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Transport Logistics
Review
Submitted: 21 Mar. 2018
Accepted: 24 Oct. 2018

INTERMODAL TERMINAL HANDLING EQUIPMENT SELECTION USING A FUZZY MULTI-CRITERIA DECISION-MAKING MODEL

ABSTRACT

Intermodal transport enables energy, costs and time savings, improves the service quality and supports sustainable development. The basic element of the intermodal transport system is an intermodal terminal, whose efficiency largely depends on the subsystems' technologies. Accordingly, the topic of this paper is the evaluation and the selection of the appropriate handling equipment within the intermodal terminal. As the decision-making on the handling equipment is influenced by different economic, technical, technological and other criteria, the appropriate multi-criteria decision-making (MCDM) methods have to be applied in order to solve the problem. In this paper, a novel hybrid model which combines the fuzzy step-wise weight assessment ratio analysis (FSWARA) and the fuzzy best-worst method (FBWM) is developed. The defined model is applied for solving the case study of selecting adequate handling equipment for the planned intermodal terminal in Belgrade. The reach stacker is selected as the most adequate handling equipment since it suits best the characteristics of the planned terminal in the given conditions and in relation to the defined criteria. Solving the case study demonstrated the justification for using the MCDM methods to solve these kinds of problems as well as the applicability of the proposed MCDM model.

KEY WORDS

intermodal transport; terminal; handling equipment; fuzzy step-wise weight assessment ratio analysis; fuzzy best-worst method;

1. INTRODUCTION

Economic globalization and market liberalization have led to the separation of production and consumption sites, which initiated the significant growth of the world trade and intercontinental goods flow. The operation of these flows requires the use of different transport modes and generates the need to interconnect them. Moreover, the transport sector faces serious problems as it generates negative economic, social, environmental and other impacts, mainly as a result of the intense growth of the road freight transportation. As the traditional methods of the development and improvement of the individual transport modes are not able to tackle this problem [1], the solution might be the integration of different transport modes achieved through the intense development of the intermodal transportation, with the aim of shifting the freight flows from road to alternative transport modes [2]. Intermodal transport is defined as the movement of goods in a single loading unit or vehicle by successive modes of transport without handling of the goods themselves when changing modes [3]. The main objective is the application of various modes of transport in order to reduce total costs, improve the quality of services, save energy, costs and time, reduce the environmental pollution, etc.

One of the major subsystems of the intermodal transport is the intermodal terminal (IT), representing the place of storage and transshipment of intermodal transport units (ITU) between different modes of transport [4]. The ITs can be of different types [5, 6, 7], dimensions and layouts [8, 9], they can have different structures of functions and subsystems [10, 11], different services [12], etc. Regardless of the differences, the intermodal terminals represent very important nodes of the transport network which serve as a link between different modes of transport. Some of the most commonly solved problems related to the ITs are: IT location selection (e.g. [13, 14, 15]), IT capacity planning (e.g. [16]), identification and optimization of the IT components (e.g. [17]), exploring the possibility of using the ITs in the goods and transport flow operations in the urban areas [18], planning of the IT berths schedule (e.g. [19]), evaluation of the logistics performance for freight mode choice at an IT (e.g. [20]), measuring the IT performance (e.g. [21]), modeling the ITs operations (e.g. [22, 23]), container storage problems (e.g. [24, 25]), transshipment optimization (e.g. [26]), spatial optimization of the IT subsystems, i.e., layout optimization (e.g. [27]), etc.

IT planning is a long-term process in which different aspects have to be taken into account. Terminal planners need to make decisions on terminal capacity, terminal size, structure of the functions and subsystems, layout, technologies, etc. Since one of the basic functions of the IT is the manipulation of the ITUs, an adequate decision on handling equipment (HE) largely determines the efficiency and performance of the terminal [28]. The productivity of the IT depends on the efficient use of labor, land and capital [1], and the capital includes, among other things, appropriate handling equipment, which is therefore the subject of numerous studies. By reviewing the literature, the following problems associated with the HE in the IT are identified: deployment of the HE to tasks [28], allocation of the container to the HE [29], the HE performance analysis [30], etc. The selection of an adequate HE stands out as a special problem class. This is a complex problem and one of the main preconditions for the adequate realization of handling operations and the efficient functioning of the IT (e.g. [1, 10, 11, 22]). For the selection of the HE, Huang & Chu [31] modeled the cost function, Vis [32] developed a simulation model, Barysienė [1] used the COPRAS G method, Yang & Liang [33] used a fuzzy AHP method, etc. When selecting the HE, it must be taken into account that ITs develop by stages and that each development stage is characterized by different conditions regarding the volumes of goods and transport flows, the number of users, the range of services, etc. The aim of this paper is the selection of the adequate handling equipment for the intermodal terminal taking into consideration the expected flow volumes, planned terminal development, potential modes of transport, available space, terminal process technologies, etc. This paper solves the case study of the selection of an appropriate handling equipment (HE) for the planned IT in Belgrade. Various types of HE may appear in the IT, but the most frequently used types of small capacity HE (e.g. [1, 10, 23, 30]) were selected for this case study, such as: front lift tractor, side loader, reach stacker, self-loading trailer and straddle carrier, which, according to their characteristics, best suit the requirements of the planned IT in Belgrade. These types of HE have a smaller capacity, they are cheaper, can be used both for the transshipment and for the internal horizontal transport and are especially suitable for use in the initial stages of the IT development.

For deciding on the most suitable HE in the given circumstances, it is necessary to consider a large number of technical, technological and economic criteria. Therefore, this is a complex multi-criteria decision-making (MCDM) problem, and its solution requires the use of appropriate methods. In this paper, a novel hybrid MCDM model which combines the fuzzy step-wise weight assessment ratio analysis (FSWARA) and the fuzzy best-worst method (FBWM) is developed for solving the defined problem. The FSWARA method is applied for obtaining the weights of the criteria for evaluating the potential HE, while the FBWM is used for evaluating the alternatives, i.e., the potential HE, and for the final ranking and selection of the most favorable one in relation to the considered criteria. The model is developed in the fuzzy environment since the fuzzy logic can effectively cope with the ambiguity of thinking and expressing the preferences by the decision makers (DMs).

The step-wise weight assessment ratio analysis (SWARA) method was developed by Keršulienė et al. [34]. The method is used to determine the criteria weights on the basis of criteria importance order (from the most important to the least important) defined by a DM or a group of DMs. The DMs evaluate the criteria according to their knowledge, experience and available information. In recent years, the SWARA method alone, or in a combination with some other methods, has found application for problem solving in various areas: supplier selection [35], product design [36], prioritization of the sustainability indicators in energy systems [37], selection of machine tools [38], landslide risk assessment [39], etc. However, as Mardani et al. [40] stated, this method is not used to the extent it was expected, therefore the popularization of the method and its application in the field of intermodal transport, in which it has not been used until now, is one of the contributions of this paper. The main advantages of the SWARA method compared to the other MCDM methods are that it is easy to use, the problem solving algorithm is not complicated and can be easily understood by the less experienced users, does not require a lot of time for implementation, can be applied equally well for group decision-making as well for decision-making by one DM, the required number of comparisons (evaluation) is not large (considerably smaller than, for example, in AHP or ANP methods), does not require a consistency check since it is ensured by arranging the criteria in a decreasing order, the method is very flexible and there is no need for a predefined scale for criteria comparison [40]. However, although the SWARA method is a good technique for evaluating problems and making decisions, DMs' judgments on decision factors are often imprecise, vague and ambiguous due to incomplete information or inability of their treatment in a decision environment. On the other hand, fuzzy set theory [41] can efficiently deal with the vagueness in thinking and expressing preferences of the DMs. There are no papers in the literature where the SWARA method is extended into the fuzzy environment.

