COMPARATIVE STUDY OF MULTIPLE CRITERIA METHODS FOR CHOOSING CARGO TRANSPORTATION MODE

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ABSTRACT
The paper considers the evaluation of the efficiency of multiple criteria methods employing for the choice of freight transportation mode and route. The following main tasks are highlighted: selection of a set of indices, characterizing efficiency of freight transportations, and formation of efficiency criteria of the transportation system on their basis; choice of multiple criteria methods for evaluation and selection of cargo transportation alternatives; evaluation and selection of cargo transportation routes and modes using AHP and ELECTRE methods; comparison of the results of choice obtained by different methods; evaluation of the efficiency of AHP and ELECTRE methods employed to solve the problem of choosing the freight transportation route and mode.

Keywords: cargo transportation, route, choice criteria, multiple criteria decision analysis

1. INTRODUCTION

Search for the best solution or finding a set of good alternatives in realization of freight transportation should be based on the different initial data, considering logistic principles, and be done using modern mathematical methods and information technologies (Ghiani, Laporte and Musmanno 2004; Lukinsky 2008). Solving the choice problem we have to take into account such important factors as: a complicated structure of transportation, high dynamics and rapidity of transport processes, the random factors influencing these processes, and geographical dispersion of participants of the transportation.

In case of freight transportation by one transport the task of finding the optimal route is solved as the shortest path problem by employing the methods of mathematical programming (for example, see Cherkassky, Goldberg and Radzik 1996; Ravindra et al. 1993). As a rule, the task is solved in the single-criterion setting, and this criterion is the shortest path of cargo transportation. Along with this the transportation companies are interested in optimization of different indicators in the process of the route choosing: delivery time, cost of transportation, number of transport facilities, etc. Even under the condition of employing several criteria the task of searching for the optimal route is quite often reduced to the single-criterion setting, moreover, all the criteria are comprised in the integral one (most commonly, it is a cost criterion), by sometimes summing up all of them with their own weights, or by choosing one optimization criterion from the group of criteria and the remaining criteria are used as constraints. Many researchers are interested in multi-criteria shortest path problems and suggest different approaches to it, they are as follows: bicriteria path problems (Hansen 1979; Henig 1985), multi-criteria shortest path problem (Martins 984), multi-criteria Pareto Search (Muller-Hannemann and Schnee 2004).

Considering the multimodal freight transportation, the task of choosing the optimal solution becomes significantly complicated, since it comprises not only the choice of route, but also mode of transportation, the freight transhipment and warehousing on route. As a rule, it is considered as the task of multiple criteria choice. This approach does not require the employment of complicated apparatus of mathematical programming and suggests numerous methods based on the expert evaluation.

There are a number of researches for expert evaluating and choosing the alternatives of cargo transportation, for example, see analysis in (Gursoy 2010). Similar to classical optimization approach, there are two variants of creating the choosing criteria: reducing all the criteria to the integrated criterion (for example, see Ivanova, Toikka and Hilmola 2006), and employing the independent choice criteria. Multiple criteria approach is implemented in the work (Gursoy 2010), where three criteria for route choice (shipping time, shipping price, shipping safety) are applied. But in practice there exist more different criteria which determine the efficiency of cargo transportation (Kopytov and Abramov 2011).

In the presented research, the following main tasks, which require solutions, are highlighted:

- Selection of a set of indices, characterizing efficiency of multimodal freight transportations, and formation of efficiency criteria of the transportation system on their basis;
- Choice of multiple criteria methods for evaluation and selection of cargo transportation alternatives;
- Evaluation and selection of cargo transportation routes and modes using suggested methods;
- Comparison the results of choice, obtained by different methods; evaluation of the efficiency of suggested methods employed to solve the problem of choosing the best route and mode of multimodal freight transportation.

2. CRITERIA OF EFFICIENCY OF FREIGHT TRANSPORTATIONS

To estimate the efficiency of transportation, the system of criteria including cost, duration, reliability and ecological safety of cargo transportation is used.

Delivery costs includes financial costs for performing transportation of goods from origin to destination points, including costs for loading, transportation and handling, costs connected to the customs clearance, documentation, storage, demurrage and others.

