MULTI-CRITERIA APPROACHES FOR CHOOSING INTERMODAL TECHNOLOGY FOR CONTAINER TRANSPORTATION

Svetla Stoilova
Technical University of Sofia, Bulgaria
stoilova@tu-sofia.bg

Abstract. In this study integrated multi-criteria approaches are developed based on the Shannon entropy method and multi-criteria analysis for the study of intermodal transport. The research methodology consists of the following steps: definition of criteria; determination of alternatives; determination of criteria weights by the Shannon's entropy method; ranking the alternatives by applying multi-criteria approaches; verification of the results. The Shannon's entropy method allows to determine the weights of the criteria in a mathematical way without using expert evaluation. The multicriteria methods – Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Complex Proportional Assessment method (COPRAS), Compromise Programming (CP) and Preference Ranking Organization method for Enrichment of Evaluation (PROMETHEE) have been applied. Seven criteria for the evaluation of five alternatives for the transport of containers by heavy-duty vehicles and by rail have been studied. The results have been verified by comparison with other studies. The obtained results show that the criteria are carbon dioxide emissions during transportation (0.30), security and safety (0.31), infrastructure charges (0.16) and infrastructure characteristic (0.13). It was found that the results for the ranking of the alternatives according to the different approaches are close. It was found that the transport of containers with block-trains is the most suitable alternative for the investigated alternative routes. The developed integrated approaches can also be applied to make research in other scientific fields.

Keywords: TOPSIS, COPRAS, CP, Shannon Entropy; PROMETHEE; intermodal transport.

Introduction

The development of unimodal and intermodal transport chains requires the reduction of harmful emissions from transport and the development of environmentally friendly transport technologies. The transport of goods in containers allows intermodal transport to be carried out in a combination of modes of transport in a transport chain. In land transport, an important problem is the selection an efficient mode of container carriage and an efficient route between the starting point and the final point. This is a multicriteria decision making (MCDM) problem as various factors influence the choice of route and mode of transport.

In [1] the authors have elaborated a route selection system in multimodal transportation based on the Fuzzy Analytic Hierarchy Process (FAHP) and artificial neural network (ANN) theory. Six main groups of the criteria as costs, transport time, transport quality, transport tools, the service in transport, the social benefits have been chosen to assess different routes. A multi-criteria model is tested for container transport in Belgium [2]. The transport price, transport time, congestion time, CO2 emissions, accident risk and noise have been studied as a factor for route selection. The AHP method has been used to determine the weights of criteria, and the PROMETHEE method has been applied to rank the alternatives. In [3] a multi-objective optimization model is elaborated for transport mode selection based on minimization of the total transportation cost for container shipment, minimization of the total travel time and minimization the total CO2 emissions generated by all transportation modes. The analytic hierarchy process (AHP) and zero-one goal programming (ZOGP) have been used to determine an optimal multimodal transportation route [4; 5]. The authors investigated criteria including transportation cost, transportation time, and factors of transportation risk.

In [6; 7] eleven criteria have been studied to determine the best mode and route for container carriage. The PROMETHEE method (Preference ranking organization method for enrichment evaluation) [6] and SIMUS method [7] have been applied. The criteria include CO2 emission, operational costs, transport fare, infrastructure charges, duration of transportation, transport door to door, transhipment operations, comfort, security, reliability, safety.

It could be concluded that the main factors used in previous studies when choosing effective intermodal technology are CO2 emission, transport costs, transport time and criteria related to the risks and security of transport. It can be summarized that the methods of multi -criterion analysis are widely used when choosing a mode of transport and route selection. There are different types of MCDM methods that are developed. The multi-criteria methods TOPSIS, PROMETHEE, COPRAS are

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commonly used in decision-making. A review of the applications of these methods is presented in [8-10]. TOPSIS is a multicriteria method that is based on the distance to the best alternative. PROMETHEE is an outranking method that uses the preference function for each criterion and net outranking flows to determine the ranking of alternatives. The compromise programming (CP) method is an old method compared to the TOPSIS and COPRAS and is also a distance based multicriteria approach. Its main advantage is application of balancing factor that represents the attitude of the decision maker.

