) \quad (10)$$

For the net outranking flow, the following conditions are valid:

$$\varphi(a_i) \in [-1; 1]; \sum_{i=1}^{m} \varphi(a_i) = 0 \quad (11)$$

The alternatives are classified taking into account the values of the net outranking flows. The best decision is determined according to the highest value of the net outranking flow.

Results and discussion

An analysis of literature sources to determine the values of the sub-criteria for the investigated technologies has been done. Four alternatives for transportation of semi-trailers by train - Modalohr Horizontal (A1), CargoBeamer (A2), CargoSpeed (A3) and Megaswing (A4) are considered in the research.

Transportation of the semi-trailers is carried out with specialized low-floor wagons that have different technical parameters. The length and tare of the Modalohr wagons (LOHR Railway System) is different depending on the type of the wagon – the length of the type UIC1 wagon is 33.87 m, 32.94 m of the type UIC2 (intermediate wagon) and 34.80 m for the type UIC3 wagon. The tare of the wagons is 41.7 t for the type UIC1, 40.7 t for UIC2 and 42.7 t for UIC3. The payload of the wagons is 75.3 t for the type UIC1, 76.3 t for the type UIC 2 and 77.3 t for the type UIC3. The data for the wagon Modalohr type UIC2 and maximum load per a semi-trailer 38 t have been used for comparison of the alternatives in the report.

The tare of the CargoBeamer wagon is 31 t, 24 t of the Cargospeed wagon and 38 t of the 6-axle Megaswing pocket wagon. The load limit of the 6-axle duo Megaswing wagon is 97 t or 48.5 t per a semi-trailer [3; 13]. The length of a single CargoBeamer wagon is 19.3 m, 18.2 m of a single Cargospeed wagon and 34.03 m of a duo 6-axle Megaswing wagon. The maximum length of a semi-trailer is 13.7 m for Modalohr, 14.2 m for CargoBeamer, 16.3 m for Cargospeed and 14.7 m for Megaswing technology [3; 8; 16].

To rank the alternatives, the values of the sub-criteria for each alternative have been determined. To be ensured of comparability between alternatives, the values of some of sub-criteria have been defined as a ratio of their individual parameters. Some of the technologies allow to use double low floor wagons for transportation of two semi-trailers at once (two parking spaces per a wagon). According to the technical parameters of the wagons, the value of the criterion TN4 has been calculated through the tare of one wagon divided by the number of parking spaces per wagon. The criterion TN4 shows what part of the tare of the wagon refers to one parking space.

The area required for operation of the loading and unloading module is expressed through the criterion TN5 (m^2/module). The value of the criterion has been calculated by the data published in [2, 13, 16] and own calculations. The manipulating area for loading or unloading of a 750 m long train is 45600 m^2 (57 m x 800 m) for Modalohr, 16050 m^2 (21.4 m x 750 m) for CargoBeamer, 45900 m^2 (60 m x 765 m) for Cargospeed and 15000 m^2 (20 m x 750 m) for Megaswing technology. The maximum number of wagons per train with the length 750 m is 22 duo wagons for Modalohr, 36 single wagons for CargoBeamer, 40 single wagons for Cargospeed and 21 duo wagons for Megaswing. The maximum number of semi-trailers onto a train is 44 for Modalohr, 36 for CargoBeamer, 40 for Cargospeed and 42 for Megaswing. The number of parking places on a train equals to the number of loading/unloading modules. The value of the sub-criterion TN5 equals of the total area for handling a train with the length 750 m divided by the total number of loading modules.

The value of the sub-criterion TN6 (coef.) equals to the maximum total weight of the semi-trailer divided by the tare of the wagon per one parking place. The values of the quantitative technological sub-criteria (TL1 and TL4) and the requirements of the qualitative technological sub-criteria (TL2, TL3 and TL5) have been determined according to the data in the literature [3, 8].

The handling time of the transshipment process per a loading unit for the alternatives has been studied. The handling cycle consists of basic and preparatory operations. The duration of the handling cycle includes the periods: preparation for unloading the semi-trailer from the wagon; unloading the trailer by a tractor; uncoupling of semi-trailer from the tractor; preparation for loading and coupling the next semi-trailer with the tractor; loading the trailer onto the wagon; uncoupling the semi-trailer from the tractor; finishing operations. The average duration of one handling cycle (TL1) is 339 s for Modalohr, 245 s for CargoBeamer and 380 s for Megaswing. The duration of the handling cycle for the technology Cargospeed is 420 s [13].

