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Choosing the container handling equipment in a rail-road intermodal terminal through multi-criteria methods

Choosing the container handling equipment in a rail-road intermodal terminal through multi-criteria methods

Svetla D Stoilova[1] and Svetoslav V Martinov

Department of Railway Engineering, Technical University – Sofia, Bulgaria

[1] E-mail: stoilova@tu-sofia.bg

Abstract. The study proposes a methodology based on the combination of multi-criteria methods for choosing the yard handling equipment in a rail-road container terminal. The methodology contains four steps. The alternative variants of the handling equipment have been determined in the first step. Three types of container handling equipment – electric Rail Mounted Gantry crane (RMG), diesel driven Rubber Tyred Gantry crane (RTG) and mobile Reach Stacker (RS), have been considered. The second step is based on a Technical, Economical, Technological and Ecological (TETE) analysis. The sub-criteria for each main TETE group to assess the alternatives have been defined. The alternatives have been assessed by applying of twenty sub-criteria. The weights of the main criteria and the sub-criteria have been determined in the third step by applying Analytic Hierarchy Process (AHP) method. The results of weights given in this step are used in the next fourth step to ranking the alternatives by using Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) method. The sub-criteria that have main impact of the choice of an alternative are procurement costs (11%), annual operation costs (9%), stacking capacity (9%), annual equipment maintenance costs (6%), flexibility (6%) and carbon dioxide emissions (6%). Three variants according the type of terminal as small, medium and large are investigated. The results have been verified by using Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method. It was found that the RS is the suitable alternative for small rail-road terminals, and the RMG is the best one for the medium and large rail-road terminals. The proposed methodology could be applied also to assess other types of handling equipment.

1. Introduction

A part of the freight transport system is the intermodal transport system. It provides an opportunity to transportation of intermodal transport units in an intermodal supply chain in combining different modes of transport – railway, road and waterways. An important element of intermodal hinterland transport of containers to and from ports is the intermodal rail transport. It also is a major transport for continental transport of containers and the other continental load units – swap bodies and semitrailers. A standard intermodal supply chain usually consist a few stages of transportation by using different modes of transport. These stages are: pre-haulage transport to an intermodal terminal, handling of intermodal units in the intermodal terminal, transportation of intermodal transport units by rail and/or ship and end-haulage. In the intermodal supply chains the major stages are transportation by rail for a land-based intermodal supply chain and transportation by ship for a waterway intermodal supply chain.

The intermodal terminals are essential elements of the intermodal transport system. They are the connecting elements, a part of the intermodal system, where the different modes of transport interacts. There are two main groups intermodal terminals in depends on the modes of transport that the terminal serviced. The first group includes intermodal terminals that serve only railway and road transport. The second group intermodal terminals are the trimodal terminals that are situated in an inland waterway or in a maritime port. The three modes of transport – railway, road and ship are serviced in the trimodal intermodal terminals.

The various possibilities for handling of intermodal transport units are determined by a large number of technological and technical characteristics of the intermodal terminals [1, 2]. Various container handling technologies at the terminals are applied globally. The most widely used technologies in the rail-road intermodal terminals [3] are Reach Stackers (RS), Rail Mounted Gantry cranes (RMG), and Rubber Tyred Gantry cranes (RTG). The choice of a handling technology is related to multiple criteria and constraints that have to take into account. In many scientific studies, different criteria for selecting the appropriate intermodal handling technology are used by the authors. Cost analysis for choosing the handling equipment is used by some authors [4-6]. In [4, 7] the authors described the main characteristics of container handling systems in terminals and analysed the factors that affect the total cost of the handling technologies. The design and construction of intermodal terminals from the point of view of expenditures for handling equipment are described in [6].

Different operational attributes, economical cost attributes and management characteristics are used by authors as selection criteria in [8]. In [9] the container loading problem in rail-truck intermodal terminals is discussed by authors considering energy consumption.

Numerous parameters and features influence the choice of technology at intermodal terminals. These parameters could be classified into different groups – economic, technical, operational, etc. As a main characteristic of the intermodal terminals could be qualified the handled volume of containers. It could be determined by the quantity of containers or other intermodal transport units that are handled into the terminal over a certain period of time [1].

In the literature, the intermodal terminals are classified into several main groups according to the handled volume of containers [1, 2, 10, 11]. In [1, 2] the container terminals are classified by the authors in five main groups. The terminals up to 10000 TEU per year and 9000 m^2 terminal area are classified as smallest terminals. And opposite, the terminals over 500000 TEU per year and terminal area 400000 m^2 are classified as large terminals. The terminals are classified by authors [10] in three main groups – small, medium and large terminals with handled volume more than 350 intermodal transport units per day. The terminals are classified [11] in three groups – small, medium and big terminals that handled respectively up to 20000 TEU/year, 20000-100000 TEU/year and over 100000 TEU/year.

The main technical and technological characteristics of the intermodal terminals discussed in [4-6] are cycle time, productivity of handling equipment, fuel consumption of combustion engine handling equipment, energy consumption for electric handling equipment, etc.

The multiple of criteria and constraints in choosing of container handling equipment requires application of multi-criteria methods. Various models based on Multi-Criteria Decision Making (MCDM) methods [12] are used in the literature for selection of container handling equipment in intermodal terminals. In [8, 13] the authors apply AHP analysis for selecting yard cranes in marine container terminals.

The MCDM methods are an appropriate basis for decision-making when many criteria are applied for select an alternative. In general, there are weighting based, distance based and outranking multi-criteria methods to make decision.

The purpose of this study is to elaborate a methodology for choosing the container handling equipment in a rail-road intermodal terminal taking into account different criteria by its nature.

2. Methodology of research

This study proposes a new methodology based on the combination of TETE analysis, AHP [14] and PROMETHEE [15] methods for selecting the most appropriate handling equipment for a rail-road intermodal terminal.

The methodology includes the following steps:

Step 1. Determination the alternatives of handling equipment for a rail-road intermodal terminal.