The aim of this study is to elaborate a multi-criteria approach based on different multi-criteria methods as TOPSIS, CP, COPRAS and PROMETHEE II for choosing intermodal technology for container transportation. The object of the study is intermodal transportation with block trains and by heavy trucks.

Materials and methods

The methodology includes the following steps:.

- Step 1: Determination of the criteria to assess the container carriage. In this step based on analysis of literature sources, the following criteria have been proposed: (C1) – carbon dioxide emissions during transportation, g/UTI; (C2) – operational costs and charges for loading and unloading operations, euro/UTI; (C3) – infrastructure charges, euro/UTI. In these fees are included the fees for the use of railway infrastructure and for the use of road infrastructure; (C4) – duration of transportation, h; (C5) – light of the route, km; (C6) – infrastructure characteristics. This criterion indicates the type of railway and road infrastructure. For rail transport, it is taken into account whether the railway line is single-track, double-track or mixed. For road transport, it is taken into account whether the road is a motorway, first-class or second-class road. When the road is a two-track railway line or a motorway, C6 = 2. If the road is entirely a single-track railway line or a first-class or second-class road, C6 = 1. If the road consists of mixed sections, the value of the criterion is determined as follows: C6 = 1 + k, where k is a coefficient indicating the relative share of double-track sections at rail transport or the percentage of sections that are motorway of the road. Criterion C6 has values between 1 and 2. (C7) – security and safety, coef. This criterion can have values 0 or 1. A value of C7 = 1 is for the transport that is more secure and safe. In this case, it is the railway transport with block trains.
- Step 2: Determination of the alternatives. The alternatives include routes by rail and by road transport.
- Step 3: Determination the criteria weights. The Shannon entropy method to calculate the criteria weights is applied. This is an objective method based on the information from the criteria. Expert judgment does not apply.
- Step 4: Ranking the alternatives by using multicriteria methods - TOPSIS, CP, COPRAS and PROMETHEE II. The application of the different multi-criteria methods serves to compare the results.
- Step 5: Verification of the results. The study applied a verification approach by comparing the obtained results with those of other studies.

The Shannon entropy uses information entropy for each criterion to determine the weights. The information entropy is determined as follows [11]:

$$E_i = -\frac{\sum_{i=1}^{n} p_{ij} \ln p_{ij}}{\ln n}, 0 \le E_i \le 1, \tag{1}$$

where E_i – information entropy;
i – number of criteria, i = 1, …, n;
p_{ij} – normalized values of decision matrix $(x_{ij})_{mxn}$;
j – number of alternatives, j = 1, …, m.

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

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}, \tag{2}$$

The weights of criteria according the Shannon entropy are:

$$w_i^E = \frac{D_i}{\sum_{i=1}^{n} D_i}, D_i = 1 - E_i . \quad (3)$$

The TOPSIS method is a distance based multi-criteria approach and is based on the shortest geometric distance from the positive ideal solution and farthest geometric distance from the negative ideal solution [12; 13]. The performance score C_i is calculated to determine the ranking of alternatives. This score presents the relative closeness of each alternative i with reference to negative ideal measure D_i^- as follow:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-}; 0 \le C_i \le 1, \quad (4)$$

$$D_i^+ = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^+\right)^2}; D_i^- = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^-\right)^2} \quad (5)$$

$$v_{ij} = r_{ij} \cdot w_j, \sum_{j=1}^{m} w_j = 1, w_j \in \{0,1\}, \quad (6)$$

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}, i = 1,...,n; j = 1,...,m \quad (7)$$

where D_i^+ – Euclidean distance from the ideal best solution;
D_i^- – Euclidean distance from the ideal worst solution;
$v_j^+ = \min_i v_{ij}$ – ideal best solution;
$v_j^- = \max_i v_{ij}$ – ideal worst solution;
r_{ij} – elements of normalized matrix;
w_i – weights of criteria.

