MULTI-CRITERIA EVALUATION OF THE INTERMODAL TERMINAL TECHNOLOGIES

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Abstract: *Intermodal transport allows energy, costs and time savings, improves the quality of services and supports sustainable development. Major subsystem of the intermodal transport is intermodal terminal representing the place of change of the transport mode and storage of the intermodal transport units. Efficiency of the intermodal terminal greatly depends on the subsystems technologies. Accordingly, the subject of this paper is the evaluation and selection of the appropriate technologies for the realization of the transport units' transshipment and handling operations in the intermodal terminal. As the decision-making process is affected by different economic, technical, technological and other criteria, fuzzy DEMATEL (for obtaining criteria weights) and fuzzy VIKOR (for alternatives ranking) methods are used. The applicability of the proposed methodology is tested by solving a real-life example.*

Keywords: *intermodal transport, terminal, technology, multi-criteria decision-making.*

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1. INTRODUCTION

Intermodal transport is defined as the movement of goods in one and the same loading unit or a vehicle, by successive modes of transport without handling of the goods themselves when changing modes (ECMT 1993). One of the major subsystems of intermodal transport is intermodal terminal (IT) defined as the place equipped for transshipment and storage of intermodal transport units between modes of transport (UNECE 2009). The most commonly solved IT problems are related to the terminals location (Roso et al., 2015, Zečević et al., 2017), terminal network design (Sorensen et al., 2012), terminals' performance measurement (Wang, 2016), etc. Since the efficiency of IT functions largely depends on the subsystem technology, subject of this paper is multi-criteria evaluation of technologies for handling intermodal transport unit (ITU). The objective is the selection of the most appropriate handling equipment (HE) by analyzing various criteria and terminal characteristics.

ITs can be structured by different criteria (Zečević, 2006), but for the HE selection the most important is the classification on the basis of size and flows intensity and connection of the transport modes. This paper discusses in more detail the HE selection for small road-rail terminal, with 1 or 2 tracks and turnover of about 80 000 ITUs per year, which is the case with the planned IT in Belgrade, Batajnica (EC, 2010-2012). Medium to large ITs (with 4 or more handling tracks) are generally equipped with bridge cranes for transshipment of the ITUs and with other HE for handling them inside the terminal. In smaller ITs, usage of bridge cranes is not justified, therefore they use the HE

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that can be used both for transshipment and internal transportation of the units. This equipment is cheaper, easier to use and can be faster put into use in the early stages of the IT development. As the HE selection is influenced by numerous economic, technical and technological criteria, this represents a multi-criteria decision-making (MCDM) problem and MCDM model that combines fuzzy DEMATEL (for obtaining criteria weights) and fuzzy VIKOR (for ranking the alternatives) is defined for its solution. More detailed model description is given below, after which the case study of the HE selection for the planned IT in Belgrade is solved. Final conclusions and future research directions are given at the end.

2. COMBINED FUZZY DEMATEL - FUZZY VIKOR MODEL

MCDM model proposed in this paper consists of two parts. The first part is the fuzzy DEMATEL method used for obtaining the criteria weights. The aim of DEMATEL (Gabus & Fontela, 1972) is to convert the relation between elements, causal dimensions from a complex system to an understandable structural model. In the second part of the model fuzzy VIKOR method is used for the alternatives evaluation in relation to the criteria and obtaining the final rank. The VIKOR method (Opricovic, 1998) is convenient for the selection problems because of its stability and ease of use with cardinal information. The method focuses on ranking and selecting from a set of alternatives against various, and in most cases conflicting and non-commensurable, decision criteria and determines compromise solutions for a problem. As the decision makers' judgments on decision criteria and alternatives are often imprecise, vague and ambiguous, the methods are solved in the fuzzy environment. Linguistic scale with corresponding triangular fuzzy numbers (Table 1) is used for the pair-vise comparison of criteria and evaluation of the alternatives in relation to the criteria. The following describes computational steps of the proposed model.

Table 1. Linguistic terms and corresponding fuzzy values

Linguistic term	**Abbreviations**	**Fuzzy scales**
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)

Step 1: Define the evaluation model. After defining the alternatives, i.e., HE in this paper, the set of criteria for their evaluation is formed.

Step 2: Establish causal relations between the criteria using fuzzy DEMATEL (Wu & Lee, 2007).

Step 2.1: Acquire fuzzy direct-relation matrix. Decision makers are making sets of the criteria pair wise comparisons, i.e., forming an *n×n* matrix $\widetilde{A}$ whose elements, triangular fuzzy numbers $\widetilde{a}_{ij} = \left(l_{ij}, m_{ij}, u_{ij}\right)$, represent the degree to which the element *i* affects the element *j*, where *l* and *u* represent the lower and upper boundaries, and *m* the most probable value of the fuzzy number $\widetilde{a}$.