Delivery time is a total time needed to move goods from origin point to destination point, including time for loading, transportation and handling, time for border crossing and customs clearance.

Reliability of the transportation system is a complex criterion, which includes indices like reliability of transportation (fulfillment of delivery time, reliability of transport means, fulfillment of other transportation contract terms and others) and safety of transportation (safety of cargo, protection from unauthorized access to cargo and others).

Ecological impact is criterion, which reflects losses from the harmful impacts of transportation means on the environment on the different routes, as well as cost of activities for protection of the environment from these harmful impacts. Another important issue is safety of activity of the people (emissions of harmful substances in the atmosphere, the soil and reservoirs, death and a traumatism of people, destruction of buildings and constructions as a consequence of their vibration, etc.).

It is easy to notice that the suggested indices have the various physical natures and are measured by different physical magnitudes. The part of indices is deterministic, the part is stochastic. Additional difficulties for estimating the system indices are related to the fact that part of indices has quantitative nature and part has qualitative nature. For example, cost and durations of transportation are quantities, but reliability, safety and environmental impact, estimated by experts, are qualitative parameters.

3. METHODS OF ESTIMATION OF THE SELECTED CRITERIA

There are currently various methods that have been developed and implemented to analyze and choose from a range of alternatives using different criteria. These methods include multiple criteria decision making (MCDM), multiple criteria decision analysis (MCDA), and multiple attribute decision making (MADM) (Köksalan, Wallenius and Zionts 2011). The existence of this variety of methods makes the issue of choosing the most suitable one rather difficult (Triantaphyllou 2000).

In the authors' opinion the MCDA methods of pairwise comparison are the most suitable for the examined problem. In the given paper the authors have analysed the possibility of employing for the choosing cargo transportation route and mode the most popular pairwise comparison methods: Analytic Hierarchy Process (AHP) method (Saaty 2001) and ELECTRE methods (Figueira, Mousseau and Roy 2005).

4. EVALUATION AND SELECTION OF CARGO TRANSPORTATION ROUTES

To illustrate the suggested AHP and ELECTRE methods efficiency for choosing the freight transportation route and mode, five alternative routes from Shanghai to Moscow have been evaluated. The suggested routes are as follows: Shanghai – Hamburg – Riga – Tver – Moscow; Shanghai – Vladivostok – Rail Terminal in Moscow – Warehouse in Moscow; Shanghai – Hamburg – Kotka – Tver – Moscow; Shanghai – Hamburg – Klaipeda – Tver – Moscow; Shanghai – Alashankou – Dostyk – Rail Terminal in Moscow – Warehouse in Moscow.

Let us consider each route and its transportation mode in details.

Route A: Shanghai – Hamburg – Riga – Tver – Moscow. This route considers transportation of cargo from Shanghai to Hamburg by mother vessel. Thereafter container is being reloaded onto feeder vessel for delivery to the port of Riga. In Riga container is reloaded onto truck and delivered to the customs terminal in Tver. After customs clearance container is delivered to warehouse in Moscow for unloading.

Route B: Shanghai – Vladivostok – Railway terminal in Moscow – Warehouse in Moscow. Cargo in container is delivered from Shanghai to Vladivostok by vessel, where customs clearance is being done. Further the container is loaded onto rail platform and delivered to rail terminal in Moscow. At the terminal the container is being reloaded on truck and delivered to the warehouse of consignee.

Route C: Shanghai – Hamburg – Kotka – Tver – Moscow. This route considers transportation of cargo from Shanghai to Hamburg by mother vessel. Thereafter container is being reloaded onto feeder vessel for delivery to the port of Kotka. In Kotka container is reloaded onto truck and delivered to the customs terminal in Tver. After customs clearance container is delivered to warehouse in Moscow for unloading.

Route D: Shanghai – Hamburg – Klaipeda – Tver – Moscow. This route considers transportation of cargo from Shanghai to Hamburg by mother vessel. Thereafter container is being reloaded onto feeder vessel for delivery to the port of Klaipeda. In Klaipeda container is reloaded onto truck and delivered to the customs terminal in Tver. After customs clearance container is delivered to warehouse in Moscow for unloading.