The best alternative based on the performance score has the highest assessment value.

The compromise programming method determines the most appropriate solution from a set of efficient solutions that is the least distant from the ideal point, [14]. The optimization criterion is:

$$\min L_p = \left[\sum_{j=1}^{m} w_j^p \cdot \left|\frac{x_j^* - x_j}{M_j - m_j}\right|^p\right]^{1/p}, \sum_{j=1}^{m} w_j = 1, 1 \le p < \infty \quad (8)$$

where L_p – distance for an alternative;
M_j – maximum value of the criterion j in a set of N number of alternatives;
m_j – minimum value of the criterion j in a set of N number of alternatives;
x_j^* – ideal value of the criterion j (at criterion maximum it is the maximum value and at minimum it is the minimum value);
w_j – weights of criteria;
p – parameter (balancing factor) that is used to represent the attitude of the decision maker regarding the trade-off between deviations from the ideal solution.

When $p = 1$, this is the so-called street block distance or Manhattan distance. When $p = 2$, it is the Euclidean distance. When $p = \infty$, this is the Chebyshev distance and corresponds to the minimax problem.

The optimal alternative according to the method of compromise programming is the one with the lowest value for the indicator L_p.

The COPRAS method is a utility based method and is based on evaluating the influence of maximizing and minimizing criteria on ranking the alternatives [15].

$$Q_i = P_i + \frac{\sum_{i=1}^{n} R_i}{R_i \sum_{i=1}^{n} \frac{1}{R_i}}, \tag{9}$$

$$P_i = \sum_{i=1}^{k} \hat{x}_{ij}, R_i = \sum_{i=k+1}^{n} \hat{x}_{ij}, \tag{10}$$

$$\hat{x}_{ij} = \bar{x}_{ij} \cdot w_j, \sum_{j=1}^{m} w_j = 1, w_j \in \{0,1\}, \tag{11}$$

where P_i – maximizing index;
R_i – minimizing index;
$\bar{x}_{ij}$ – normalization of the decision matrix
w_j – weights of criteria.

The PROMETHEE II method is an outranking method in multi-criteria analysis, [16; 17]. The alternatives are ranked according to the net outranking flows. The ranking is according to the decreasing values of the net outranking flows.

Results and discussion

The alternative routes in Bulgarian railway and road network have been investigated in this research according to the data given in [6; 7]: A1 – Freight block train: Sofia-Gorna Oryahovitsa-Varna; A2 – Freight block train: Sofia - Karlovo-Karnobat -Varna; A3 – Route R1: Road train Sofia-Veliko Tarnovo-Varna; A4 – Route R2: Road train Sofia-Plovdiv-Burgas-Varna; A5 – Route R3: Road train Sofia-Plovdiv-Karnobat-Shumen-Varna. Alternatives A1 and A2 include rail transport; alternatives A3-A5 are for road transport. A1 is fully double-track rail service. Rail transport for A2 is on a one-way-two-way railway line. A3 is a main road for Northern Bulgaria and has about 210 km of secondary road. A lot of the A4 and A5 is motorway.

The research was conducted in the following conditions: The carriage by railway transport is by block freight trains composed of 20 wagons; gross train weight 1086 t. The wagons are loaded with 40-foot containers (intermodal transport unit – UTI) with gross mass 20t. The parameters of research are according to the data given in [6, 7]. The decision matrix is represented in Table 1.

Table 1 shows the decision matrix which presents the values of the criteria and the type of optimization of the criteria. It could be seen that for each of the criteria the best alternative is different. For example, based on criterion C1, the best alternative is A1; based on criterion C2, the best alternative is A2; based on criterion C3, the best alternative is A3; based on criterion C4, the best alternative is A3; based on criterion C5, the best alternative is A3; based on criterion C6, the best alternative is A1; based on criterion C7, the best alternatives are A1 and A2. The aim of this research is to assess the alternatives according to all of the criteria taken together.

