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17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

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EVALUATION MODEL OF RAILWAY INFRASTRUCTURE POTENTIAL FOR ESTABLISHMENT OF FREIGHT INTERMODAL TERMINALS

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Abstract

The present study is aimed at exploring and analyzing the possibilities of optimizing freight transport and developing intermodal connections for a specific railway infrastructure. A model has been proposed to identify the railway infrastructure potential in regions for their development through the establishment of intermodal terminals. The model enables comparability of the results obtained for the different options. The expected outcomes are aimed at improving the planning, development and interaction of transport systems to achieve better connectivity between railway transport and other modes of transport.

Keywords: Intermodal transport, Intermodal terminal, Railway infrastructure, Decision making, Evaluation model, Multi-criteria, WSM, MCDM

1 Introduction

The choice of a decision among many alternatives often depends on different parameters that affect the final result [1]. This requires the use of Multiple Criteria Decision Making (MCDM) models. The Weighted Sum Model (WSM) is the most commonly used multi-criteria decision making method [2]. The metod is based on a comparison between different alternatives by determining their weighted sums. The weighted sum for each alternative is calculated through the value of the alternative and its individual importance. The importance of each criterion is represented as a weight coefficient. The method allows to compare variants with the same significance (dimensions) of the criteria. It is necessary to apply the same criteria for decision-making for all studied alternatives. The choice of an option for alternatives of the 'benefits' type is determined by the maximum obtained value of the weigthed sum. The choice of an option for the 'costs' type alternatives is determined by the minimum obtained value of the weigthed sum. The model of the weighted sum is applicable in evaluating alternatives containing a multitude of identical (of the same dimension) criteria. It makes the weighted sum method inappropriate for study of alternatives consisting of different criteria.

2 Weighted sum method

The Weighted sum method is a simple multi-criteria decision making method for evaluation of alternatives in terms of certain decision criteria. The weighted sums are used for evaluating the alternatives. In order to determine the value of the weighted sum for r-alternative of the 'benefits' type and choose an option we use:

$$A_r = \sum_{i=1}^{I} a_{ir} \cdot w_i \rightarrow \max, \quad r = 1,2,\ldots,R \tag{1}$$

Where: A_r is the value of the weighted sum for r-th alternative; a_{ir} is the value of r-th alternative for i-th decision criterion; w_i is the weight coefficient of i-th criterion (i = 1, 2,…,I); I is the number of the same type criteria; R is the number of the compared alternatives (R ≥ 2).

In order to determine the value of the weighted sum for r-alternative of the 'costs' type and choose an option we use:

$$A_r = \sum_{i=1}^{I} a_{ir} \cdot w_i \rightarrow \min, \quad r = 1,2,\ldots,R \tag{2}$$

The weighted sum model is applicable in evaluating the railway infrastructure potential for developing intermodal terminals. In the model we have to use identical type of criteria. This will ensure that the model can be used in alternative evaluation on both type of functions – 'costs' and 'benefits'. The model is not suitable for evaluation of alternatives that consist of both type of elements – 'cost' and 'benefits'.

3 Decision making model through conversion of the estimates

The present paper proposes a model for multicriteria estimate of multiple alternatives by extending the application of the weighted sum method. This can be achieved by converting the values of various incomparable units into identical dimensionless units within a defined interval [3]. Conversion to dimensionless units makes it possible to compare different alternatives by using multi-criteria analysis methods, which are not suitable for comparing parameters of different dimensions. A comparison between the main stages and their sequence in the weighted sum model algorithm and the value conversion model algorithm is shown in Figure 1. The proposed model introduces a 'Conversion of the estimates' step in the weighted sum model algorithm. After evaluating the values of the alternatives in terms of the criteria in the weighted sum model, they are transformed into dimensionless estimates. These dimensionless estimates are used for evaluation of the alternatives. The conversion of the values of the alternatives into comparable dimensionless units allows us to use them in decision models requiring uniformity of the values. The estimates change in a predefined interval.