Route E: Shanghai – Alashankou – Dosty – Rail Terminal in Moscow – Warehouse in Moscow. Cargo in container is delivered from Shanghai to Alashankou by short see vessel. In Alashankou container is reloaded onto railway platform and further delivered to Dostyk, Chinese/Kazakhstan border point. In Dostyk the container is reloaded onto railway platform of Kazakhstan railways (changing the gauge). Further the container is being delivered to rail terminal in Moscow, where customs clearance is done. After customs clearance the container is reloaded on truck and delivered to the warehouse of consignee.

Results of calculations of two basic indices of efficiency (average transportation cost and delivery time) of the chosen routes of freight transportation are presented in Table 1 (see Kopytov and Abramov 2012).

Table 1: Efficiency indices of logistic systems

Route	Transportation cost, USD	Delivery time, days
A	6300	40
B	7500	25
C	6600	40
D	6800	42
E	9000	40

As it is evident from the table the decision-maker can not get a clear answer on the question what route to choose. On the one hand, the route A has the lowest cost of cargo transportation, but its delivery time is 15 days greater than the smallest time. On the other hand, the route B, which has the smallest delivery time, is more expensive (the cost is 19% greater). For the choice of route the priority between cost and delivery time should be chosen or multiple criteria decision method should be applied. Implementation of multiple criteria approach allows taking into consideration other criteria in the process of choosing the mode and route of the freight transportation; in considered case they are safety and ecological compatibility of transportation.

5. CHOICE OF TRANSPORTATION ROUTE AND MODE USING AHP METHOD

Complete calculation by 22 criteria, offered by the authors and united into such groups as cost, duration, reliability and ecological safety of transportation of cargo, is considered in (Kopytov and Abramov 2012). In present article we consider only the calculation of four criteria of the first hierarchy level for each group.

To perform the calculations of criteria, the authors have used standard algorithms of the AHP method with the commonly used pairwise comparison scale 1-9. This scale proposed by Saaty (2001) has the following values:

1 – if alternatives A and B are equal in importance;
3 – if A is slightly more important than B;
5 – if A is significantly more important than B;
7 – if A is very significantly more important than B;
9 – if A is absolutely more important than B;

and 2, 4, 6, and 8 are intermediate values between the two adjacent judgments.

The summary data of the experts' pairwise comparisons for criteria of cargo transportation are presented in Table 2. The importance of the criteria is evident from the evaluation of the criteria priority vector. It is easy to notice that criterion "Cost" with value 0,5813 of priority vector is more important for the multimodal freight transportation.

Table 2: Paired comparisons matrix for criteria

Criteria	Cost	Time	Reliability	Ecological impact	Priority vector
Cost	1	4	5	6	0,581288
Time	1/4	1	2	5	0,220842
Reliability	1/5	1/2	1	5	0,147686
Ecological impact	1/6	1/5	1/5	1	0,050185

The evaluations of the vector of the global alternatives priorities are shown above in Table 3. The results of the evaluations show that route B has the highest value of priority 0,291997 and will be selected for cargo transportation from Shanghai to Moscow.

Table 3: Evaluating result for freight transportation from Shanghai to Moscow

Alternatives	Criteria				Global priorities
	Cost	Time	Reliability	Ecological impact	
	Numerical value of priority vector				
	0,581288	0,220842	0,147686	0,050185	
Route A	0,290658	0,079618	0,125299	0,063250	0,208218
Route B	0,194134	0,487666	0,371898	0,329346	0,291997
Route C	0,226390	0,121666	0,108371	0,074537	0,178212
Route D	0,223518	0,068267	0,135682	0,067550	0,168433
Route E	0,065299	0,242783	0,258749	0,465317	0,153140

6. CHOICE OF TRANSPORTATION ROUTE AND MODE USING ELECTRE METHOD

The authors have chosen ELECTRE 1, the first outranking method of the ELECTRE methods family (Figueira, Mousseau and Roy 2005; Bouyssou et al. 2006), for applying in considered research. The algorithm of sorting and choosing the best alternatives of freight transportation for the specified criteria includes the following steps:

1) determining the weights of criteria;
2) determining the scales for criteria;

3) estimation of the alternatives according to all criteria;

4) calculation of the concordance and discordance set and determining the concordance dominance matrix;

5) determining the dominating and the dominated alternatives for suggested levels of the concordance and discordance and generating the new core of alternatives by eliminating the dominated alternatives from the existing set of alternatives;

6) if, in analyst's opinion, the number of alternatives within the core is high, specifying the "weaker" values of concordance and discordance levels (the lower value of concordance level and higher value of discordance level) and repeating the process from point 5, otherwise finishing the actions.