Table 1

Decision matrix

Alternative	C1	C2	C3	C4	C5	C6	C7
	Co2, g/UTI	EUR/UTI	EUR/UTI	h	km	-	-
	min	**min**	**min**	**min**	**min**	**max**	**max**
A1	238257	152	96	9.05	543	2	2
A2	247250	147	94	8.57	514	1	2
A3	442887	190	51	7.14	447	1.53	1
A4	519180	227	61	8.12	524	1.75	1
A5	545931	189	65	8.62	551	1.82	1

Table 2 gives the results for determining the weights of the criteria using the Shannon entropy method. The results indicate that the main importance have the criteria carbon dioxide emissions during transportation (0.30), security and safety (0.31), infrastructure charges (0.16) and infrastructure characteristics (0.13). The small importance has the criterion light of the route (C5).

Table 3 - Table 6 show the results of the application of the TOPSIS, CP and COPRAS multi-criteria methods. The alternative A1 is the best way of transportation according to the TOPSIS method (Table 3). There is small difference between the score of alternatives A1 and A2. It could be seen that the container block trains are the best way to transport.

Table 4 and Table 5 show the results of the application of the CP method. To apply the CP method a transformation of the decision matrix is required. For this purpose, the elements of the decision matrix corresponding to the criterion of minimum are written with a "–". The study using the method of compromise programming was carried out for different values of the balancing factor. For the $p = \infty$ case, $p = 10$ is assumed. It could be seen that alternative A1 is the best according to the values of the balancing factor $p = 1$ or 2. The alternative A2 is the best according to the value $p = 10$ of the the balancing factor. It can be concluded that the transportation with container block trains is the best. There is small difference between the score of alternatives A1 and A2. As the value of $p = 2$ is the most frequently used, the ranking of alternative A1 in the first place according to the CP method can be accepted as a decision.

Table 6 represents the results by the COPRAS method. The results are close to those of TOPSIS and CP methods. It can be seen that the alternative A1 is the best. It can be concluded that the results given by different distance-based multicriteria methods are close.

Table 2

Parameters of the Shannon entropy method

$-p_{ij}\ln p_{ij}$	C1	C2	C3	C4	C5	C6	C7
A1	0.254	0.300	0.351	0.332	0.328	0.345	0.358
A2	0.259	0.295	0.349	0.326	0.321	0.258	0.358
A3	0.334	0.327	0.274	0.303	0.304	0.315	0.278
A4	0.350	0.347	0.298	0.319	0.324	0.331	0.278
A5	0.355	0.327	0.306	0.326	0.330	0.335	0.278
$-\sum_{i=1}^{n} p_{ij} \ln p_{ij}$	1.552	1.597	1.579	1.606	1.607	1.585	1.550
E_j	0.964	0.992	0.981	0.998	0.998	0.985	0.963
$D_j = 1 - E_j$	0.036	0.008	0.019	0.002	0.002	0.015	0.037
w_j^E	0.30	0.07	0.16	0.02	0.01	0.13	0.31

Table 3

TOPSIS method – results

Alternative	D_i^+	D_i^-	C_i	Rank
A1	0.121	0.251	0.6747	1
A2	0.120	0.244	0.6700	2
A3	0.182	0.146	0.4454	3
A4	0.234	0.098	0.2949	4
A5	0.251	0.086	0.2560	5

Table 4

CP method – transformation of the decision matrix

Criteria type	C1 min	C2 min	C3 min	C4 min	C5 min	C6 max	C7 max
A1	-238257	-152	-96	-9.05	-543	2	2
A2	-247250	-147	-94	-8.57	-514	1.25	2
A3	-442887	-190	-51	-7.14	-447	1.53	1
A4	-519180	-227	-61	-8.12	-524	1.75	1
A5	-545931	-189	-65	-8.62	-551	1.82	1
M_j	-238257	-147.24	-51.08	-7.14	-447	2	2
m_j	-545931	-227.22	-96.2	-9.05	-551	1.25	1
$M_j - m_j$	307674	79.98	45.12	1.91	104	0.75	1