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Step 2. Definition of quantitative and qualitative criteria for the assessment of alternatives. This step of the model proposes a TETE analysis including Technical, Economics, Technological and Ecological criteria to assess the handling equipment. The sub-criteria for each main criterion of TETE group are defined for the evaluation of the alternatives. The sub-criteria are systematized in four main groups – Technical (sub-criteria C1, C2, C3 and C4), Economics (sub-criteria C5, C6, C7, C8, C9 and C10), Technological (sub-criteria C11, C12, C13, C14 and C15) and Ecological (sub-criteria C16, C17, C18, C19 and C20). In this research the following sub-criteria are proposed:

- C1 – Cycle time, min/move – it is a key characteristic of container handling equipment in the container terminals. It depends of different technical and technological factors. The value of the cycle time is equal of the average time for one move of a container in terminal;
- C2 – Productivity, moves/h – it is a parameter of handling equipment that express the number of movements that could be done per an hour;
- C3 – Energy consumption, kgoe/cont. – it expresses the amount of electricity or diesel fuel consumed to handling of a single container in container terminal. The energy that is consumed is measured by kilograms of oil equivalent per container;
- C4 – Equipment safety, rate – in this study the equipment safety is measured by a rate that indicates the presence of dangerous routes when handling equipment is moving into the container terminal. It is considered that the rail mounted gantry cranes have a higher rate of safety than mobile handling equipment as reach stackers;
- C5 – Annual operation costs, cost ratio – they are expressed by cost ratio between different types of container handling equipment;
- C6 – Annual equipment maintenance costs, % – they are expressed as percent of the initial procurement costs for handling equipment;
- C7 – Container yard development costs, EUR/m^2 – they include costs for engineering, designed and construction of container yard;
- C8 – Container yard maintenance costs, % – the annual maintenance costs of container yard are percent from container yard development costs;
- C9 – Procurement costs, EUR – total procurement costs for container handling equipment in the container terminal;
- C10 – Economic life, years – the expected economic life of the container handling equipment;
- C11 – Number of handlings of a container per number of rows high in the stacking yard, moves/row – relationship between average number of handlings per container at the yard and the average number of rows high of containers in the container yard;
- C12 – Flexibility, rate – it is measured by a rate that indicates the potential for replacement of the container handling equipment if it is necessary. The flexibility of the technology evaluates the ability to replace an existing type of handling equipment in the terminal with another type. In this study the flexibility assesses the existence or absence of a possibility of replacing the handling equipment with another similar or more advanced technology. Restrictions in this respect are imposed by the accompanying infrastructure for RMG cranes (rail-track and power supply). Such restrictions do not exist for the mobile reach stacker;
- C13 – Mobility, rate – it reflects the possibilities of the container handling equipment to handles containers in areas, different from the container stacking area;
- C14 – Stacking capacity, cont./ha – this indicator reflects the average number of containers that could be placed in the terminal stacking area at the same time;
- C15 – Average number of handlings at yard, moves/cont. – average number of handlings per container at the container yard excluding the operations of loading and unloading of the containers from the trucks and the container wagons;
- The ecological sub-criteria in the study are CO_2 emissions (C16), CO emissions (C17), NO_2 emissions (C18), SO_2 emissions (C19) and Particulate matter (PM) emissions (C20). All emissions are equal in kg per container.

Step 3. Determination the weights of criteria. In this step the AHP method is applied.
Step 4. Ranking the alternatives. The PROMETHEE multi-criteria method is proposed to make a decision.
Step 5. Verification of the results. To verify the results obtained by PROMETHEE method we propose other approach of multi-criteria analysis – TOPSIS method [16] that is distance-based.

2.1. Determination the values of the criteria

The study includes quantitative and qualitative criteria. The values of the qualitative criteria are set with values of 1, 2 or 3. The value of 3 shows the best score for the criterion and the value of 1 the lowest. The criteria equipment safety (C4), flexibility (C12) and mobility (C13) are qualitative ones.

A methodology to determine the values of parameters connected to the quantitative criteria has been developed.

The fuel consumption expresses energy consumption of different handling equipment in kilograms of oil equivalent per container (kgoe/cont.). The average energy consumption for engine driven RS and RTG cranes could be equal through:

$$EC = PH\ FC\ 0.83\ 1.01, kgoe/cont., \tag{1}$$

where EC is the energy consumption, kgoe/cont.; PH – the average period for handling of one container in the intermodal terminal, h/cont.; FC – average fuel consumption of one handling equipment per an hour, l/h; 0.83 – the weighs of one litre diesel fuel, kg/l; 1.01 is energy content of 1 kg diesel fuel, kgoe/kg [17].

The average number of container handling equipment in terminal could be equal through:

$$NHE = (PH\ N_{CONT})/WT\ , number, \tag{2}$$

where NHE is the average number of container handling equipment in the terminal; PH – the average period for handling of one container in the terminal, h/cont.; N_{CONT} – the average number of containers handling in the terminal per day, cont./day; WT – the average working time of the container terminal, h/day.

It is assumed that the all container handling equipment are identical and have the same productivity.

$$PH = CT\ MC, h/cont., \tag{3}$$

where CT is the average time cycle of container handling equipment in the terminal, h/move; MC is the average total number of handlings per container in the terminal yard, moves/cont.

$$MC = HCY + 2, moves/cont., \tag{4}$$

where HCY is the average number of handlings per container in the yard of the terminal, moves/cont.

The average number of handlings at yard is determined as follow:

$$HCY = (SH/MSH)\ NH, moves/cont., \tag{5}$$

where SH is the average height of stacking of the containers in container yard, rows; MSH is the maximum stacking height of container handling equipment, rows; NH is average number of handlings per container at yard in depends of container handling equipment [4], moves/cont.

The value of HCY does not include the moves of loading and unloading of a container from trucks and container wagons.