Parallel loading and unloading are not possible for the Megaswing technology (sub-criterion TL2). To load the next semi-trailer onto the wagon, it is necessary to complete the unloading of the previous semi-trailer. The other studied technologies – Modalohr, CargoBeamer and Cargospeed allowed parallel unloading and loading, but two tractors are necessary.

An additional terminal facility for loading and unloading of semi-trailers through the Megaswing system is not required. For the systems Modalohr, CargoBeamer and Cargospeed at least two terminals are needed (sub-criterion TL3).

Research of the intermodal relations by using the studied technologies has been done (sub-criterion TL6). The *Modalohr* technology (Groupe LOHR, France) is operating since 2003. The system Modalohr is in operation at terminals of the following 8 intermodal relations: Aiton (Chambéry, France) – Orbassano (Turin, Italy); Bettembourg (Luxembourg) – Le Boulou, Perpignan (France); Calais – Le Boulou (France); Zeebrugge (Belgium) – Paris – Sète (France); Calais (France) – Orbassano (Italy);

Bettembourg (Luxembourg) – Lyon (France); Bettembourg (Luxembourg) – Barcelona (Spain); Calais – Mâcon – Le Boulou (France). The technology *CargoBeamer* (CargoBeamer AG, Germany) is operating since 2013. The system CargoBeamer is in operation on 4 relations: Domodossola (Italy) – Kaldenkirchen (Germany); Domodossola (Italy) – Calais (France)/Ashford (United Kingdom); Perpignan (France) – Calais (France)/Ashford (United Kingdom); Perpignan (France) – Kaldenkirchen (Germany). The technology *Cargospeed* (BLG Consult Gmbh, Germany and The Warbreck Engineering and Dry Dock company Ltd, United Kingdom) was tested in 2006 in Sweden. The system is not in operation. The technology *Megaswing* (Kockums Industries, Sweden) is in production since 2011. The system was tested in Germany and Sweden. There are no realized intermodal relations by using the Megaswing system.

The economic sub-criterion E1 ($EUR \cdot m^{-2}$) has been calculated through the value of the investment costs for construction of the manipulating area divided by the area of the zone. The investment costs for establishing of the terminal infrastructure for the discussed alternatives have been studied [2; 17]. The costs are calculated for the manipulating zone that could be able to serve a train to 750 m length. The investment costs for establishing of the manipulating area for a train to 750 m length are 11 million Euro for Modalohr Horizontal, 16.5 million Euro for CargoBeamer and 20 million Euro for Cargospeed technology. Special terminal equipment is not necessary for the Megaswing technology. The minimal requirement to the handling area is a drivable lane for the tractors and semi-trailers along the railway track.

The sub-criterion E2 (Euro/module) shows the costs for establishing of one transshipment module. The value of the sub-criterion E2 has been calculated through the total investment costs for establishing of the transshipment infrastructure divided by the number of transshipment modules. The value of the economic sub-criterion E3 (Euro/LU) has been calculated through the cost of one wagon divided by the number of the semi-trailers that could be transported on it at the same time (number of parking places on the wagon). The cost of the wagon includes the cost for additional equipment (wagon base – pallets) for the CargoBeamer technology [3; 8]. Table 2 shows the initial decision matrix.

Table 2

Initial decision matrix

Alter-native	**Technical criteria**						**Technological criteria**						**Ecologic criteria**		
	TN1, t	**TN2, t**	**TN3, m**	**TN4,** t/LU	**TN5,** m^2/ module	**TN6, Coef.**	**TL1, s**	**TL2, Coef.**	**TL3, Coef.**	**TL4, count**	**TL5, coef.**	**TL6, count**	**E1,** EUR $\cdot m^{-2}$	**E2,** EUR· $module^{-1}$	**E3,** EUR $\cdot LU^{-1}$
A1	38.00	40.70	13.70	20.35	1036	1.87	339	1	1	1	1	8	241	250000	192500
A2	37.00	31.00	14.20	31.00	446	1.19	245	1	1	0	1	4	1028	445946	400000
A3	38.50	24.00	16.30	24.00	1148	1.60	420	1	1	1	0	0	436	500000	180000
A4	48.50	38.00	14.70	19.00	357	2.55	380	0	0	1	1	0	0	0	150000
type	max	min	max	min	min	max	min	max	min	min	max	max	min	min	min