The best-worst method (BWM) was developed by Rezaei [42], and it is based on the fact that the DM determines the best (i.e., the most desirable, the most important) and the worst (i.e., the least desirable, the least important) criterion, after which the pair-wise comparisons of these criteria (the best and the worst) with all the other criteria is performed. In order to determine the importance (weights, values) of the criteria, it is necessary to formulate and solve the maximin problem. The same procedure can also be applied to determine the significance of the alternative, but for obtaining the final values in this case it is necessary to summarize the values of the alternatives in relation to each criterion used for the evaluation. In the past few years, the BWM, either independently or in the combination with some other methods, has found wide application for problem solving in various areas: supply chain sustainability estimation [43, 44], supplier selection [45, 46], evaluation of the quality of services in the airline industry [47], selection of sludge-removing technologies in sewage drains [48], airport evaluation [49], etc. The basic advantages of the BWM in relation to other methods based on the pair-wise comparisons of elements (criteria and alternatives), such as, for example, AHP and ANP methods, arise from differences in comparing the pairs of elements. The greatest problem with the methods based on the pair-wise comparison of the elements is the difficulty in achieving the consistency of comparison matrices in practice [50]. In comparison to other methods, the BWM requires a significantly smaller amount of data on the elements comparison, achieves a significantly higher degree of consistency, which results in more reliable results, minimizes "violation" (situations in which worse assessed elements by the decision makers have a higher resulting value at the end), enables less total deviation (the measure of the Euclidian distance between the weights of the elements and the value of the comparison of the corresponding pair of elements), minimizes duplication because no secondary comparison is performed and has a higher degree of conformity with other MCDM methods (compliance of the obtained results with the results obtained using other MCDM methods) [42, 51]. The problem with the conventional BWM can also be the uncertainty of the DMs in defining the preferences, which can be solved by introducing the fuzzy logic. The extension of the BWM into the fuzzy environment is performed by Mou et al. [52] and Guo & Zhao [51]. These were, until now, the only applications of the FBWM in the literature, which further emphasizes the importance of this paper for the popularization and wider application of the FBWM for solving problems from different fields.

There are not many papers in the literature where MCDM methods are used for the HE selection, i.e., where the HE is selected in such a comprehensive manner that takes into account a large number of criteria. There are also no papers in which the SWARA method is extended into the fuzzy environment, nor works in which the FBWM is combined with some other methods. Accordingly, the main contributions of this paper are the development of the new FSWARA method obtained by extending the conventional SWARA method into the fuzzy environment, development of the new hybrid MCDM model that combines FSWARA and FBWM, popularization of the application of the MCDM in the field of intermodal transportation and highlighting the importance of an adequate selection of the HE in the IT planning as well as the necessity of considering multiple criteria in this procedure.

The remainder of the paper is organized as follows. Section 2 provides the description of the proposed hybrid model for solving the defined problem, with the detailed application steps. The applicability of the model is demonstrated by solving the case study of the HE selection for the planned IT in Belgrade. The case study and the results of the model application are described in Section 3. Section 4 analyzes and discusses the results and the model applicability. The paper ends with the concluding remarks and future research directions.

2. PROPOSED HYBRID MCDM MODEL

In this paper, the novel hybrid MCDM model, which combines the FSWARA and the FBWM, is proposed for solving the defined problem. The general concept of the proposed model is shown in *Figure 1*, and the detailed description of the steps is given in the following.

Step 1: Define the problem structure, i.e., form a set of alternatives and a set of criteria for evaluating the alternatives.

Step 2: Define the fuzzy scale for evaluation of criteria and alternatives by the decision makers. Linguistic terms and corresponding triangular fuzzy values are given in *Table 1*.

Table 1 – Linguistic terms and corresponding fuzzy values

Linguistic term	Abbreviations	Fuzzy scale
None	N	(1, 1, 2)
Very low	VL	(1, 2, 3)
Low	L	(2, 3, 4)
Fairly low	FL	(3, 4, 5)
Medium	M	(4, 5, 6)
Fairly high	FH	(5, 6, 7)
High	H	(6, 7, 8)
Very high	VH	(7, 8, 9)

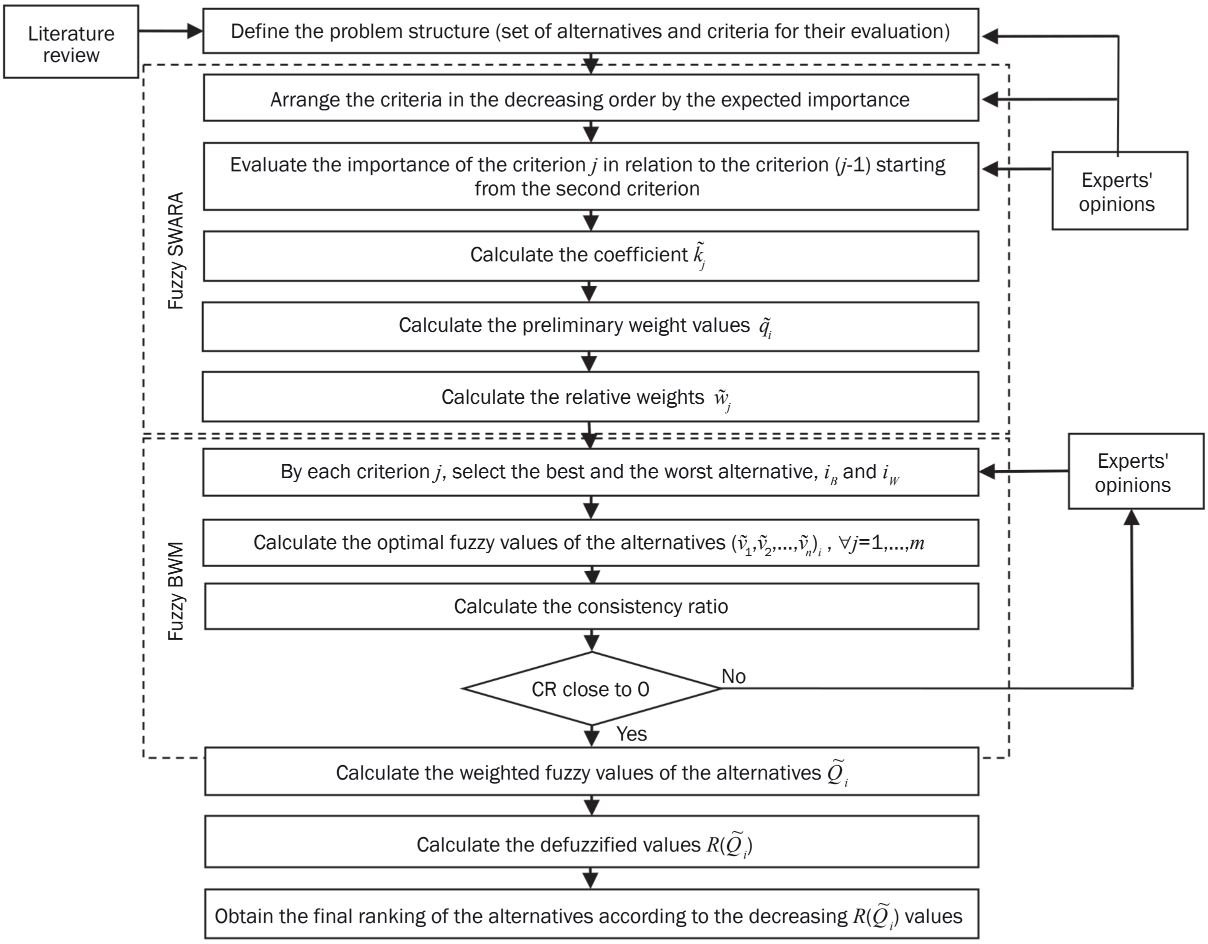

Figure 1 – Concept of the proposed hybrid MCDM model

Step 3: Obtain the criteria weights by applying the FSWARA method. The steps of the method (3.1–3.5) are explained below, and the equations in these steps are obtained by expanding the conventional SWARA method [34] into the fuzzy environment by the authors of this paper.