The required container capacity of the intermodal terminal is:

$$RCC = N_{CONT}\ DW, cont., \tag{6}$$

where RCC is required container capacity of the stacking area of the intermodal terminal, cont.; DW – the average dwell time of one container in the yard of the intermodal terminal, days.

The average stacking height in container yard could be determined by:

$$SH = RCC/N_{GS}\ , rows, \tag{7}$$

where N_{GS} is the number of ground slots in container yard, ground slots.

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The land utility of the intermodal terminal could be determined through:

$$SC = RCC/SA\,, cont./ha, \tag{8}$$

where SC is stacking capacity of container yard, cont./ha; SA – stacking area of the container terminal, ha.

The ratio between the average number of handlings per a container and the average stacking height of containers in the stacking area of the terminal is determined through:

$$HHR = HCY/SH\,, moves/row, \tag{9}$$

where HHR is the ratio between average number of handlings at terminal yard per container and the stacking height of containers, moves/row.

The average amount of emissions by pollutants (CO_2, CO, SO_2, NO_2 and PM) released in the atmosphere per container that is handled by an electric container handling equipment is determined through:

$$EM_E = MP\ EL, kg/cont., \tag{10}$$

where EM_E are emissions by pollutants per container, kg/cont.; MP – the mass of the pollutants (CO_2, CO, SO_2, NO_2 and PM) released into the atmosphere for production of electricity, t/kWh; EL – the average value of the electricity needed to handling a container, kWh/cont.

The average amount of emissions by pollutants (CO_2, CO, SO_2, NO_2 and PM) released in the atmosphere from an internal combustion engine of the container handling equipment in the intermodal terminal is:

$$EM_C = PH\ EP\ EF\ LF\ 10^{-3}, kg/cont., \tag{11}$$

where EM_C are non-road engine exhaust emissions by pollutants, kg/cont.; EP – the engine power of non-road engine of the container handling equipment, kW; EF – the emission factor by pollutants, g/kWh; LF – load factor that is the ratio of average load used during normal operations as compared to full load at maximum rated horsepower [18, 19], coef.

To determine the emission CO_2, SO_2, CO, NO_2 and PM of the container handling equipment with diesel combustion engine it is necessary to determine emission factors of different pollutants.

Emission factor for CO_2 of a non-road container handling equipment with diesel combustion engine [20] could be determined through:

$$EF_{CO_2} = (BSFC - HC)\ 0.87\ (44/12), g/kWh, \tag{12}$$

where EF_{CO_2} is emission factor for CO_2, g/kWh; $BSFC$ – the in-use adjusted fuel consumption, g/kWh; HC – the in-use adjusted hydrocarbon emissions, g/kWh; 0.87 – the carbon mass fraction of diesel fuel (87% of carbon by mass), coef.; 44/12 – ratio of CO_2 mass to carbon mass (44 g CO_2 / 12 g C), coef.

Emission factor for SO_2 of a non-road container handling equipment with diesel combustion engine could be determined through [20]:

$$EF_{SO_2} = [BSFC\ (1 - FFS) - HC]\ 0.01\ WPS\ 2, g/kWh, \tag{13}$$

where FFS is the fraction of fuel sulfur converted to direct particulate matter, coef.; 0.01 – the conversion rate from weight percent to weight fraction, coef.; WPS – the weight percent of sulfur in diesel fuel, %; 2 – SO_2 (in grams) formed from a gram of sulfur, g.

Formulas (1-13) are used to determine the values of criteria for each of alternatives. The value of sub-criterion C3 (energy consumption) of technical mean group is determined according formula (1). The values of sub-criterion C9 (procurement costs) of economics main group and sub-criterion C15 of technological main group are determined using formulas (2-5). The values of sub-criteria C11 (number of handlings of a container per number of rows high in yard) and C14 (Stacking capacity) of technological main group are determined by formulas (6-9). The values of ecological criteria are determined by formulas (10-13).

2.2. Determination the weights of criteria by AHP Method

In the study we used the AHP method to determine the weights of criteria. This method is based on experts' assessments and pair-wise comparison of criteria by applying the fundamental Saaty's scale. Table 1 presents Saaty's scale for pair-wise comparison [14, 21].

The experts' assessments are verified by AHP consistency index CR. The value of consistency of the decision-maker has to satisfy the following condition: $CR \leq 0.1$.

Table 1. Saaty's scale for pair-wise comparison.

Explanation	Intensity of importance	Reciprocal values
Equal importance	1	1
Moderate importance	3	1/3
Strong importance	5	1/5
Very strong importance	7	1/7
Extreme importance	9	1/9
Average intermediate values between two close judgments	2; 4; 6; 8	1/2; 1/4; 1/6; 1/8

2.3. Ranking the alternatives of handling equipment by using PROMETHEE Method

The PROMETHEE multi-criteria analysis method is an outranking approach to prioritize the alternatives. In the study, the weights are determined in advance using the AHP method. For each criterion it is necessary to be set the type of optimization – maximum or minimum; the weight; the preference function which characterizes the difference for a criterion between the evaluations obtained by two possible decisions into a preference degree ranking from 0 to 1. The PROMETHEE method uses six basic preference functions: usual criterion; quasi criterion; criterion with linear preference; level criterion; criterion with linear preference and indifference area; Gaussian criterion.

The best alternative is determined according the maximum value of net outranking flows φ_i, which corresponds to the alternative with highest priority. The net outranking flows φ_i of alternative i ($i = 1, \dots, n$) is determined as a difference between the positive outranking flow φ_i^+ and the negative outranking flow φ_i^-. The positive outranking flow shows how much an alternative – outranks the others. The negative outranking flow presents how much an alternative is outranked by the others.

$$\varphi_i = \varphi_i^+ - \varphi_i^-; \varphi_i \in [-1; 1]; \sum_{i=1}^{m} \varphi_i = 0 \tag{14}$$

The explanation and mathematical calculation steps of the PROMETHEE method are given in [15].