The type of optimization for each sub-criterion is shown in the last row of the table. The normalized decision matrix is shown in Table 3. Table 4 represents the results of the Shannon entropy method. Table 5 shows the global and local weights of sub-criteria and the weights of the main criteria. Figure 1 illustrates the global weights of all sub-criteria. Figure 2 shows the main criteria weights. It can be seen that the number of locations of operation lines (TL6), the ratio of the investment costs and the manipulating area, and the cost of the transshipment infrastructure per one transshipment module (E2) have the greatest impact on prioritization of the semi-trailer rail transport technologies. The results show that the economic (50%) and technological criteria (45%) have the greatest impact. The technical criteria have little impact (5%).

Table 3

Normalized decision matrix

Alt.	**TN1**	**TN2**	**TN3**	**TN4**	**TN5**	**TN6**	**TL1**	**TL2**	**TL3**	**TL4**	**TL5**	**TL6**	**E1**	**E2**	**E3**
A1	0.235	0.30	0.23	0.22	0.35	0.26	0.24	0.33	0.33	0.33	0.33	0.67	0.14	0.21	0.21
A2	0.228	0.23	0.24	0.33	0.15	0.17	0.18	0.33	0.33	0.00	0.33	0.33	0.60	0.37	0.43
A3	0.238	0.18	0.28	0.25	0.38	0.22	0.30	0.33	0.33	0.33	0.00	0.00	0.26	0.42	0.20
A4	0.299	0.28	0.25	0.20	0.12	0.35	0.27	0.00	0.00	0.33	0.33	0.00	0.00	0.00	0.16

Table 4

Parameters of Shannon entropy method

Param.	**TN1**	**TN2**	**TN3**	**TN4**	**TN5**	**TN6**	**TL1**	**TL2**	**TL3**	**TL4**	**TL5**	**TL6**	**E1**	**E2**	**E3**
E_i	0.00	0.01	0.00	0.01	0.080	0.03	0.01	0.21	0.21	0.21	0.21	0.54	0.33	0.24	0.06
D_i	0.005	0.014	0.002	0.014	0.082	0.027	0.013	0.208	0.208	0.208	0.208	0.541	0.329	0.236	0.060
w_i	0.002	0.007	0.001	0.006	0.038	0.012	0.006	0.096	0.096	0.096	0.096	0.251	0.153	0.110	0.028

Table 5

Weights of criteria and sub-criteria

Main group	**Sub-criteria**	**Global weight w_{gk}**	$\sum_{k=1}^{K} w_{gk}$	**Local weight w_{lk}**	K	$\overline{w_g}$	**Main group weigh w_g**
Technical	TN1	0.002	0.066	0.032	6	0.01	0.05
	TN2	0.007		0.099			
	TN3	0.001		0.011			
	TN4	0.006		0.095			
	TN5	0.038		0.575			
	TN6	0.012		0.188			
Technological	TL1	0.006	0.643	0.010	6	0.11	0.50
	TL2	0.096		0.150			
	TL3	0.096		0.150			
	TL4	0.096		0.150			
	TL5	0.096		0.150			
	TL6	0.251		0.391			
Economic	E1	0.153	0.290	0.527	3	0.10	0.45
	E2	0.109		0.377			
	E3	0.028		0.096			
Total		1.00	1.00	3.00	15.00	0.21	1.00