Table 5

CP method – results

L_p	$p = 1$	L_p	$p = 2$	L_p	$p = 10$
0.362	1	0.244	1	0.185	2
0.425	2	0.249	2	0.181	1
0.856	3	0.671	5	0.651	5
0.860	4	0.461	3	0.342	3
0.910	5	0.487	4	0.351	4

Table 6

COPRAS method – results

Alternative	P_i	R_i	$1/R_i$	$R_i \sum_{i=1}^{n} \frac{1}{R_i}$	Q_i	**Rank**
A1	0.238	0.221	4.519	4.378	0.303	1
A2	0.224	0.221	4.528	4.370	0.289	2
A3	0.128	0.249	4.016	4.927	0.193	5
A4	0.133	0.294	3.402	5.816	0.198	4
A5	0.134	0.301	3.321	5.958	0.199	3
Total	-	1.286	19.786	-	-	-

Figure 1 shows the results of the PROMETHEE method obtained using the Visual PROMETHEE software. The PROMEHTEE method requires to be set the preference function for each of the criteria. For criteria C1-C6 is set the linear preference function; for criterion C7 is set the usual preference function as the values of these criteria are two numbers. The first part of Fig.1 shows the net outranking flows, and the second part shows the weights of the criteria. It can be seen that the alternative A1 is the best. The results of both rail alternatives are close.

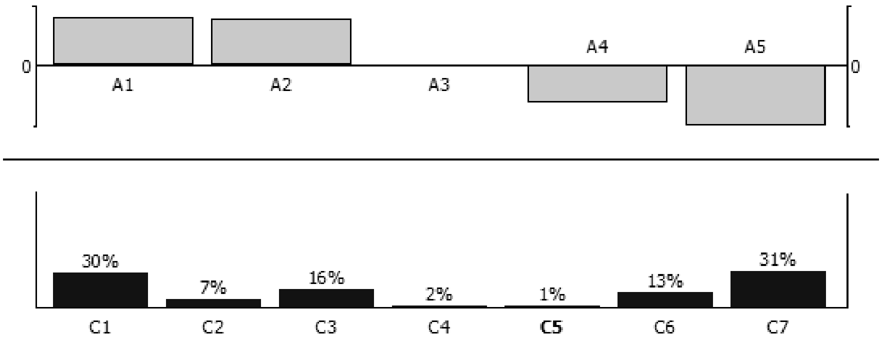

Fig. 1. **Ranking the alternative in Visual PROMETHEE**

Figure 2 shows a comparison of the results of the application of the TOPSIS, CP, COPRAS and PROMETHEE methods. It can be concluded that the results by using distance-based methods and the outranking method are close. The comparison of the results given by different multi-criteria approaches shows that the alternatives that include container block trains are the best variants of transportation. The research shows that the most suitable alternative is the transportation with container block trains on the route Sofia-Oryahovitsa-Varna. Rail service is better transportation alternative. There are minor discrepancies in the ranking of road transport routes by the different methods.

Figure 3 shows a sensitivity analysis of the criteria weights. It could be seen that the weights of criteria C2 (operational costs), C3 (infrastructure charges) and C5 (light of the route) have a small interval of change, i.e. they have a strong sensitivity. The weights of criteria C1 (carbon dioxide emissions), C6 (infrastructure characteristic) and C7 (security and safety) have a wide interval of variation.