2.4. Verification the results by TOPSIS method for ranking the alternatives

To verify the results we used the distance-based multi-criteria decision analysis method. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is based on the principle that best alternative should have the shortest distance from the ideal solution and farthest distance from the negative ideal solution [16]. TOPSIS consists the following steps:

- Step 1: Determination the decision matrix $(x_{ij})_{mxn}$ consisting of *n* alternatives and *m* criteria. Calculation of normalization matrix $(r_{ij})_{mxn}$. The values of normalization matrix are:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}, i = 1, \dots, n; j = 1, \dots, m, \tag{15}$$

where $i = 1, \dots, n$ is the number of alternatives; $j = 1, \dots, m$ – the number of criteria.

- Step 2: Calculate weighted normalized matrix $(v_{ij})_{mxn}$. The elements of this matrix are:

$$v_{ij} = r_{ij}\, w_j; \sum_{j=1}^{n} w_j = 1, \tag{16}$$

where w_j is the weight of criterion j.

- Step 3: Calculate the ideal best v_j^+ and ideal worst v_j^- value for each criterion j.

$$v_j^+ = \min_i v_{ij} \text{ for no benefits criteria; } v_j^+ = \max_i v_{ij} \text{ for benefits criteria;} \quad (17)$$

$$v_j^- = \max_i v_{ij} \text{ for no benefits criteria; } v_j^- = \min_i v_{ij} \text{ for benefits criteria.} \quad (18)$$

- Step 4: Determination the Euclidean distance from the ideal best D_i^+ solution and the Euclidean distance from the ideal worst D_i^- solution.

$$D_i^+ = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^+)^2} \; ; D_i^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^-)^2} \quad (19)$$

- Step 5: Calculate Performance Score C_i that presents the relative closeness of each alternative i with reference to negative ideal measure D_i^- as follow:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \; ; 0 \leq C_i \leq 1. \quad (20)$$

The ranking of the alternatives is based on the C_i values. The higher is the C_i value, the better the alternative.

3. Results and discussion

The object of this study is a rail-road intermodal terminal. It is accepted that the handling of the containers in the terminal is done with identical container handling equipment and all cranes have the same productivity. Three variants for manipulating of containers in the terminal are discussed in the study – Reach Stacker (RS), Rubber Tyred Gantry crane (RTG) and Rail Mounted Gantry crane (RMG). The Reach Stacker and Rubber Tyred Gantry crane are diesel driven by a diesel combustion engine. The Rail Mounted Gantry crane is electricity driven and the crane moves on the fix rail-tracks.

Three types of container terminals have been discussed in the study according to volume – small, medium and large terminal. In the first variant up to 20000 TEU per year (V1) are handled in the terminal. In the second (V2) and third variant (V3) the containers handled in the terminal are between 20000 to 50000 TEU per year and between 50000 to 100000 TEU per year respectively.

The cycle time is a main characteristic of container handling equipment in container terminals. It could be expressed by the average time for one move of a container. The average cycle time for handling equipment is approximately 3-3.5 min for RS, 2.5-3 min for RTG and 2-2.5 min for RMG [4].

In the study we assume an average value of cycle time 3 min/move for RS, 2.5 min/move for RTG and 2 min/move for RMG crane [2, 4]. Productivity expresses the average number of the moves that the container handling equipment performs per an hour. Productivity of RS in container handling is approximately 25 moves/h for loading or unloading of railcars, 15 moves/h for stacking and 10 moves/h for loading or unloading of road trucks. Productivity of RMG cranes in container handling is approximately 30 moves/h for loading or unloading of railcars, 25 moves/h for stacking and 20 moves/h for loading or unloading of road trucks. Productivity of RTG cranes in container handling is approximately 30 moves/h for loading or unloading of railcars, 20 moves/h for stacking and 15 moves/h for loading or unloading of road trucks. The actual productivity of the intermodal terminal handling equipment depends on the work conditions and can be varied. In variant V3 for handled volumes over 55000 TEU/year, 65000 TEU/year and 80000 TEU/year two RS, RTG and RMG cranes are needed in the terminal respectively. The average number of handling equipment that is needed for handling containers at intermodal terminal is shown in table 2.

Table 2. Average number of the handling equipment.

Variant	Volume of terminal, TEU/year	RS	RTG	RMG
V1	up to 20000	1	1	1
V2	20000-50000	1	1	1
V3	50000-100000	2	2	1

The land utility of the stacking area in an intermodal terminal is assessed through storage capacity. The static storage yard capacity of a rail-road intermodal terminal could be determined by the density of the storage area (in cont./ha or TEU/ha) and the average stacking height (rows high).

The different handling systems [3, 7] can be achieved storage yard capacity up to 500 TEU/ha, based on 3-high stacking for RS systems, up to 1100 TEU/ha for RMG cranes and up to 1000 TEU/ha for RTG systems, based on 4-high stacking.

Information about land utility in the stacking area of the intermodal terminal, the number of ground slots and the average stacking height of containers in the terminal for different types of yard handling equipment is shown in table 3. The stacking yard of the terminal is 500 m length at a width of 22 m for RS and between 21 m and 72 m wide for the RTG crane and RMG crane. It is assumed that 20 foot and 40 foot containers are manipulated in the terminal and they are distributed in ratio 50% to 50%.

Table 3. Land utility in the stacking area for Variants 1, 2 and 3 (V1, V2 and V3).