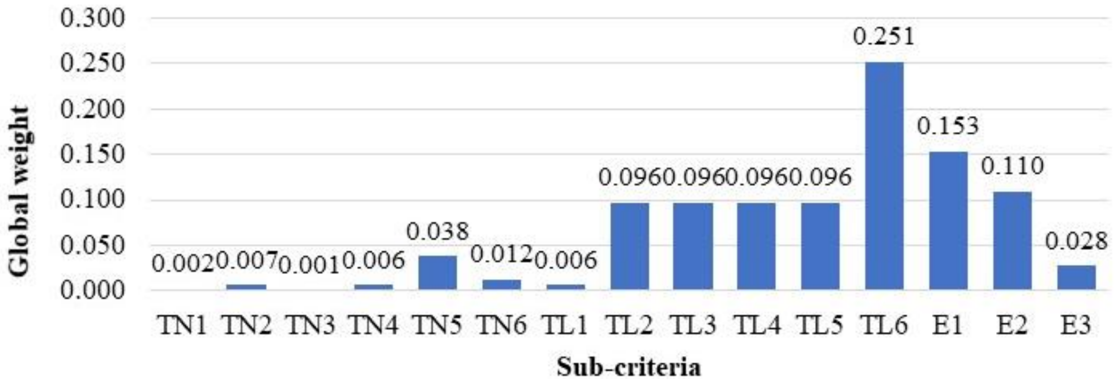

Fig. 1. **Global weights of sub-criteria**

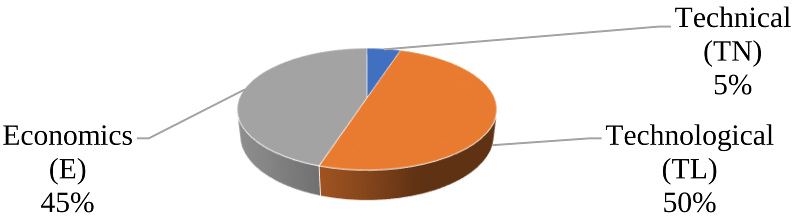

Fig. 2. **Weights of main group criteria**

Visual PROMETHEE software was used for prioritization of the semi-trailer rail transport technologies [18]. The study was conducted in two scenarios: the first consists of all investigated technologies, the second examines only the technology which is in operation, i.e. Modalohr Horizontal and CargoBeamer. Figure 3 illustrates the results of prioritization for the first scenario. The figure consists of two parts: the first shows the ranking based on the net outranking flows, and the second shows the values of the sub-criteria. It was found that the Modalohr horizontal is the best variant of semi-trailer rail transport technologies. Table 6 represents the stability intervals in which the ranking is retained. It can be seen that small stability intervals between 0 and 20% have the following sub-criteria: TN1, TN2, TN5, TL3, E3. This shows that they have a strong influence on the ranking. Figure 4 illustrates the ranking in the case of equal weights of sub-criteria. The results show that in this case the ranking is changed – the best technology is Megaswing. Figure 4 shows the ranking for the second scenario. It can be seen that the Modalohr horizontal is again the best variant of semi-trailer rail transport technologies.