Step 3.1: Arrange the criteria in a decreasing order by the expected importance.

Step 3.2: Evaluate the relative importance of the criterion j in relation to the criterion (j-1) starting from the second criterion. This relation is called the comparative importance of the average value, and it is denoted as $\tilde{s}_j$, where $\tilde{s}_j=(l_j,m_j,u_j)$, j=1,...,m, is a triangular fuzzy number which corresponds to the linguistic terms given in *Table 1*. l, m and u denote a lower, middle and upper value of the triangular fuzzy number, respectively.

Step 3.3: Calculate the coefficient $\tilde{k}_j$ in the following way:

$$\tilde{k}_j=\begin{cases}(1,1,1), & j=1\\ \left(\dfrac{l_j}{\max\limits_j u},\dfrac{m_j}{\max\limits_j u},\dfrac{u_j}{\max\limits_j u}\right)+(1,1,1), & j>1,\ldots,m\end{cases} \quad (1)$$

Step 3.4: Calculate the preliminary weight values $\tilde{q}_j$ in the following way:

$$\tilde{q}_j=\begin{cases}(1,1,1), & j=1\\ \dfrac{\tilde{q}_{j-1}}{\tilde{k}_j}, & j>1,\ldots,m\end{cases} \quad (2)$$

Step 3.5: Calculate the relative weights $\tilde{w}_j$ in the following way:

$$\tilde{w}_j=\frac{\tilde{q}_j}{\sum_j \tilde{q}_j} \quad (3)$$

Step 4: Evaluate the alternatives by applying the FBWM. The application of the method includes several steps (4.1–4.3) explained below, in which the equations adapted from the paper [51] are used.

Step 4.1: By each criterion j, j=1,...,m, select the best and the worst alternative, i_B and i_W, i=1,...,n, respectively. For each criterion j evaluate all other alternatives in relation to the best and the worst alternative by applying the linguistic terms which can be converted into triangular fuzzy numbers by applying the relations given in *Table 1*. In this way, fuzzy vectors of "the best in relation to others", $\widetilde{A}_B=(\tilde{a}_{B1},\tilde{a}_{B2},\ldots,\tilde{a}_{Bn})$, and "others in relation to the worst", $\widetilde{A}_W=(\tilde{a}_{1W},\tilde{a}_{2W},\ldots,\tilde{a}_{nW})$, are obtained.

Step 4.2: By each criterion j (in relation to which the alternatives are compared) calculate the optimal fuzzy values of the alternatives $(\tilde{v}_1, \tilde{v}_2, \ldots, \tilde{v}_n)_j, \forall j = 1, \ldots, m$ in the following way:

$$\min_i \max \left\{ \left| \frac{\tilde{v}_B}{\tilde{v}_i} - \tilde{a}_{Bi} \right|, \left| \frac{\tilde{v}_i}{\tilde{v}_W} - \tilde{a}_{iW} \right| \right\}$$
$$\text{subject to} \begin{cases} \sum_{i=1}^{n} R(\tilde{v}_i) = 1 \\ l_i^v \le m_i^v \le u_i^v \\ l_i^v \ge 0 \\ i = 1, 2, \ldots, n \end{cases} \tag{4}$$

where, $\tilde{v}_B = (l_B^v, m_B^v, u_B^v)$ is the optimal fuzzy value of the best alternative, $\tilde{v}_W = (l_W^v, m_W^v, u_W^v)$ is the optimal fuzzy value of the worst alternative, $\tilde{v}_i = (l_i^v, m_i^v, u_i^v)$ is the optimal fuzzy value of the alternative i, i=1,...,n, $i \neq i_B, i_W$, $\tilde{a}_{Bi} = (l_{Bi}, m_{Bi}, u_{Bi})$ is the fuzzy value which reflects the degree of importance of the best alternative over the alternative i, $\tilde{a}_{iW}$ =" (l_{iW}, m_{iW}, u_{iW}) is the fuzzy value which reflects the degree of importance of the alternative i over the worst alternative, $R(\tilde{v}_i)$ is the defuzzified value of the fuzzy value $\tilde{v}_i$ obtained by applying the following equation (adapted from [53]):

$$R(\tilde{v}_i) = \frac{l_i^v + 4 \cdot m_i^v + u_i^v}{6} \tag{5}$$

Equation 4 can be transformed into the following nonlinear optimization problem:

$$\min \tilde{\xi}$$
$$\text{subject to} \begin{cases} \left| \frac{\tilde{v}_B}{\tilde{v}_i} - \tilde{a}_{iW} \right| \le \xi \\ \left| \frac{\tilde{v}_i}{\tilde{v}_W} - \tilde{a}_{iW} \right| \le \xi \\ \sum_{i=1}^{n} R(\tilde{v}_i) = 1 \\ l_i^v \le m_i^v \le u_i^v \\ l_i^v \ge 0 \\ i = 1, 2, \ldots, n \end{cases} \tag{6}$$

where $\xi = (l^\xi, m^\xi, u^\xi)$. As $l^\xi \le m^\xi \le u^\xi$, it can be assumed that $\tilde{\xi}^* = (k^*, k^*, k^*), k^* \le l^\xi$, therefore problem *6* can be transformed in the following way:

$$\min \tilde{\xi}^*$$
$$\text{subject to} \begin{cases} \left| \frac{l_B^v, m_B^v, u_B^v}{(l_i^v, m_i^v, u_i^v) - (l_{Bi}, m_{Bi}, u_{Bi})} \right| \le (k^*, k^* k^*) \\ \left| \frac{l_i^v, m_i^v, u_i^v}{(l_W^v, m_W^v, u_W^v) - (l_{iW}, m_{iW}, u_{iW})} \right| \le (k^*, k^* k^*) \\ \sum_{i=1}^{n} R(\tilde{v}_i) = 1 \\ l_i^v \le m_i^v \le u_i^v \\ l_i^v \ge 0 \\ i = 1, 2, \ldots, n \end{cases} \tag{7}$$

By solving *Equation 7*, optimal fuzzy values of the alternatives $(\tilde{v}_1, \tilde{v}_2, \ldots, \tilde{v}_n)$ are obtained, and this procedure needs to be repeated for each criterion j.

Step 4.3: Check the consistency of the comparisons. In order to control the results of the method, it is necessary to calculate the consistency ratio (CR) by applying the equation:

$$CR = \frac{R(\tilde{\xi}^*)}{CI} \tag{8}$$

where $R(\tilde{\xi}^*)$ is the crisp value of the fuzzy value $\tilde{\xi}^*$ obtained by applying *Equation 5*, and CI represents the consistency index which is obtained as the maximum value of the following quadratic equation:

$$CI^2 - (1 + 2u_{BW})CI + (u_{BW}^2 - u_{BW}) = 0 \tag{9}$$

where u_{BW} is the upper value of the fuzzy number $\tilde{a}_{BW} = (l_{BW}, m_{BW}, u_{BW})$ which actually represents the maximum fuzzy value of the comparison of the best element with the other, i.e., all other elements with the worst:

$$\tilde{a}_{BW} = \max_i \{ \tilde{a}_{Bi}, \tilde{a}_{iW} \} \tag{10}$$

The comparison is considered consistent if the CR value is close to 0 [42, 43, 44, 46, 51].