Step 2.2: Acquire normalized fuzzy direct-relation matrix $\widetilde{X}$ obtained from the matrix $\widetilde{A}$:

$$\widetilde{X} = s \times \widetilde{A} \tag{1}$$

where $s = 1/\max_{1 \le i \le n} \sum_{j=1}^{n} u_{ij}$ and $\widetilde{a}_{ij} = \left(l_{ij}, m_{ij}, u_{ij}\right)$.

Step 2.3: Acquire fuzzy total-relation matrix $\widetilde{T}$ by applying the equation:

$$\widetilde{T} = \widetilde{X}\left(1 - \widetilde{X}\right)^{-1}. \tag{2}$$

Step 2.4: Obtain the criteria weights. In order to obtain criteria weights from the matrix $\widetilde{T}$, variables r_i and c_j are introduced:

$$r_i = \sum_{j=1}^{n} \widetilde{t}_{ij} \tag{3}$$

$$c_j = \sum_{i=1}^{n} \widetilde{t}_{ij} \tag{4}$$

where r_i indicates the degree of influence of the criterion *i* on all other criteria, and c_j indicates the degree of influence of all other criteria on criterion *i*. $r_i + c_j$ indicates the criterion importance degree for the entire system. The criteria weights are obtained by the equation:

$$\widetilde{w}_j = \frac{r_i + c_j}{\sum_{i=1}^{n}\sum_{j=1}^{n} r_i + c_j}, i = j \tag{5}$$

Crisp values of the weights are obtained after the defuzzyfication using the following equation:

$$P(w_j) = (l_j + 4m_j + u_j)/6 \tag{6}$$

Step 3: Evaluate the alternatives by using fuzzy VIKOR. The procedure is adapted from the paper (Opricovic, 2011), and computational steps are described below.

Step 3.1: Construct the fuzzy performance matrix ($\widetilde{D}$) elements of which $\widetilde{f}_{kj} = (l_{kj}, m_{kj}, u_{kj})$ indicate triangular fuzzy evaluations of the alternative HE_k in relation to criterion C_j.

Step 3.2: Determine the ideal $\widetilde{f}_j^* = (l_j^*, m_j^*, u_j^*)$ and the nadir $\widetilde{f}_j^\circ = (l_j^\circ, m_j^\circ, u_j^\circ)$ values of all criterion functions according to the benefit (J^b) or cost functions (J^c).

$$\begin{aligned} \widetilde{f}_j^* &= \max_k \widetilde{f}_{kj},\ \widetilde{f}_j^o = \min_k \widetilde{f}_{kj} \quad for\ j \in J^b \\ \widetilde{f}_j^* &= \min_k \widetilde{f}_{kj},\ \widetilde{f}_j^o = \max_k \widetilde{f}_{kj} \quad for\ j \in J^c \end{aligned} \tag{7}$$

Step 3.3: Compute the normalized fuzzy difference $\widetilde{d}_{kj}$:

$$\widetilde{d}_{kj} = \frac{\widetilde{f}_j^*(-)\widetilde{f}_{kj}}{u_j^* - l_j^\circ} \quad for\ j \in J^b \qquad \widetilde{d}_{kj} = \frac{\widetilde{f}_{kj}(-)\widetilde{f}_j^*}{u_j^\circ - l_j^*} \quad for\ j \in J^c \tag{8}$$

Step 3.4: Compute the values $\widetilde{S}_k = (S_k^l, S_k^m, S_k^u)$, which represent the normalized fuzzy difference, i.e. the maximum group utility, and $\widetilde{R}_k = (R_k^l, R_k^m, R_k^u)$, which represent the maximum fuzzy difference, i.e. minimum individual regret, by the relations:

$$\widetilde{S}_k = \sum_{j=1}^{n} w_j (\times) \widetilde{d}_{kj} \tag{9}$$

$$\widetilde{R}_k = \max_j w_j (\times) \widetilde{d}_{kj}. \tag{10}$$

Step 3.5: Compute the values $\widetilde{Q}_k = (Q_k^l, Q_k^m, Q_k^u)$, i.e. the overall distances of the alternatives from the ideal solution, by the relation:

$$\widetilde{Q}_k = v \frac{\widetilde{S}_k(-)\widetilde{S}^*}{S^{\circ u} - S^{*l}} (+)(1-v) \frac{\widetilde{R}_k(-)\widetilde{R}^*}{R^{\circ u} - R^{*l}}, \tag{11}$$

where $\widetilde{S}^* = \min_k \widetilde{S}_k$, S^{*l} is the lower value of the triangular fuzzy number $\widetilde{S}^*$, $S^{\circ u} = \max_k S_k^u$, $\widetilde{R}^* = \min_k \widetilde{R}_k$, R^{*l} is the lower value of the triangular fuzzy number $\widetilde{R}^*$ and $R^{\circ u} = \max_k R_k^u$. The value *v* is introduced as a weight for the strategy of "the majority of criteria" (or "the maximum group utility"), whereas *1 – v* is the weight of the individual regret.