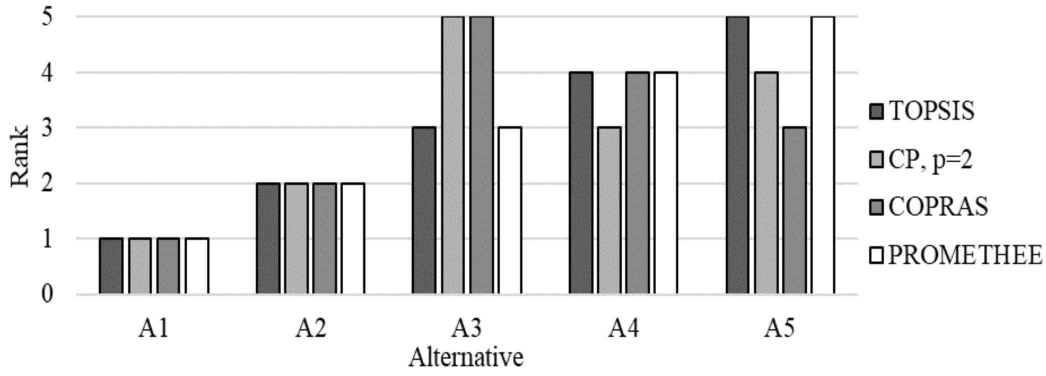

Fig. 2. **Comparison of the results**

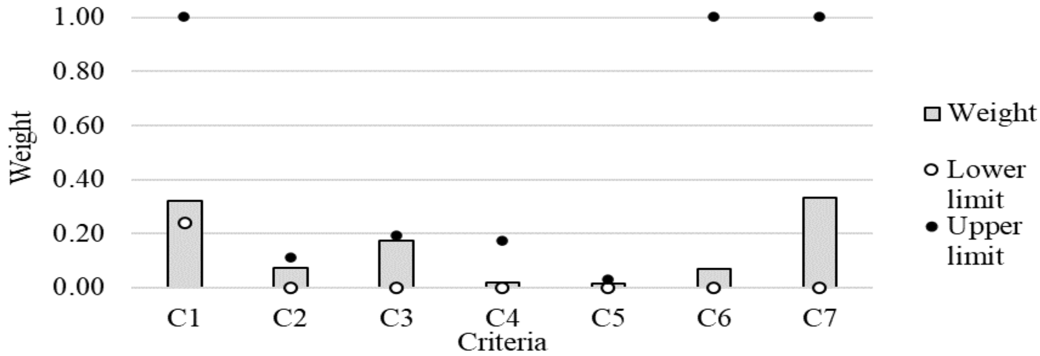

Fig. 3. **Weights – lower and upper level**

The verification was carried out by comparing the results of the study with those obtained in other studies of the author [6; 7]. The best alternative according to [6] is alternative A2 (Freight block train: Sofia-Karlovo-Karnobat-Varna). The best alternative according to [7] is alternative A1 (Freight block train: Sofia-Gorna Oryahovitsa-Varna). The difference of ranking between [6] and [7] is due to the way the weights of the criteria have been calculated. In the study [7] the weights of criteria are not taken into account as a linear programming has been used; while in [6] the weights have been considered. The results in [6; 7] show that the carriage with block trains is the best alternative which is also the conclusion of the present study.

Conclusions

1. In this study a methodology for assessment intermodal technology for container transportation based on different multi-criteria methods and Shannon entropy has been elaborated.
2. A new criterion was introduced taking into account the type of the transport infrastructure, and a method for its quantitative determination was also proposed.
3. The weights of criteria have been determined based on the objective approach – Shannon entropy method. It was found that the criteria carbon dioxide emissions during transportation (0.30), security and safety (0.31), infrastructure charges (0.16) and infrastructure characteristics (0.13) have a great impact for ranking the alternatives.
4. It was found that the criteria operational costs (C2), infrastructure charges (C3) and light of the route (C5) have a small interval of change, i.e. they have a strong sensitivity.
5. It was found that the results given by distance-based methods and outranking methods are close.
6. The comparison of the results given by different multi-criteria approaches shows that the alternatives that include container block trains are the best variants of transportation.

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