Step 5: Obtain the final ranking of the alternatives. First, it is necessary to obtain the weighted fuzzy values of the alternatives $\tilde{Q}_i$ by applying the following equation:

$$\tilde{Q}_i = \sum_{j=1}^{m} \tilde{w}_j \cdot \tilde{v}_i, \forall i = 1, \ldots, n \tag{11}$$

Afterwards, it is necessary to obtain the defuzzified values $R(\tilde{Q}_i)$ by applying *Equation 5* and arrange them in the decreasing order. In this way the final ranking of the alternatives is obtained.

3. CASE STUDY - SELECTION OF THE HANDLING EQUIPMENT

The ITs can be structured according to different criteria [54], but for the selection of the HE the most important differentiation is based on the size and the intensity of flows, and the connection of transport modes. The proposed model is used to select the most favorable HE at the planned road-rail IT in Belgrade, Batajnica. The IT belongs to a class of smaller road-rail terminals with 1 or 2 transshipment tracks and the throughput of about 80,000 ITUs per year [55]. Larger and medium sized ITs (with 4 or more transshipment tracks) are, as a rule, equipped with gantry cranes for the transshipment of the ITUs and with the additional HE for the transport within the terminal. In smaller ITs, the application of gantry cranes is not justified, therefore HE which can be used for both transshipment and internal transport of units is being used. These pieces of HE are cheaper, simpler to use and can be easier and faster put into use in the initial stages of the IT development.

Size of the terminal and intensity of flows is used as the global criteria based on which the potential types of smaller-capacity HE are defined, while the final HE selection is performed based on 15 criteria divided into 3 sets: technical, economic and technological. Among the technical criteria, the following are taken into account: productivity (C_1), which refers to the possible number of the ITU manipulations in a given period of time; load capacity (C_2) that includes the maximum permissible burden of the HE when manipulating the ITU; speed (C_3), implying the speed at which the HE can move unloaded or loaded by the ITU; load lifting height (C_4), determining the maximum height to which the HE can handle the ITUs to transship, store or retrieve them; required manipulation area (C_5), referring to the surface required for maneuvering the loaded or unloaded HE, the required aisle widths, as well as the necessity of their existence. Considering the economic criteria, the following are defined: purchase price (C_6) that refers to the investment costs needed to purchase a particular HE; maintenance costs (C_7) that include the regular maintenance, servicing, repairs, etc., of the HE; lifetime (C_8), which implies the expected period of use of the HE depending on the working conditions at the IT; operational costs (C_9) that include the costs of the everyday activities of the HE and include the costs of energy, labor, work preparation, etc.; terminal design costs (C_{10}) that relate to the costs required to equip and adapt the terminal and all of its subsystems to work with the selected HE; applicability in the next stage of the terminal development (C_{11}) which implies the possibility of applying the HE in conditions of increased flows volume and alignment with the work of other HE of greater capacity that might appear in the following stages of the IT development. The group of technological criteria includes: integration with other technologies (C_{12}) that refers to the degree of compliance of the HE characteristics with the technologies of other subsystems (e.g. storage); need for planning/organization (C_{13}) that relates to the degree of complexity of the handling operations and the need for planning and organizing operations before their realization; process automation possibility (C_{14}) that refers to the possibility of applying modern technology solutions that enable the automatic realization of the processes and achieving a certain level of the HE autonomy; required training for operating (C_{15}) examines whether the operation of the HE requires special permits and training, and if so, how long does this periods of licensing or training last.

Although another HE may also appear in the IT, such as: rubber-tired gantry crane, rail mounted gantry crane, bridge crane, etc., the following are evaluated as the potential HE: front lift tractor (HE_1), side loader (HE_2), reach stacker (HE_3), self-loading trailer (HE_4) and straddle carrier (HE_5). These types of HE are selected because they are the most commonly used small capacity HEs and most closely correspond to the conditions defined by the planned IT in Belgrade. The front lift tractor (HE_1) and side loader (HE_2) are characterized by a small turning radius and relatively large width of the working aisle. Their purchase price is low, and no special training or license is needed to operate them, but their automation ability is low. In addition, the side loader has lower productivity, load capacity and lifting height than the front lift tractor. The reach stacker (HE_3) is characterized by a high lifting height with a relatively small turning radius. It easily fits with other technologies and has the ability to automate certain processes. On the other hand, its purchase price is slightly higher and it requires a shorter training and operating license. The self-loading trailer (HE_4) is characterized by a low purchase price, high speed of movement and the ability to operate without special training and permits, but it has low productivity, low lifting height and a large turning radius. The straddle carrier (HE_5) is quite expensive, not suitable for the transshipment from the railway, and requires training and special operating license, but it has a high productivity, speed and load capacity, as well as the possibility of complete automation.

After defining the problem structure, i.e., the alternatives (types of HE), and the criteria for their evaluation, it is necessary to obtain the criteria weights using the FSWARA method (Step 3). As described in Step 3.1, first the criteria are arranged in a decreasing order of expected importance. Then, starting from the second criterion, the relative importance of each criterion in relation to the next one in line is evaluated (Step 3.2). Using *Equation 1*, the values $\tilde{k}_j$ for each criterion are obtained (Step 3.3), and then using *Equation 2*, the preliminary weight values $\tilde{q}_j$ are calculated (Step 3.4). The relative criteria weights $\tilde{w}_j$ are obtained using *Equation 3* (Step 3.5). *Table 2* shows the order of the criteria by its relevance for the HE selection, the criteria evaluation by the DM, and the values $\tilde{k}_j, \tilde{q}_j$ and $\tilde{w}_j$ for each criterion.

After obtaining the criteria weights, it is necessary to rank the alternatives (Step 4). The best and the worst alternatives, i_B and i_W, for each criterion are defined and all other alternatives are evaluated in relation to them (Step 4.1) by the DM based on the research of the various HEs belonging to the defined types. Evaluation of the alternatives in relation to the i_B and i_W is shown in *Table 3* on the example of evaluating alternatives in relation to the most important criterion C_6 – purchase price. By solving the non-linear optimization problem (7) for the given values, the optimal fuzzy values of the alternatives $\tilde{v}_i$ with respect to criterion C_6 (Step 4.2) are obtained and also shown in *Table 3*. For the performed evaluation, a consistency ratio is calculated using *Equation 8* in order to determine the consistency of the evaluation by the decision

Table 2 – Results of the FSWARA method for obtaining criteria weights

		$\tilde{s}_j$	$\tilde{k}_j$	$\tilde{q}_j$	$\tilde{w}_j$
C_6	/	/	(1.00,1.00,1.00)	(1.00,1.00,1.00)	(0.269,0.335,0.404)
C_1	L	(2,3,4)	(1.33,1.50,1.67)	(0.60,0.67,0.75)	(0.161,0.224,0.303)
C_{11}	L	(2,3,4)	(1.33,1.50,1.67)	(0.36,0.44,0.56)	(0.097,0.149,0.227)
C_3	M	(4,5,6)	(1.67,1.83,2.00)	(0.18,0.24,0.34)	(0.048,0.081,0.136)
C_4	N	(1,1,2)	(1.17,1.17,1.33)	(0.14,0.21,0.29)	(0.036,0.070,0.117)
C_5	M	(4,5,6)	(1.67,1.83,2.00)	(0.07,0.11,0.17)	(0.018,0.038,0.070)
C_7	VL	(1,2,3)	(1.17,1.33,1.50)	(0.05,0.09,0.15)	(0.012,0.029,0.060)
C_{14}	N	(1,1,2)	(1.17,1.17,1.33)	(0.03,0.07,0.13)	(0.009,0.024,0.052)
C_{12}	L	(2,3,4)	(1.33,1.50,1.67)	(0.02,0.05,0.10)	(0.005,0.016,0.039)
C_9	FL	(3,4,5)	(1.50,1.67,1.83)	(0.01,0.03,0.06)	(0.003,0.010,0.026)
C_2	N	(1,1,2)	(1.17,1.17,1.33)	(0.01,0.02,0.05)	(0.002,0.008,0.022)
C_8	FL	(3,4,5)	(1.50,1.67,1.83)	(0.00,0.01,0.04)	(0.001,0.005,0.015)
C_{13}	N	(1,1,2)	(1.17,1.17,1.33)	(0.00,0.01,0.03)	(0.001,0.004,0.013)
C_{10}	VL	(1,2,3)	(1.17,1.33,1.50)	(0.00,0.01,0.03)	(0.001,0.003,0.011)
C_{15}	N	(1,1,2)	(1.17,1.17,1.33)	(0.00,0.01,0.02)	(0.000,0.003,0.009)