Step 3.6: Defuzzify $\widetilde{S}_k$, $\widetilde{R}_k$ and $\widetilde{Q}_k$ using Eq. (6).

Step 3.7: Rank the alternatives, HEs, sorting by the crisp values in increasing order. The results are three ranking lists $\{HE\}_S$, $\{HE\}_R$ and $\{HE\}_Q$ according to *crisp(S)*, *crisp(R)* and *crisp(Q)*, respectively.

Step 3.8: Propose as a compromise solution the alternative $HE^{(1)}$ which is the best ranked by the measure *Q,* if the following two conditions are satisfied:

Co.1. "Acceptable Advantage": Adv ≥ DQ where $Adv = \left[Q\left(HE^{(2)}\right) - Q\left(HE^{(1)}\right)\right] / \left[Q\left(HE^{(m)}\right) - Q\left(HE^{(1)}\right)\right]$ is the advantage rate of the alternative $HE^{(1)}$ ranked first, $HE^{(2)}$ s the alternative with second position in $\{HE\}_Q$, and *DQ = 1/(m – 1)* is the threshold.

Co.2. "Acceptable Stability in decision making": The alternative $HE^{(1)}$ must also be the best ranked by *S* or/and *R*.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of: **CS1.** Alternatives $HE^{(1)}$ and $HE^{(2)}$ if only the condition Co.2 is not satisfied, or **CS2.** Alternatives $HE^{(1)}$, $HE^{(2)}$, ..., $HE^{(M)}$ if the condition Co.1 is not satisfied; $HE^{(M)}$ is determined by the relation $\left[Q\left(HE^{(M)}\right) - Q\left(HE^{(1)}\right)\right] / \left[Q\left(HE^{(m)}\right) - Q\left(HE^{(1)}\right)\right] < DQ$ or maximum *M* (the positions of these alternatives are "in closeness").

3. CASE STUDY

The proposed model is used for selection of the HE for the planned road-rail IT in Belgrade, Batajnica, in the first stage of the development (EC, 2010-2012). For HE selection, 3 groups of criteria are defined: technical (productivity - C_1; capacity - C_2; speed - C_3; lifting height - C_4; required manipulation area - C_5), economic (price - C_6; maintenance costs - C_7; life cycle - C_8; operating costs - C_9; costs of the terminal preparation - C_{10}; applicability in the next stages of the terminal development - C_{11}) and technological (fitting with other technologies - C_{12}; need for planning/organization - C_{13}; automation possibility - C_{14}; training requirements - C_{15}). The following potential HE are evaluated: Front Lift Tractor (HE_1), Side Loader (HE_2), Reach Stacker (HE_3), Self Loading Trailer (HE_4) and Straddle Carrier (HE_5). Front Lift Tractor and Side Loader are characterized by small turning radius, but not that small aisle width. Their prices are low and they do not require special training or operating license, but their ability for automation is low. In addition, Side Loader has a lower productivity, capacity and lifting height than the Front Lift Tractor. Reach Stacker is characterized by high lifting height with not so large turning radius. It fits easily with other technologies and has the ability for automation of the certain processes. On the other hand, its price is slightly higher and requires short training and operating license. Self Loading Trailer is characterized by low price, high speed, operating without special training and licenses, but on the other hand has low productivity, low lifting height and a large turning radius. Reach Stacker is quite expensive, not suitable for rail transshipments and requires special training and operating license, but on the other hand it has great productivity, speed, capacity and ability for the complete automation.

Causal relations between the criteria are established by applying the linguistic terms (Table 2) which are transformed into triangular fuzzy numbers thus forming the direct-relation matrix $\widetilde{A}$, which is then normalized by the equation (1) in order to obtain the matrix $\widetilde{X}$. By applying the equation (2), the fuzzy total-relation matrix $\widetilde{T}$ is obtained, based on which the values r_i and c_j are obtained by applying the equations (3) and (4), respectively. By applying the equation (5) for the obtained values of r_i and c_j, fuzzy criteria weights $\tilde{w}$ are obtained, which are then defuzzyfied by applying the equation (6) in order to obtain the crisp values of the criteria weights w. The following criteria weights are obtained (0.108, 0.082, 0.101, 0.098, 0.092, 0.109, 0.090, 0.074, 0.084, 0.067, 0.105, 0.087, 0.073, 0.090, 0.065).