Type of handling equipment	RS			RTG			RMG		
Variant	V1	V2	V3	V1	V2	V3	V1	V2	V3
Stacking height (up to rows)	3	3	3	4+1	4+1	4+1	4+1	4+1	4+1
Total number of ground slots	44-88	88-264	264-396	300	300	300	300	300	300
Number of ground slots per ha (ground slots/ha)	49-84	84-110	93-100	273	273	273	273	273	273
Average stacking height (rows)	1.8	2.3	2.5	0.4	1.3	2.8	0.4	1.3	2.8
Average storage capacity (cont./ha)	88-151	193-253	233-275	109	355	764	109	355	764

Gross electricity generation of Bulgaria was 45.28 TWh in 2016 [17]. In production was being emitted 25.42 million tons CO_2 [22]. The thermal power plant are major sources of pollutions. The main part of the electricity production in Bulgaria is from thermal power plants (over 45%) [23, 24]. On the basis of the produced electricity and the total emissions released by the thermal power plants in 2016 in Bulgaria are defined the values of pollutant emissions from the electricity: CO_2 – 0.56 t/MWh; SO_2 – 0.013 t/MWh; NO_2 – 0.0006 t/MWh; CO – 0.00004 t/MWh; PM – 0.00003 t/MWh.

The values of economics sub-criteria are defined according data given in [2, 4-6]. The values of qualitative criteria equipment safety (C4), flexibility (C12) and mobility (C13) are set with 1, 2 and 3, when 3 is the maximal score.

Studies related to energy consumption for container handling in container terminals indicate different average energy consumption. In [25] authors reported energy consumption of 7.25 kWh per move for an electric rail mounted stacking crane. The values of energy consumption reported in the other studies are 4.4 kWh per TEU [26, 27], 5-7.25 kWh per move [28] and 3.1-4.2 kWh per container [29]. In this study we assume average energy consumption 6 kWh per move for electric RMG crane.

The average fuel consumption of diesel driven container handling equipment depends from the work conditions, the load factor and the type of crane. The fuel consumption of diesel driven mobile cranes and Reach Stacker reported in different studies are 5 litres per km [25], average 3.34 litres per box [30] and 16 litres per an hour [28]. The consumption of diesel fuel for RTG is 24 litres per an hour or 2.4 litres per move at 10 moves per an hour [31]. We assumed 16 litres per hour average fuel consumption for RS and 22.2 litres per an hour for RTG crane. The values of emission factors of CO, NO_2 and PM pollutants have been defined by the limitations of Stage III A/B emission standards for non-road diesel engines category L in the power range between 130 and 560 kW [20, 32]: CO=3.5 g/kWh, NO_2=2.0 g/kWh and PM=0.025 g/kWh. To determine EF_{SO_2} we accept WPS=0.33 % and FFS=0.022.

The safety of the equipment is a parameter that expresses the absence of hostile routes when the handling equipment operating. The RMG crane has the maximum rate from the three alternatives due to the movement on a separate fix rail track. The values of sub-criteria for intermodal terminal with handled volume up to 20000 TEU/year, 20000-50000 TEU/year and 50000-100000 TEU/year are given respectively in table 4.

Table 4. Values of sub-criteria for Variants 1, 2 and 3 (V1, V2 and V3).

Sub-criteria	Dimension	RS			RTG			RMG			Type of optimization
		V1	V2	V3	V1	V2	V3	V1	V2	V3	
C1	min/move	3	3	3	2.5	2.5	2.5	2	2	2	min
C2	moves/h	20	20	20	25	25	25	30	30	30	max
C3	kgoe/cont.	2.21	2.48	2.55	1.78	2.33	3.18	1.19	1.55	2.12	min
C4	rate	1	1	1	2	2	2	3	3	3	max
C5	cost ratio	0.7	0.7	0.7	1	1	1	0.5	0.5	0.5	min
C6	%	5.5	5.5	5.5	6.5	6.5	6.5	4	4	4	min
C7	EUR/m^2	28	28	28	53	53	53	70	70	70	min
C8	%	0.6	0.6	0.6	0.75	0.75	0.75	0.5	0.5	0.5	min
C9	EUR	380000	380000	760000	520000	520000	1040000	700000	700000	700000	min
C10	years	10	10	10	15	15	15	20	20	20	max
C11	moves/row	0.73	0.74	0.72	0.75	0.77	0.75	0.75	0.77	0.75	min
C12	rate	3	3	3	2	2	2	1	1	1	max
C13	rate	3	3	3	2	2	2	1	1	1	max
C14	cont./ha	122	224	262	111	354	758	111	354	758	max
C15	moves/cont.	1.3	1.7	1.8	0.3	1.0	2.1	0.3	1.0	2.1	min
C16	kg/cont.	10.7702	12.0757	12.4020	11.1769	14.5786	19.9241	7.7280	10.0800	13.7760	min
C17	kg/cont.	0.0725	0.0812	0.0834	0.0660	0.0861	0.1177	0.0006	0.0007	0.0010	min
C18	kg/cont.	0.0414	0.0464	0.0477	0.0377	0.0492	0.0672	0.0083	0.0108	0.0148	min
C19	kg/cont.	0.0218	0.0244	0.0251	0.0226	0.0295	0.0403	0.1794	0.2340	0.3198	min
C20	kg/cont.	0.0005	0.0006	0.0006	0.0005	0.0006	0.0008	0.0004	0.0005	0.0007	min

3.1. Determination the weights of criteria

This research uses 7 experts with experience in intermodal transport (academics specialists in freight transportation and managers of transport companies). The experts were asked to perform pairwise comparisons of the main criteria and the sub-criteria. They are given an overall assessment using Saaty's scale. Table 5 shows the results of expert assessment for main TETE group. Tables 6 and 7 present expert assessments for sub-criteria for each main group, and the local weights (LW) and the global weights (GW) of sub-criteria. The local weights are the normalised values that show the weight of each sub-criterion in the group. The global weights show the priority of all sub-criteria taking into account of the weights of main TETE criteria.

Table 5. Pair-wise comparison of main TETE criteria.

Main Criteria	CR=0.05				
	Technical	Economics	Technological	Ecological	Weight
Technical	1	1/2	1/2	1/2	0.14
Economics	2	1	2	2	0.39
Technological	2	1/2	1	2	0.28
Ecological	2	1/2	1/2	1	0.19

Table 6. Pair-wise comparison of sub-criteria of Technical and Economics group criteria.