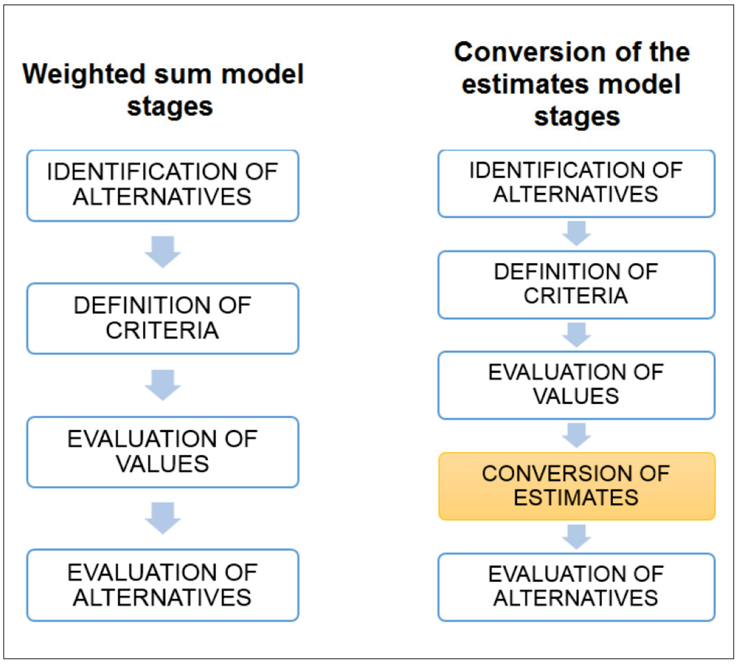

Figure 1 Comparison of the algorithms

3.1 Target function

Depending on the type of research, the type of the selected target function is chosen – ‘benefits’ or ‘costs’. The selection of a variant using converted estimates model is made after the weighted sums of all alternatives have been determined. The weighted sums are determined by:

$$A_r^c = \sum_{n=1}^{N} M_{nr} \cdot d_n \rightarrow \max\,(\text{or}\ \min), \quad r = 1,2,\ldots,R \tag{3}$$

where: A_r^c is the value of the weighted sum for r-th alternative; M_{nr} – is the grade of r-th alternative for n-decision criterion; d_n – weight coefficient of n-th criterion (n = 1, 2,…,N), N – the number of the criteria; R – the number of the compared alternatives (R ≥ 2).

$$d_n \geq 0 \tag{4}$$

Depending on the method of evaluation of the weight coefficients, the sum of all coefficients can be equal (eqn 5) or not equal (eqn 6) to 1.

$$\sum_{n=1}^{N} d_n = 1 \tag{5}$$

$$0 < \sum_{n=1}^{N} d_n \neq 1 \tag{6}$$

3.2 Conversion of the grades

When alternative options are evaluated, the criteria can be classified as proportionate (in direct ratio) and disproportionate (in inverse ratio). With proportional criteria, the higher value of the n-th criterion is a sign of increased efficiency, and on the contrary – the low value is the basis for reduced performance. For the inverse criteria, the opposite correlation is in effect – the higher value of the n-th criterion is a sign of decreased efficiency, and the low estimate is the basis for increased efficiency. Conversion of values of the different alternatives to grades for each n = 1, 2,…,N and r = 1, 2,…,R is carried out by:

$$M_{nr} = \begin{cases} L_{nr,max} \cdot \dfrac{\left(V_{nr} - V_{n,min}\right)}{\left(V_{n,max} - V_{n,min}\right)} + L_{nr,min}, & \text{for direct ratio} \\ L_{nr,max} \cdot \dfrac{\left(V_{n,max} - V_{nr}\right)}{\left(V_{n,max} - V_{n,min}\right)} + L_{nr,min}, & \text{for inverse ratio} \end{cases} \tag{7}$$

Where: $L_{nr,min}$ and $L_{nr,max}$ are respectively the minimum and the maximum values determining the length of the interval of conversion of the grade of the n-th criterion of r-th alternative; V_{nr} is the current value of the n-th criterion of r-th alternative; $V_{n,min}$ is the minimum possible value of the n-th criterion; $V_{n,max}$ is the maximum possible value of the n-th criterion.

The value of $L_{nr,min}$ is:

$$L_{nr,min} \geq 0 \tag{8}$$

The value of $L_{nr,max}$ could be determined by:

$$L_{nr,min} \leq L_{nr,max} \quad \text{for} \quad L_{nr,min} > 0 \tag{9}$$

or:

$$L_{nr,min} < L_{nr,max} \quad \text{for} \quad L_{nr,min} = 0 \tag{10}$$

The interval of change of assessement M_{nr} is determined by the values of $L_{nr,min}$ and $L_{nr,max}$:

$$M_{nr} \in \left[L_{nr,min}, \quad L_{nr,min} + L_{nr,max}\right] \tag{11}$$

The length of the interval of change of the grades and their lower and upper limits should be the same for all criteria.This will ensure comparability of the weighted sums for all alternatives.