Table 3 – Evaluation of the alternatives in relation to criterion C6 and alternatives' values

			$\widetilde{A}_b$		$\widetilde{A}_b$	$\tilde{v}_i$
HE_1		L	(2,3,4)	FL	(3,4,5)	(0.099,0.136,0.233)
HE_2	I_W	/	/	FH	(5,6,7)	(0.270,0.295,0.313)
HE_3		FL	(3,4,5)	L	(2,3,4)	(0.054,0.093,0.126)
HE_4		VL	(1,2,3)	M	(4,5,6)	(0.146,0.179,0.205)
HE_5	I_B	FH	(5,6,7)	/	/	(0.040,0.043,0.046)

Table 4 – Optimal fuzzy values of the alternatives

		HE_1	HE_2	HE_3	HE_4	HE_5
	$\tilde{w}_j$	$\tilde{v}_i$				
C_1	(0,16;0,22;0,30)	(0,12;0,19;0,20)	(0,05;0,05;0,07)	(0,12;0,19;0,20)	(0,05;0,05;0,05)	(0,23;0,28;0,30)
C_2	(0,00;0,01;0,02)	(0,12;0,12;0,33)	(0,05;0,05;0,12)	(0,12;0,12;0,14)	(0,07;0,07;0,09)	(0,35;0,35;0,42)
C_3	(0,05;0,08;0,14)	(0,07;0,11;0,14)	(0,05;0,07;0,07)	(0,07;0,11;0,14)	(0,23;0,29;0,29)	(0,11;0,18;0,20)
C_4	(0,04;0,07;0,12)	(0,06;0,12;0,15)	(0,05;0,05;0,05)	(0,32;0,37;0,37)	(0,05;0,05;0,08)	(0,12;0,17;0,19)
C_5	(0,02;0,04;0,07)	(0,06;0,08;0,12)	(0,28;0,34;0,34)	(0,05;0,06;0,06)	(0,06;0,08;0,12)	(0,14;0,20;0,22)
C_6	(0,27;0,34;0,40)	(0,10;0,14;0,23)	(0,27;0,29;0,31)	(0,05;0,09;0,13)	(0,15;0,18;0,21)	(0,04;0,04;0,05)
C_7	(0,01;0,03;0,06)	(0,06;0,10;0,12)	(0,10;0,15;0,17)	(0,05;0,06;0,06)	(0,20;0,25;0,25)	(0,16;0,21;0,22)
C_8	(0,00;0,01;0,01)	(0,11;0,16;0,24)	(0,11;0,16;0,20)	(0,11;0,16;0,20)	(0,16;0,24;0,28)	(0,04;0,04;0,04)
C_9	(0,00;0,01;0,03)	(0,07;0,09;0,11)	(0,15;0,26;0,26)	(0,06;0,08;0,09)	(0,20;0,26;0,27)	(0,07;0,08;0,11)
C_{10}	(0,00;0,00;0,01)	(0,08;0,14;0,17)	(0,14;0,19;0,22)	(0,05;0,06;0,07)	(0,24;0,32;0,34)	(0,05;0,06;0,06)
C_{11}	(0,10;0,15;0,23)	(0,12;0,17;0,20)	(0,05;0,05;0,06)	(0,33;0,36;0,39)	(0,05;0,05;0,08)	(0,07;0,11;0,15)
C_{12}	(0,01;0,02;0,04)	(0,26;0,26;0,34)	(0,14;0,18;0,29)	(0,14;0,18;0,23)	(0,05;0,05;0,08)	(0,05;0,05;0,06)
C_{13}	(0,00;0,00;0,01)	(0,14;0,22;0,25)	(0,14;0,19;0,21)	(0,11;0,17;0,17)	(0,03;0,03;0,03)	(0,11;0,17;0,17)
C_{14}	(0,01;0,02;0,05)	(0,02;0,12;0,14)	(0,02;0,02;0,24)	(0,03;0,14;0,14)	(0,02;0,24;0,24)	(0,24;0,24;0,26)
C_{15}	(0,00;0,00;0,01)	(0,13;0,19;0,22)	(0,17;0,19;0,22)	(0,10;0,15;0,19)	(0,13;0,19;0,22)	(0,03;0,03;0,03)

Table 5 – Final ranking of the alternatives

	HE_1	HE_2	HE_3	HE_4	HE_5
	$\tilde{w}_j \cdot \tilde{v}_i$				
C_1	(0.02,0.04,0.06)	(0.01,0.01,0.02)	(0.02,0.04,0.06)	(0.01,0.01,0.02)	(0.04,0.06,0.09)
C_2	(0.00,0.00,0.01)	(0.00,0.00,0.00)	(0.00,0.00,0.00)	(0.00,0.00,0.00)	(0.00,0.00,0.01)
C_3	(0.00,0.01,0.02)	(0.00,0.01,0.01)	(0.00,0.01,0.02)	(0.01,0.02,0.04)	(0.01,0.01,0.03)
C_4	(0.00,0.01,0.02)	(0.00,0.00,0.01)	(0.01,0.03,0.04)	(0.00,0.00,0.01)	(0.00,0.01,0.02)
C_5	(0.00,0.00,0.01)	(0.01,0.01,0.02)	(0.00,0.00,0.00)	(0.00,0.00,0.01)	(0.00,0.01,0.02)
C_6	(0.03,0.05,0.09)	(0.07,0.10,0.13)	(0.01,0.03,0.05)	(0.04,0.06,0.08)	(0.01,0.01,0.02)
C_7	(0.00,0.00,0.01)	(0.00,0.00,0.01)	(0.00,0.00,0.00)	(0.00,0.01,0.02)	(0.00,0.01,0.01)
C_8	(0.00,0.00,0.00)	(0.00,0.00,0.00)	(0.00,0.00,0.00)	(0.00,0.00,0.00)	(0.00,0.00,0.00)
C_9	(0.00,0.00,0.00)	(0.00,0.00,0.01)	(0.00,0.00,0.00)	(0.00,0.00,0.01)	(0.00,0.00,0.00)
C_{10}	(0.00,0.00,0.00)	(0.00,0.00,0.00)	(0.00,0.00,0.00)	(0.00,0.00,0.00)	(0.00,0.00,0.00)
C_{11}	(0.01,0.02,0.05)	(0.00,0.01,0.01)	(0.03,0.05,0.09)	(0.00,0.01,0.02)	(0.01,0.02,0.04)
C_{12}	(0.00,0.00,0.01)	(0.00,0.00,0.01)	(0.00,0.00,0.01)	(0.00,0.00,0.00)	(0.00,0.00,0.00)
C_{13}	(0.00,0.00,0.00)	(0.00,0.00,0.00)	(0.00,0.00,0.00)	(0.00,0.00,0.00)	(0.00,0.00,0.00)
C_{14}	(0.00,0.00,0.01)	(0.00,0.00,0.01)	(0.00,0.00,0.01)	(0.00,0.01,0.01)	(0.00,0.01,0.01)
C_{15}	(0.00,0.00,0.00)	(0.00,0.00,0.00)	(0.00,0.00,0.00)	(0.00,0.00,0.00)	(0.00,0.00,0.00)
$\widetilde{Q}_i$	(0.07,0.15,0.30)	(0.10,0.15,0.25)	(0.08,0.18,0.30)	(0.07,0.13,0.22)	(0.07,0.15,0.26)
$R(\widetilde{Q}_i)$	0.160	0.161	0.182	0.136	0.152
Rank	3	2	1	5	4

maker (Step 4.3). The value CR=0.055 is obtained, which is very close to 0, therefore it can be said that the evaluation is consistent.