	Technical group; CR=0.05					
	C1	C2	C3	C4	LW	GW
C1	1	2	1/2	1/2	0.20	0.03
C2	1/2	1	1/2	1/2	0.14	0.02
C3	2	2	1	2	0.39	0.05
C4	2	2	1/2	1	0.27	0.04

	Economics group; CR=0.07							
	C5	C6	C7	C8	C9	C10	LW	GW
C5	1	1	4	2	1/2	3	0.23	0.09
C6	1	1	4	1	1/3	1	0.16	0.06
C7	1/4	1/4	1	1/3	1/2	1/2	0.06	0.03
C8	1/2	1	3	1	1/2	1/2	0.12	0.05
C9	2	3	2	2	1	2	0.29	0.11
C10	1/3	1	2	2	1/2	1	0.14	0.05

Table 7. Pair-wise comparison of sub-criteria of Technological and of Ecological group criteria.

	Technological group; CR=0.04								Ecological group; CR=0.05						
	C11	C12	C13	C14	C15	LW	GW		C16	C17	C18	C19	C20	LW	GW
C11	1	1/2	1	1/2	2	0.17	0.05	C16	1	3	2	2	1	0.31	0.06
C12	2	1	1	1/2	1	0.20	0.06	C17	1/3	1	3	2	1/2	0.19	0.04
C13	1	1	1	1/2	1	0.16	0.04	C18	1/2	1/3	1	1	1/2	0.11	0.02
C14	2	2	2	1	2	0.32	0.09	C19	1/2	1/2	1	1	1/2	0.12	0.02
C15	1/2	1	1	1/2	1	0.15	0.04	C20	1	2	2	2	1	0.27	0.05

The results show that the consistency index CR for all main criteria and sub-criteria satisfy the condition: $CR \leq 0.1$. It was found that the main importance of TETE group has the economics group criteria (39%). The sub-criteria that have main impact of the choice of an alternative are procurement costs C9 (11%), annual operation costs C5 (9%), stacking capacity C14 (9%), annual equipment maintenance costs C6 (6%), flexibility C12 (6%) and CO_2 emissions C16 (6%).

3.2. Ranking the alternatives by using PROMETHEE Method

After determining the weights of the criteria the PROMETHEE method is applied for ranking the handling equipment. The weights of the all sub-criteria determined by AHP method are used in the PROMETHEE method to estimate the alternatives. The study applied the Visual PROMETHEE software to make research [33]. The type of optimization of sub-criteria C2, C4, C10, C12, C13 and C14 are of maximum; for others sub-criteria the optimization is of minimum. A usual preference functions have been set for the sub-criteria C4, C12 and C13; for others sub-criteria have been set the linear preference.

Figures 1, 3 and 5 show the ranking of the handling equipment for studied variants. In the first part of the figures in the ordinate axis are presented the ranking according values of net outranking flows; the second part shows the global weights of the sub-criteria.

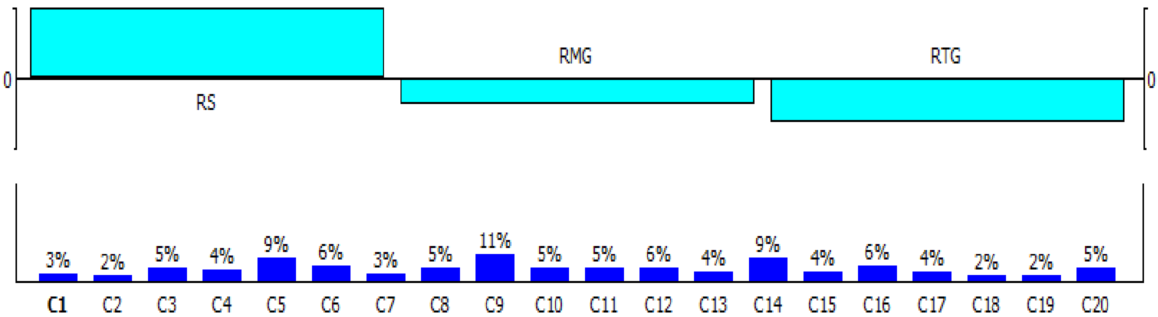

Figure 1. Ranking of alternatives for variant 1 in Visual PROMETHEE Software.

It can be concluded that the RS is the best alternative of handling equipment for variant 1 (up to 20000 TEU/year). The RMG is the best handling equipment for variants 2 and 3 (20000-50000 TEU/year and 50000-100000 TEU/year).

Figure 2 presents the net outranking flows for the criteria according the best alternative RS for variant 1. The main impact of choosing the best alternative has the criteria container yard development costs (C7), procurement costs (C9), flexibility (C12), mobility (C13) and stacking capacity (C14). Figure 4 presents the net outranking flows for the criteria according the best alternative RMG for variant 2. The main impact of choosing the best alternative has the criteria productivity (C2), equipment safety (C4), annual equipment maintenance costs (C6), economic life (C10), stacking capacity (C14) and CO_2 emissions (C16).

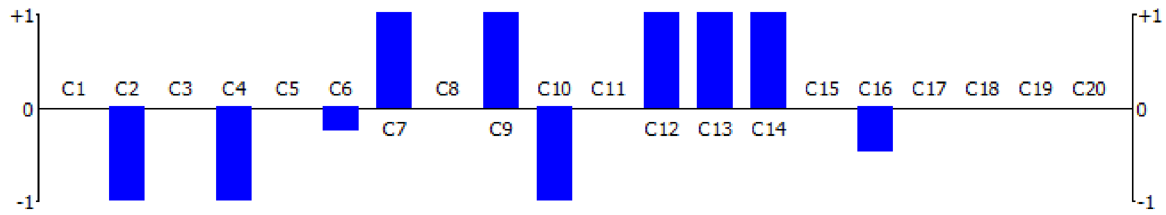

Figure 2. Net outranking flows for all criteria for alternative RS, variant 1.