Table 2. Evaluation of the criteria causal relations

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
C_1	/	FL	L	L	FL	VH	H	M	M	M	L	M	M	L	L
C_2	H	/	M	L	L	FH	FH	FL	M	FL	VL	L	L	LI	VL
C_3	VH	VL	/	N	H	FH	FH	FL	FH	VL	FH	FL	L	VL	VL
C_4	M	VL	N	/	M	H	H	FL	FL	FL	H	M	M	L	FH
C_5	L	VL	M	L	/	FL	VL	VL	L	H	M	L	L	L	L
C_6	L	VL	VL	VL	VL	/	VH	FL	L	N	N	M	N	VH	VL
C_7	L	VL	L	L	N	VH	/	FH	VL	N	N	N	N	N	N
C_8	N	VL	N	L	L	FH	M	/	N	N	N	N	N	N	N
C_9	N	N	L	L	L	FH	VL	N	/	VL	M	VL	N	N	VL
C_{10}	N	N	FL	L	L	VL	N	N	N	/	N	N	N	N	N
C_{11}	FL	FL	M	H	M	FL	FL	FL	FH	FL	/	L	FL	FL	FL
C_{12}	L	N	L	N	L	L	N	VL	FL	L	L	/	H	H	M
C_{13}	L	N	L	N	N	N	N	N	VL	VL	L	FL	/	M	N
C_{14}	FH	N	FL	N	L	M	L	VL	L	FL	FL	L	FL	/	FL
C_{15}	L	N	N	N	N	VL	N	L	FL	N	L	N	VL	N	/

Once the criteria weights are obtained, the evaluation of the HEs in relation to the criteria is performed (Tabela 3) by applying the liguistic terms given in Table 1, which are then transformed into triangular fuzzy numbers thus forming the matrix $\tilde{D}$.

Table 3. Evaluation of the handling equipment in relation to the criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
HE_1	H	FH	FH	M	M	FH	M	H	FH	FH	FH	VH	VH	VL	VH
HE_2	FL	L	M	L	VH	VH	FH	H	VH	H	L	H	VH	VL	VH
HE_3	H	M	FH	VH	FL	M	FL	H	FH	FL	VH	H	H	FH	H
HE_4	FL	FH	VH	L	M	H	H	VH	VH	VH	L	FL	L	L	VH
HE_5	VH	VH	H	FH	H	L	H	FL	FH	FL	M	FL	H	VH	L

Table 4. Results of applying the fuzzy VIKOR method

		HE_1	HE_2	HE_3	HE_4	HE_5
$\tilde{S}$	S^l	-0,050	0,004	-0,050	-0,003	-0,028
	S^m	0,396	0,450	0,396	0,443	0,417
	S^u	0,841	0,895	0,842	0,889	0,863
	Crisp S	0,396	0,450	0,396	0,443	0,417
	Rank	1	5	2	4	3
$\tilde{R}$	R^l	0,045	0,045	0,031	0,045	0,047
	R^m	0,067	0,075	0,061	0,075	0,078
	R^u	0,090	0,108	0,092	0,108	0,109
	Crisp R	0,067	0,075	0,061	0,075	0,078
	Rank	2	3	1	4	5
$\tilde{Q}$	Q^l	-0,443	-0,418	-0,450	-0,421	-0,432
	Q^m	0,004	0,033	0,001	0,030	0,019
	Q^u	0,452	0,486	0,452	0,483	0,471
	Crisp Q	0,004	0,033	0,001	0,030	0,019
	Rank	2	5	1	4	3

By applying the equation (7), the ideal and the nadir values are obtained based on which the values of normaized fuzzy difference $\tilde{d}_{kj}$ are obtained by applying the equation (8). By applying the equations (9-11), the values $\tilde{S}_k$, $\tilde{R}_k$ and $\tilde{Q}_k$ are obtained, based on which the ranking of the alternatives is obtained (Table 4). It can be seen from the table that the best ranked alternative is the HE_3 – Reach Stacker.

4. CONCLUSION

The efficiency of the transport and handling processes in the IT is largely dependent on the equipment. When selecting the equipment it is necessary to consider the large number of criteria, therefore this represents the MCDM problem. This paper used the fuzzy DEMATEL method for obtaining the criteria weights, and fuzzy VIKOR method for ranking and selection of the HE. The applicability of the model is demonstrated by solving the case study of selecting the HE for the planned IT in Belgrade. Future research could be related to the HE selection for other types of the intermodal terminals, in terms of the present transportation modes, sizes and flow volumes.

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