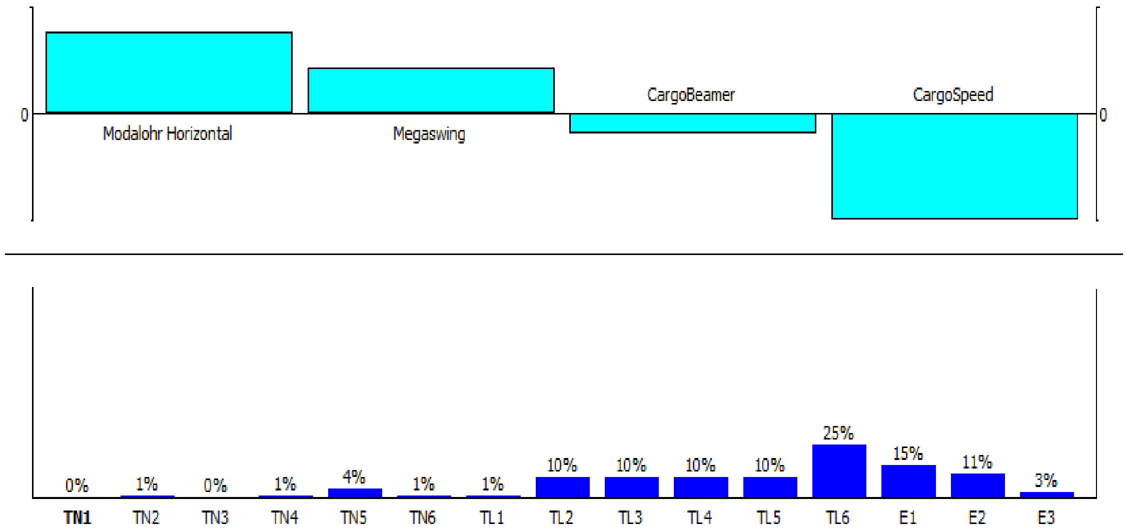

Fig. 3. **Prioritization in Visual PROMETHEE software – scenario 1**

Table 6

Stability level

Level	**TN1**	**TN2**	**TN3**	**TN4**	**TN5**	**TN6**	**TL1**	**TL2**	**TL3**	**TL4**	**TL5**	**TL6**	**E1**	**E2**	**E3**
Lower, %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.79	0.00	0.00	0.00
Upper, %	10.28	18.92	40.08	39.47	13.53	56.06	39.93	100	18.76	100	100	100	30.88	27.28	12.63

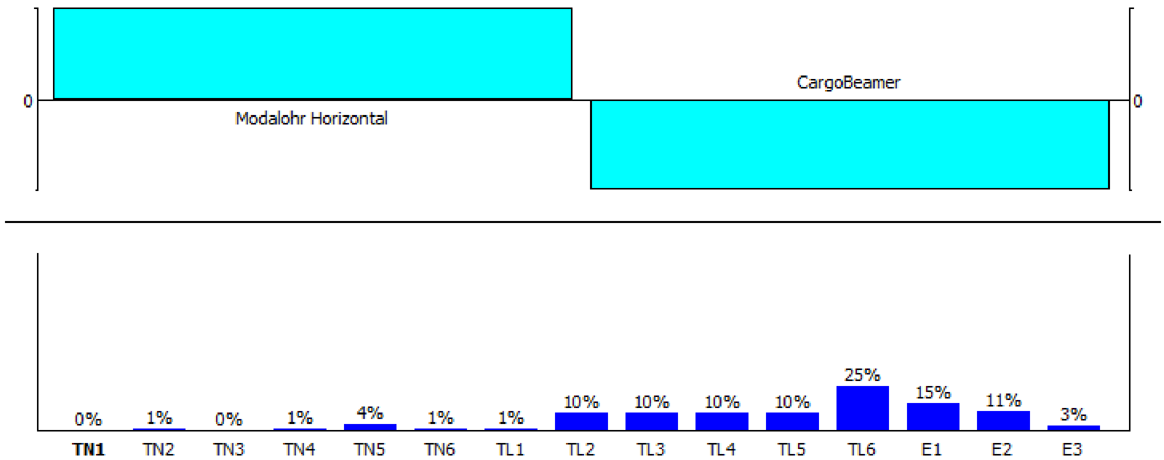

Fig. 4. **Prioritization in Visual PROMETHEE software – scenario 2**

In order to verify the results, a comparison of the results with the actual use of the considered technologies was made. Among the considered technologies for unaccompanied rail transport of semi-trailers, the Modalohr Horizontal technology is in operation on 8 intermodal relations followed by the CargoBeamer technology that is in operation on 4 relations.

Conclusions

1. The paper presents a combination of the Shannon entropy method and PROMETHEE method to evaluate the alternatives of semi-trailer rail transport technologies.
2. The main criteria and sub-criteria have been defined. It was found that economic (50%) and technological criteria (45%) have the greatest impact. The technical criteria have little impact (5%).
3. The most important sub-criterion in the technical group is the area per one module (5%); for the technological group the main sub-criterion is the number of locations of operation lines (25%); for the economics group this is the cost of the transshipment infrastructure per one transshipment module (11%).
4. The results show that according to the sub-criteria the number of locations of operation lines (25%), the ratio of the investment costs and the manipulating area (15%), and the cost of the transshipment infrastructure per one transshipment module (11%) have the greatest impact on prioritization of the semi-trailer rail transport technologies.
5. It was found that the Modalohr Horizontal is the best variant of semi-trailer rail transport technologies.

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Author contributions

Conceptualization, S.S and S.M.; methodology, S.S and S.M.; validation, S.S and S.M; formal analysis, S.S and S.M..; investigation, S.S and S.M.; data curation, S.S and S.M.; writing – original draft preparation, S.S and S.M.; writing – review and editing, S.S and S.M.; visualization, S.S and S.M. All authors have read and agreed to the published version of the manuscript.

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