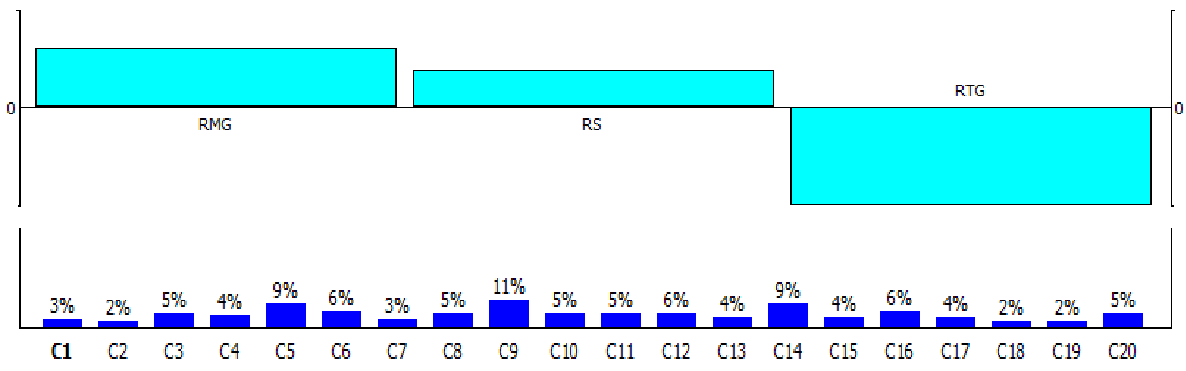

Figure 3. Ranking of alternatives for variant 2 in Visual PROMETHEE Software.

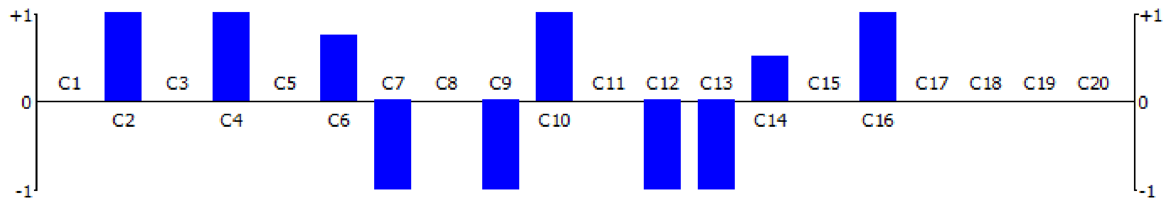

Figure 4. Net outranking flows for all criteria for alternative RMG, variant 2.

Figure 6 presents the net outranking flows for the criteria according the best alternative RMG for variant 3. The main impact of choosing the best alternative has the criteria productivity (C2), equipment safety (C4), annual equipment maintenance costs (C6), procurement costs (C9), economics life (C10), staking capacity (C14) and CO_2 emissions (C16).

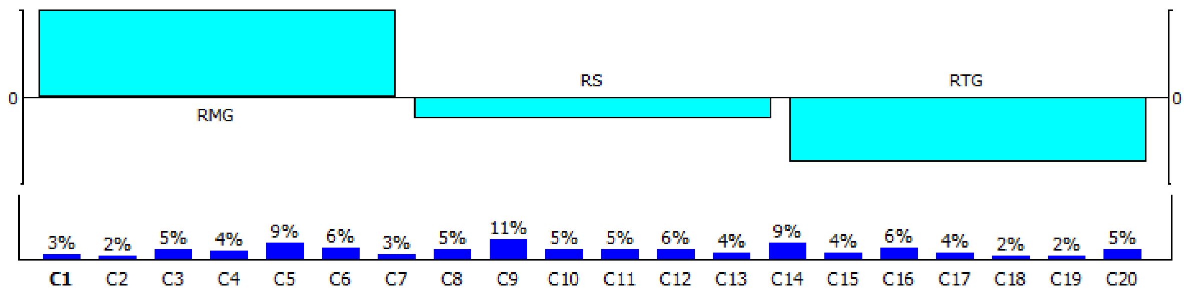

Figure 5. Ranking of alternatives for variant 3 in Visual PROMETHEE Software.

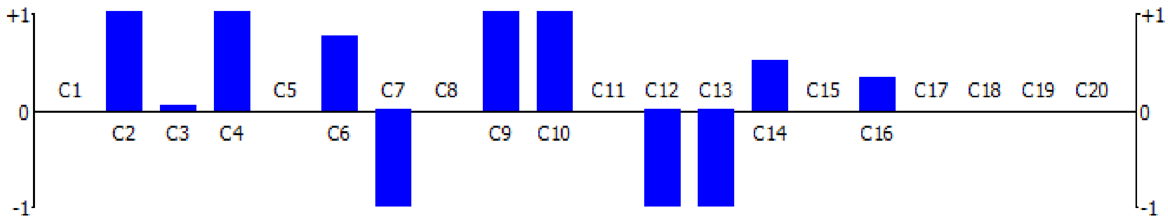

Figure 6. Net outranking flows for all criteria – alternative RMG, variant 3.

The sensitivity analysis was made for the studied variants. Table 8 presents the stability intervals of the weights by variants. The criteria with stability intervals [0-100%] are not given in the table.

Table 8. Stability intervals.

Variant 1	Criteria	C2	C3	C4	C6	C10	C16				
	From, %	0	0	0	0	0	0				
	To, %	11.8	92.2	13.6	23.2	14.5	18. 1				
Variant 2	Criteria	C2	C4	C6	C7	C9	C10	C12	C13	C14	C16
	From, %	1.49	3.34	5.01	0	0	4.50	0	0	8.36	5.0
	To, %	100	100	100	3.73	11.46	100	6.09	4.50	100.0	100.0
Variant 3	Criteria	C7	C12	C13	C16						
	From, %	0.0	0.0	0.0	0.0						
	To, %	14.4	16.2	15.3	45.5						

3.3. Verification the results by TOPSIS method

The results of ranking by PROMETHEE method have been verified by TOPSIS according the methodology. Table 9 presents the values of Euclidean distance from the ideal best D_i^+ solution, the Euclidean distance from the ideal worst D_i^- solution and the values of performance score C_i according formulas (19-20).