$$L_{nr,min} = \text{const} \tag{12}$$

$$L_{nr,max} = \text{const} \tag{13}$$

The values of $V_{n,min}$ and $V_{n,max}$ could be determined by:

$$V_{n,min} = \min V_{nr} \tag{14}$$

$$V_{n,max} = \max V_{nr} \tag{15}$$

$$V_{nr} \geq 0 \tag{16}$$

The limits for the value of $V_{n,min}$ and $V_{n,max}$ are:

$$0 \leq V_{n,min} < V_{n,max} \tag{17}$$

With criteria which do not allow to be evaluated with an evaluation scale but are evaluated by the presence or absence of a characteristic (an attribute), the estimate is made by means of equation 7. Depending on the type of criterion (proportional or inversely proportional) and the type of function – 'costs' or 'benefits' it is accepted V_{nr} acquires $V_{n,max}$ or $V_{n,min}$ value. Thus, the M_{nr} grade will get as value the low limit of the interval ($M_{nr} = L_{nr,min}$) or the top limit of the interval ($M_{nr} = L_{nr,min} + L_{nr,max}$).

4 Evaluation of the railway infrastructure potential for establishment of intermodal terminals

The choice of a location for the establishment of an intermodal terminal depends on factors of different type and importance [4]. These factors impact and determine the potential of railway infrastructure for development of intermodal transport. Part of these factors are related to the opportunities provided by the existing railway infrastructure or infrastructure planned to be developed.

The model described in point 3 has been employed to select a variant for the development of an intermodal terminal. Three alternative variants are compared. The different variants are evaluated in terms of four criteria related to railway infrastructure (Table 1). The time interval under Criterion 2 takes into account the total duration of the construction of the intermodal terminal and its accompanying railway infrastructure. Criterion 4 is assessed as three grades – Low (Grade 1), Medium (Grade 2), and High (Grade 3). The difficulty of implementation takes into account the risk of carrying out the project activities.

Table 1 Criteria description

Criteria	Description	Dimension
Criterion 1	Total length of the railway lines to connect the intermodal terminal to the existing rail network.	km
Criterion 2	Time for designing and construction of the railway lines.	months
Criterion 3	Price for design and construction of the railway lines and accompanying railway infrastructure.	EUR
Criterion 4	Difficulty in implementing the project.	rate

The indicative values of the parameters for the compared alternatives are shown in Table 2. The research parameters are different by type and the values cannot be compared without conversion. For the conversion of the parameter values into grades we have used the model described in point 3.

Table 2 Values of the parameters

Criteria	Dimension	Alternatives			Type of criterion
		Alternative 1	Alternative 2	Alternative 3	
Criterion 1	km	12	16	9	in direct ratio
Criterion 2	months	14	16	18	in direct ratio
Criterion 3	EUR	21,600,000	24,960,000	15,480,000	in direct ratio
Criterion 4	rate	2	1	3	in direct ratio

The coefficients of importance of the criteria are determined by the Analytical Hierarchy Process (AHP) method [5-7]. The significance of the criteria is shown in Table 3. The weights of criteria (Table 3) are determined by the Super Decision software [8]. The degree of inconsistency is 0.05877. The intervals of change of the grades and the final results are shown in Table 4.

Table 3 Pairwise comparison matrix and priorities

Criteria	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Weight
Criterion 1	1	1/3	1/4	1/3	0.08
Criterion 2	3	1	1/2	2	0.26
Criterion 3	4	2	1	5	0.51
Criterion 4	3	1/2	1/5	1	0.15

Table 4 Final results

Criteria	$L_{nr,min}$	$L_{nr,max}$	M_{nr}		
			Alternative 1	Alternative 2	Alternative 3
Criterion 1	0	1	0.43	1.00	0.00
Criterion 2	0	1	0.00	0.50	1.00
Criterion 3	0	1	0.65	1.00	0.00
Criterion 4	0	1	0.50	0.00	1.00
A_r^c	0.44	0.72	0.41		

The values of weighted sums for all alternatives are determined for a target function of the 'costs' type. The value of the weighted sum for alternative 3 is $A_r^c = 0.41$. This result is lower than the results from alternatives 1 and 2. Alternative 3 is the optimal decision.

5 Conclusion

The proposed decision-making model allows us to broaden the scope for applying to the weighted sum model through conversion of the estimates. By converting of dimension values into dimensionless grades, the multi-criterion model becomes applicable to a wide range of dimensions. It allows for the evaluation of both characteristics that can be evaluated by an evaluation scale and characteristics that are assessed by the presence or absence of a feature. The proposed model is a multi-criteria decision making model when we are need to determining the potential of railway infrastructure for intermodal transport development. The proposed model serves as a multicriteria analysis in determining the potential of rail infrastructure for intermodal transport development. It can support the process of analysis and selection of location for intermodal terminals.

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