The previously described procedure was repeated for all other criteria. The optimal fuzzy values of the alternatives in relation to each criterion are shown in *Table 4*.

After obtaining the optimal fuzzy values for each criterion, the weighted fuzzy values of the alternatives $\widetilde{Q}_i$ are calculated using *Equation 11*. By applying *Equation 5*, defuzzified values $R(\widetilde{Q}_i)$ are obtained and then arranged in a decreasing order, forming a final ranking of the alternatives. The weighted and defuzzified values of the alternatives, as well as the final ranking of the alternatives, are shown in *Table 5*.

Based on the presented results, the reach stacker (HE_3) turned out to be the best-ranked alternative, while the worst-ranked alternative is the self-loading trailer (HE_4).

4. ANALYSIS AND DISCUSSION OF RESULTS

The problem solved in this paper involved the selection of the most favorable HE in the initial stage of the development of the IT in Belgrade. The reach stacker (HE_3) was selected as the most suitable HE in the given circumstances and in relation to the defined criteria, with the value of 0.182. In spite of the facts that, according to the most important criterion — purchase price (C_6)—HE_3 is not the best solution and that it generates considerable maintenance (C_7) and operating costs (C_9), it is still ranked as the most appropriate solution since it has very good technical and exploitation features, such as productivity (C_1), loading capacity (C_2), speed (C_3) and lifting height (C_4), in addition to the acceptable amount of the area occupancy (C_5). Besides, this type of HE has a solid lifetime (C_8), requires low terminal design costs (C_{10}), it is applicable in bigger terminals (C_{11}), easily fits with other technologies (C_{12}), has a great capacity of process automation (C_{14}) and does not require significant process planning (C_{13}) nor long-term training of operators (C_{15}), which additionally contributed to its selection. On the other hand, the least favorable HE was the self-loading trailer (HE_4) with the value of 0.136. This HE does not have poor characteristics by the economic criteria (C_6, C_7, C_8, C_9 and C_{10}), except by the applicability in the next stage of the IT development (C_{11}), but has terrible technical and technological characteristics which contributed to its ranking. Except the speed (C_3) and required training (C_{15}), this HE has very weak characteristics by the other criteria from these groups, especially considering the automation possibility (C_{14}) and integration with other technologies (C_{12}). Concerning the other HEs, HE_2 and HE_1 are ranked as the second and the third, with very close values (0.161 and 0.160, respectively), although these HEs have very different characteristics regarding the observed criteria. HE_2 has very good characteristics in terms of C_5 and C_6, as well as solid characteristics concerning the other economic and technological criteria, while it is poorly assessed by most of the technical criteria. HE_3 is well-rated in terms of C_{12} but moderately in relation to most of the other criteria. The HE_5, which is ranked as the penultimate (with the value of 0.152), has very good characteristics in terms of C_2, C_1 and C_{14}, but has very poor characteristics in terms of the other criteria. Relatively poorer characteristics in terms of the very important criteria for the selection process, such as C_1, C_{11}, C_3 etc., mostly contributed to the lower ranking of this HE.

By solving the defined problem, the applicability of the proposed hybrid model that combines the FSWARA and the FBWM is demonstrated. The FBWM is selected for ranking the HE since it obtains even higher comparison consistency than the conventional BWM [51], whose advantages are described with more details in the introduction. As the defined problem also required the weighting of the HE evaluation criteria, the model included the newly developed FSWARA method. This method has been selected due to its advantages as explained in the introduction, while the use of fuzzy extension and defining of the fuzzy linguistic scale considerably facilitated the evaluations and resulted in a more realistic ratio between the criteria weights compared to the conventional method. Criteria weights obtained by the conventional method imply that some criteria are unfairly neglected regarding the significance they should have based on the DM evaluations. The defined model is easy to use, provides fast results, has a high degree of consistency and is particularly suitable for solving large-scale problems because it does not require a large number of comparisons and evaluations of elements (criteria and alternatives), while the fuzzy component of the used methods allows more adequate consideration of the DMs' opinions.

The MCDM model developed in this paper is not limited to the application of the described case study. The model can be applied for selecting the multiple (two or more) HEs that would simultaneously work in an IT, especially since it takes into account criteria such as applicability in the next stage of development, integration with other technologies and process automation possibility, when ranking the potential HE. In this case, the HE types would be selected going down the final ranking list. The model could also be applied for selecting different HEs for bigger ITs, using the same or different criteria depending on the characteristics of the problem, which is confirmed by the examples of the MCDM method use for the selection of the HE for bigger ITs (e.g. [33]). After certain adjustments, the model can also be used to solve MCDM problems in some other areas.

5. CONCLUSION

In the paper, a novel hybrid MCDM model is proposed, which is a universally applicable expert system, the applicability of which is demonstrated by solving a case study of the HE selection for the IT in the initial stages of development. Five potential types of the HE are defined, which, according to their exploitation characteristics, correspond to the expected scope and type of operations. Each HE is characterized by different features and performances, therefore in order to rank them and select the most favorable one in the given circumstances, it was necessary to analyze their applicability in all aspects. For this purpose, fifteen technical, technological and economic criteria have been defined. After solving the case study, it can be concluded that the proposed model represents an adequate MCDM tool that enables quick, easy and efficient solution to the problem. It can also be concluded that smaller ITs at the initial stages of development are better suited to smaller HEs, that are cheaper and easier to use, as well as that among the most commonly used smaller HEs, the most suitable one for the defined problem is the reach stacker, which was obtained as the best solution due to the most favorable relationship between the exploitation characteristics and the costs that it generates.

The proposed model that combines FSWARA and FBWM, as well as the extension of the SWARA method in the fuzzy environment, is the main contribution of this paper. By reviewing the literature, the lack of research using the SWARA method for solving problems from different fields was noted, therefore the contribution of this paper is the popularization of this method as well. There are also not many references where MCDM methods are used for selecting the technologies within intermodal terminals, therefore this is another contribution of this paper. Future research could be directed towards expanding the problem by including various factors that could influence the definition and prioritization of the criteria in a similar manner as in [18]. The model itself could be applied for selecting the HE in the later stages of IT development when higher flow volumes can be expected, or, for bigger terminals, in the way it was done in [33]. The model could also be used to solve some other problems in the field of intermodal transport which can demonstrably be efficiently solved by applying MCDM models and methods, such as, for example, the selection of the IT location [13], the selection of the IT layout [56], the evaluation of the IT development projects [57], etc., as well as for problems in other areas. In addition, the model could also be expanded to include more decision makers advocating the demands of different stakeholders, as was done, for example, in [13]. On the other hand, new hybrid models which would include the proposed model or some of its parts could be developed to address various MCDM problems. The model could also include the methods which would allow unification of the evaluations in the case of multiple decision makers, as well as for the creation of a critical set of criteria or factors (e.g. Delphi method) like in [13].