Table 9. Ranking by TOPSIS method.

Variant 1					Variant 2					Variant 3				
	D_i^+	D_i^-	C_i	rank		D_i^+	D_i^-	C_i	rank		D_i^+	D_i^-	C_i	rank
RS	0.058	0.073	0.555	1	RS	0.064	0.074	0.534	2	RS	0.079	0.075	0.488	2
RTG	0.080	0.048	0.376	3	RTG	0.080	0.056	0.412	3	RTG	0.079	0.072	0.479	3
RMG	0.061	0.072	0.539	2	RMG	0.062	0.071	0.535	1	RMG	0.051	0.090	0.639	1

The RS is the best alternative for variant 1; the RMG is the best handling equipment for variants 2 and 3. The results for ranking of RS and RMG for variant 2 are close.

Figure 7 presents the comparison of score for alternatives by the both methods for each variant. The scores for PROMETHEE method are the values of net outranking flows, the scores for TOPSIS method are the performance scores. Figure 8 shows the ranking by both methods. It can be concluded that the results are similar.

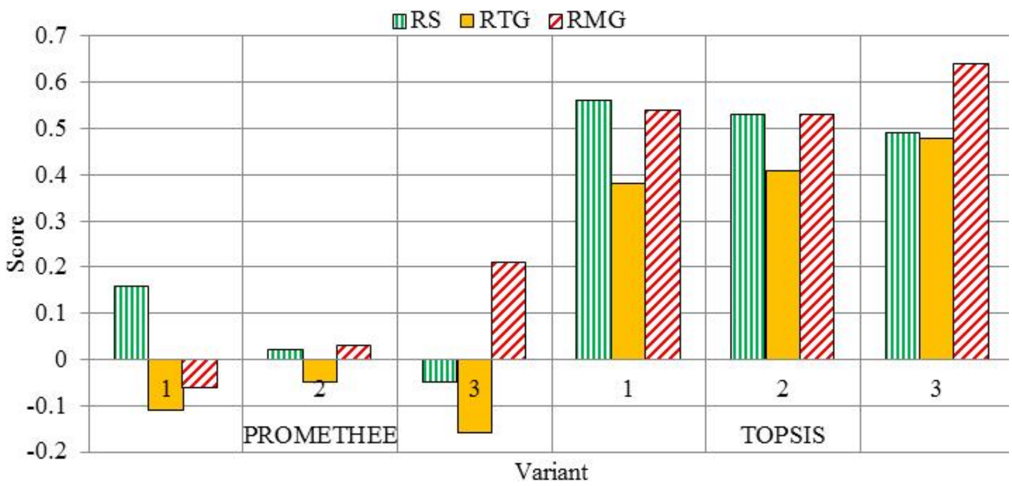

Figure 7. Comparison of results by PROMETHEE method and TOPSIS method.

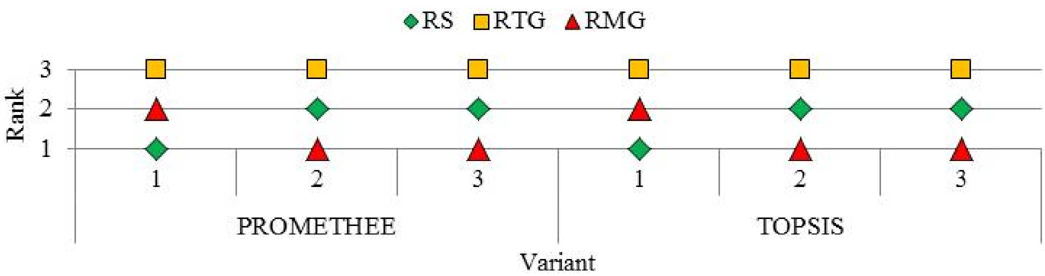

Figure 8. Ranking the handling equipment by PROMETHEE method and TOPSIS method.

4. Conclusion

A methodology for choosing the container handling equipment in a rail-road intermodal terminal has been elaborated. The multi-criteria analysis has been proposed as a tool to make decision. The integration of AHP and PROMETHEE methods have been studied. Three types of container handling equipment – electric Rail Mounted Gantry crane (RMG), diesel driven Rubber Tyred Gantry crane (RTG) and mobile Reach Stacker (RS), have been studied.

The TETE analysis that includes Technical, Economical, Technological and Ecological main groups of criteria has been introduced to study the indices influencing the choice of handling equipment. The sub-criteria for each main group have been determined. A total of twenty quantitative and qualitative criteria have been defined. The weights of main TETE criteria and sub-criteria have been determined by applying AHP method. It was found that the main importance of TETE group has the economics group criteria (39%). The sub-criteria that have main impact of the choice of an alternative are procurement costs C9 (11%), annual operation costs C5 (9%), stacking capacity of the terminal stacking area C14 (9%), annual equipment maintenance costs C6 (6%), flexibility C12 (6%) and CO_2 emissions C16 (6%).

A methodology to determine the values of the quantitative criteria has been developed.

Three types of rail-road terminals have been studied – small, medium and large terminal according the number of TEU per year. The necessary handling equipment from one type has been determined. It was found that the mobile Reach Stacker (RS) is the suitable alternative for small rail-road terminals, and the electric Rail Mounted Gantry crane (RMG) is the best one for the medium and large rail-road terminals.

The results have been verified by applied TOPSIS multi-criteria method. The verification shows that the both methods TOPSIS and PROMETHE give similar results. It can be concluded that the developed methodology and the results obtained are correct.

The elaborated methodology could be applied to investigate real rail-road terminals or to determine the handling equipment when planning a new ones.

The methodology could help to rail-road terminal's operators to make decision when planning the development and the activities of the terminal.

The presented approach, defined criteria and created methodology could be used to investigate and other types of intermodal or freight terminals.

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