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IZBOR MANIPULATIVNIH SREDSTAVA U INTERMODALNOM TERMINALU PRIMENOM FAZI MODELA VIŠEKRITERIJUMSKOG ODLUČIVANJA

ABSTRAKT

Intermodalni transport omogućava uštede u energiji, troškovima i vremenu, unapređuje kvalitet usluga i podržava održivi razvoj. Osnovni element sistema intermodalnog transporta su intermodalni terminali čija efikasnost velikim delom zavisi od tehnologije podsistema. U skladu sa tim predmet ovog rada je vrednovanje i izbor odgovarajućih sredstava za manipulisanja transportnim jedinicama u intermodalnom terminalu. Kako na donošenje odluke o izboru manipulativnih sredstava utiču različiti ekonomski, tehnički, tehnološki i drugi kriterijumi, za rešavanje problema je potrebno primeniti odgovarajuće metode višekriterijumskog odlučivanja (VKO). U ovom radu je razvijen novi hibridni model koji kombinuje metode fuzzy step-wise weight assessment ratio analysis (FSWARA) i fuzzy best-worst method (FBWM). Definisani model je primenjen za rešavanje studije slučaja izbora adekvatnog manipulativnog sredstva za planirani intermodalni terminal u Beogradu. Kao najadekvatnije manipulativno sredstvo izabran je teleskopski manipulator jer u najvećoj meri odgovara karakteristikama planiranog terminala u datim uslovima i u odnosu na definisane kriterijume. Rešavanje studije slučaja je demonstriralo opravdanost korišćenja VKO metoda za rešavanje ovakvih problema i primenjivost predloženog VKO modela.

KLJUČNE REČI

intermodalni transport; terminal; manipulativno sredstvo; fuzzy step-wise weight assessment ratio analysis; fuzzy best-worst method;

REFERENCES

[1] Barysienė J. A multi-criteria evaluation of container terminal technologies applying the COPRAS-G method. *Transport*. 2012;27(4): 364-372.

[2] European Commission (EC). *White Paper: Roadmap to a Single European Transport Area – Towards a Competitive and Resource Efficient Transport System.* Brussels; 2011. Available from: http:// eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52011DC0144:EN:NOT [Accessed 16th March 2018]

[3] ECMT – European Conference of Ministers of Transport. *Terminology on combined transport.* Brussels; 1993. Available from: ftp://ftp.cordis.europa.eu/pub/transport/docs/ intermodal_freight transport_en.pdf [Accessed 16th March 2018]

[4] UNECE – United Nations Economic Commission for Europe. *Illustrated glossary for transport statistics.* Luxembourg: Publications Office of the European Union; 2009. Available from: http://www.unece.org/fileadmin/ DAM/trans/main/ wp6/pdfdocs/glossen4.pdf. [Accessed 16th March 2018]

[5] Roso V, Woxenius J, Lumsden K. The dry port concept: connecting container seaports with the hinterland. *Journal of Transport Geography*. 2009;17(5): 338-345. Available from: doi: 10.1016/j.jtrangeo.2008.10.008.

[6] Woxenius J. Alternative transport network designs and their implications for intermodal transhipment technologies. *European Transport – Trasporti Europei*. 2007;35: 27-45.

[7] Sirikijpanichkul A, Ferreira L. 2005. Multi-objective evaluation of intermodal freight terminal location decisions, In: (eds.) *Proceedings of 27th conference: Australian institute of transport research (CAITR), 7-9 December 2005,* Queensland University of Technology (QUT), Brisbane.

[8] Lee BK, Kim KH. Optimizing the block size in container yards. *Transportation Research Part E: Logistics and Transportation Review.* 2010;46(1): 120-135. Available from: doi: 10.1016/j.tre.2009.07.001

[9] Golbabaie F, Seyedalizadeh Ganji SR, Arabshahi N. 2012. Multi-criteria evaluation of stacking yard configuration. *Journal of King Saud University – Science.* 2012;24(1): 39-46. Available from: doi: 10.1016/j.jksus.2010.08.010

[10] Stahlbock R, Voß S. Operations research at container terminals: a literature update. *OR Spectrum.* 2008;30(1): 1-52. Available from: doi: 10.1007/s00291-007-0100-9

[11] Steenken D, Voß S, Stahlbock R. Container terminal operation and operations research – a classification and literature review. *OR Spectrum*. 2004;26(1): 3-49. Available from: doi: 10.1007/s00291-003-0157-z

[12] Hsu WKK. Improving the service operations of container terminals. *The International Journal of Logistics Management.* 2013;24(1): 101-116. Available from: doi: 10.1108/IJLM-05-2013-0057

[13] Zečević S, Tadić S, Krstić M. Intermodal transport terminal location selection using a novel hybrid MCDM model. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*. 2017;25(6): 853-876. Available from: doi: 10.1142/S0218488517500362

[14] Roso V, Brnjac N, Abramovic B. Inland Intermodal Terminals Location Criteria Evaluation: The Case of Croatia. *Transportation Journal*. 2015;54(4): 496-515. Available from: doi: 10.5325/transportationj.54.4.0496

[15] Vidović M, Zečević S, Kilibarda M, Vlajić J, Bjelić N, Tadić S. The p-hub model with hub-catchment areas, existing hubs, and simulation: A case study of Serbian intermodal terminals. *Networks and Spatial Economics*.

2011;11(2): 295-314. Available from: doi: 10.1007/s11067-009-9126-7

[16] Garcia TR, Cancelas NG, Soler-Flores F. Setting the port planning parameters in container terminals through bayesian networks. *Promet – Traffic & Transportation*. 2015;27(5): 395-403. Available from: doi: 10.7307/ptt.v27i5.1689

[17] Stojkovic M, Twrdy E. A decision support tool for container terminal optimization within the berth subsystem. *Transport*. 2015;31(1): 29-40.

[18] Tadić S, Zečević S, Krstić M. A novel hybrid MCDM model based on fuzzy DEMATEL, fuzzy ANP and fuzzy VIKOR for city logistics concept selection. *Expert Systems with Applications.* 2014;41(18): 8112-8128. Available from: doi: 10.1016/j.eswa.2014.07.021

[19] Zhang Q, Zeng Q, Yang H. A lexicographic optimization approach for berth schedule recovery problem in container terminals. *Transport*. 2016;31(1): 76-83.

[20] Kunadhamraks P, Hanaoka S. Evaluation of logistics performance for freight mode choice at an intermodal terminal, In: Taniguchi E, Thompson RG (Eds.) *Recent Advances in City Logistics,* Elsevier Science Ltd: 2005. p. 191-205.

[21] Wang Y. Performance Evaluation of International Container Ports in Taiwan and Neighborhood Area by Weakness and Strength Indices of FMCDM. *Journal of Testing and Evaluation.* 2016;44(5): 1840-1852. Available from: doi: 10.1520/jte20140326

[22] Carlo HJ, Vis IFA, Roodbergen KJ. Storage yard operations in container terminals: Literature overview, trends, and research directions. *European Journal of Operational Research.* 2014a;235: 412-430. Available from: doi: 10.1016/j.ejor.2013.10.054

[23] Carlo HJ, Vis IFA, Roodbergen KJ. Transport operations in container terminals: Literature overview, trends, research directions and classification scheme. *European Journal of Operational Research.* 2014b;236: 1-13. Available from: doi: 10.1016/j.ejor.2013.11.023

[24] Eliiyi DT, Mat G, Özmen B. Storage optimization for export containers in the port of Izmir. *Promet – Traffic & Transportation*. 2013;25(4): 359-367. Available from: doi: 10.7307/ptt.v25i4.1170

[25] Zhang C, Liu J, Wan Y, Murty KG, Linn RJ. Storage space allocation in container terminals. *Transportation Research Part B.* 2003;37: 883-903. Available from: doi: 10.1016/S0191-2615(02)00089-9

[26] Jurjević M, Hess S. The operational planning model of transhipment processes in the port. *Promet – Traffic & Transportation*. 2016;28(2): 81-89. Available from: doi: 10.7307/ptt.v28i2.1815

[27] Taner ME, Kulak O, Koyuncuoglu MU. Layout analysis affecting strategic decisions in artificial container terminals. *Computers & Industrial Engineering.* 2014;75: 1-12. Available from: doi: 10.1016/j.cie.2014.05.025

[28] Lau HYK, Zhao Y. Integrated scheduling of handling equipment at automated container terminals. *International Journal of Production Economics.* 2008;112: 665-682. Available from: 10.1016/j.ijpe.2007.05.015

[29] Zaghdoud R, Mesghouni K, Dutilleul SC, Zidi K, Ghedira K. A Hybrid Method for Assigning Containers to AGVs in Container Terminal. *IFAC-PapersOnLine.* 2016;49(3): 96-103. Available from: doi: 10.1016/j.ifacol.2016.07.017

[30] Yang YC, Lin CL. Performance analysis of cargo-handling equipment from a green container terminal perspective. *Transportation Research Part D.* 2013;23: 9-11. Available from: doi: 10.1016/j.trd.2013.03.009

[31] Huang WC, Chu CY. A selection model for in-terminal container handling systems. *Journal of Marine Science and Technology*. 2004;12(3): 159-170. Available from: http://jmst.ntou.edu.tw/marine/12-3/159-170.pdf [Accessed 21th March 2018]

[32] Vis IFA. A comparative analysis of storage and retrieval equipment at a container terminal. *International Journal of Production Economics*. 2006;103: 680-693. Available from: doi: 10.1016/j.ijpe.2006.01.002

[33] Yang WS, Liang GS. Evaluating handling equipment operating systems in container yard. *Journal of Engineering for the Maritime Environment*. 2015;229(2): 187-200. Available from: doi: 10.1177/1475090213511428

[34] Keršuliene V, Zavadskas EK, Turskis Z. Selection of rational dispute resolution method by applying new step wise weight assessment ratio analysis (SWARA). *Journal of Business Economics and Management.* 2010;11: 243-258.

[35] Alimardani M, Zolfani SH, Aghdaie MH, Tamošaitienė J. A novel hybrid SWARA and VIKOR methodology for supplier selection in an agile environment. *Technological and Economic Development of Economy.* 2013;19: 533-548.

[36] Zolfani SH, Zavadskas EK, Turskis Z. Design of products with both international and local perspectives based on Yin-Yang balance theory and SWARA method. *Economic Research – Ekonomska Istraživanja.* 2013;26: 153-166.

[37] Zolfani SH, Saparauskas J. New Application of SWARA Method in Prioritizing Sustainability Assessment Indicators of Energy System. *Engineering Economics.* 2013;24: 408-414.

[38] Aghdaie MH, Zolfani SH, Zavadskas EK. Decision making in machine tool selection: An integrated approach with SWARA and COPRAS-G methods. *Engineering Economics.* 2013;24: 5-17.

[39] Dehnavi A, Aghdam IN, Pradhan B, Varzandeh MHM. A new hybrid model using step-wise weight assessment ratio analysis (SWARA) technique and adaptive neuro-fuzzy inference system (ANFIS) for regional landslide hazard assessment in Iran. *Catena.* 2015;135: 122-148. Available from: doi: 10.1016/j.catena.2015.07.020

[40] Mardani A, Nilashi M, Zakuan N, Loganathan N, Soheilirad S, Saman MZM, Ibrahim O. A systematic review and meta-Analysis of SWARA and WASPAS methods: Theory and applications with recent fuzzy developments. *Applied Soft Computing.* 2017;57: 265-292. Available from: doi: 10.1016/j.asoc.2017.03.045

[41] Zadeh LA. Fuzzy sets. *Information & Control*. 1965;8: 338-353.

[42] Rezaei J. Best-Worst Multi-Criteria Decision-Making Method. *Omega*. 2015;53: 49-57. Available from: doi: 10.1016/j.omega.2014.11.009

[43] Ahmadi HB, Kusi-Sarponga S, Rezaeic, J. Assessing the social sustainability of supply chains using Best Worst Method. Resources. *Conservation & Recycling.*

2017;126: 99-106. Available from: doi: 10.1016/j.resconrec.2017.07.020

[44] Ahmad WNKW, Rezaei J, Sadaghiani S, Tavasszy LA. 2017. Evaluation of the external forces affecting the sustainability of oil and gas supply chain using Best Worst Method. *Journal of Cleaner Production.* 2017;153: 242-252. Available from: doi: 10.1016/j.jclepro.2017.03.166

[45] Gupta H, Barua MK. Supplier selection among SMEs on the basis of their green innovation ability using BWM and fuzzy TOPSIS. *Journal of Cleaner Production.* 2017;152: 242-258. Available from: doi: 10.1016/j.jclepro.2017.03.125

[46] Rezaei J, Nispeling T, Sarkis J, Tavasszy L. A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method. *Journal of Cleaner Production.* 2016;135: 577-588. Available from: doi: 10.1016/j.jclepro.2016.06.125

[47] Gupta H. Evaluating service quality of airline industry using hybrid best worst method and VIKOR. *Journal of Air Transport Management*. 2018;68: 35-47. Available from: doi: 10.1016/j.jairtraman.2017.06.001

[48] Ren J, Liang H, Chan FTS. Urban sewage sludge, sustainability, and transition for Eco-City: Multi-criteria sustainability assessment of technologies based on best-worst method. *Technological Forecasting & Social Change*. 2017;116: 29-39.

[49] Shojaei P, Haeri SAS, Mohammadi S. Airports evaluation and ranking model using Taguchi loss function, best-worst method and VIKOR technique*. Journal of Air Transport Management*. 2018;68: 4-13. Available from: doi: 10.1016/j.jairtraman.2017.05.006

[50] Herman MW, Koczkodaj WW. A Monte Carlo study of pairwise comparison*. Information. Processing Letters*. 1996;57: 25-9. Available from: doi: 10.1016/0020-0190(95)00185-9

[51] Guo S, Zhao H. Fuzzy best-worst multi-criteria decision-making method and its applications. *Knowledge-Based Systems*. 2017;121: 1-9. Available from: doi: 10.1016/j.knosys.2017.01.010

[52] Mou Q, Xu Z, Liao H. 2016. An intuitionistic fuzzy multiplicative best-worst method for multi-criteria group decision making. *Information Sciences*. 2016;374: 224-239. Available from: doi: 10.1016/j.ins.2016.08.074

[53] Kutlu AC, Ekmekcioglu M. Fuzzy failure modes and effects analysis by using fuzzy TOPSIS/based fuzzy AHP. *Expert Systems with Applications*. 2012;39: 61-67. Available from: doi: 10.1016/j.eswa.2011.06.044

[54] Zečević S. *Robni terminali i robno-transportni centri*, Belgrade, Faculty of Transport and Traffic Engineering, University of Belgrade; 2006. Serbian

[55] EC Delegation to the Republic of Serbia. *Facilitating Intermodal Transport in Serbia.* Republic of Serbia; 2010-2012.

[56] Janic M, Reggiani A, Nijkamp P. Sustainability of the European freight transport system: Evaluation of innovative bundling networks. *Transportation Planning and Technology.* 1999;23:129-156. Available from: doi: 10.1080/03081069908717644

[57] Kapros S, Panou K, Tsamboulas DA. Multicriteria approach to the evaluation of intermodal freight villages. *Transportation Research Record.* 2005;1906: 56-63. Available from: doi: 10.3141/1906-07