It is necessary to note that the last core comprises the best alternatives. The cores succession determines the sorting of alternatives by quality. The results of implementing the specified steps of algorithm are presented below in Table 4 – Tables 9.

Step 1. The criteria weights are shown in Table 4. The importance of β_i criterion is estimated by 10-grades scale (see line 2 of the table), and the criteria weights W_i are calculated by formula:

$$W_i = \frac{\beta_i}{\sum_{i=1}^{4}\beta_i}; \quad i = 1, 2, ..., 4. \qquad (1)$$

Table 4: Weights of criteria

	Cost	Time	Reliability	Ecological impact
i	1	2	3	4
β_i	8	5	3	1
W_i	0,471	0,294	0,176	0,059

Step 2. There introduced the scales for measuring the indicators: 25-grade scale for transportation cost and time, and 4-grade scale for other indicators (see Table 5).

Step 3. Every route is estimated by implementing the calculation results from Table 1 and assessment given by experts for two last indicators; they result in Table 6. It is evident that route D is dominated by route A and not included in Pareto set of solutions. Using the ELECTRE method, the route D is left at the initial set of alternatives, such approach corresponds to the existing practice.

Pairwise comparisons of routes by every criterion are presented in Table 7. For the pair of routes A-B we denote by "+" the case when A is strictly preferred to B; by "=" the case when A is indifferent (equals) to B, and by "–" the case when B is strictly preferred to A.

Step 4. The set of criteria $\mathbf{I} = \{1, 2, 3, 4\}$ is divided into three subset for every pair of alternatives A and B: subset $\mathbf{I}^{+}$ in which A is more preferable than B; subset $\mathbf{I}^{-}$ in which B is more preferable than A; and subset $\mathbf{I}^{=}$ in which A is indifferent to B.

Table 5: Criteria scales

Criterion	Value	Scale value
Cost	6000 - 6800 USD	25
	6900 - 7800 USD	20
	7900 - 8800 USD	15
	8900 - 9800 USD	10
Time	25 - 30 days	25
	30 - 35 days	20
	35 - 40 days	15
	40 - 45 days	10
Reliability	Bad	1
	Satisfactory	2
	Good	3
	Very Good	4
Ecological impact	Bad	1
	Satisfactory	2
	Good	3
	Very Good	4

Table 6: Assessment of the routes

Route	Cost	Time	Reliability	Ecological impact
A	25	10	2	2
B	15	25	3	3
C	20	15	2	2
D	20	10	2	2
E	10	20	3	4

Employing sets $\mathbf{I}^{+}$, $\mathbf{I}^{-}$ and $\mathbf{I}^{=}$ the concordance indices C_{AB} and disconcordance indexes D_{AB} are calculated for every pair of alternatives A and B using the following formulae:

$$C_{\mathrm{AB}} = \frac{\sum_{i \in \mathbf{I}^{+}} W_i + 0{,}5 \sum_{i \in \mathbf{I}^{=}} W_i}{\sum_{i=1}^{4} W_i}; \qquad (2)$$

$$D_{\mathrm{AB}} = \max_{i \in \mathbf{I}^{-}} \frac{l_{\mathrm{B}}^{(i)} - l_{\mathrm{A}}^{(i)}}{L_i}, \qquad (3)$$

where $l_{\mathrm{B}}^{(i)}$ and $l_{\mathrm{A}}^{(i)}$ are values of i-th criterion for A и B respectively; L_i is maximum value of i-th criterion scale.

The results of concordance and discordance matrices calculations are presented in Tables 8 and 9.

Step 5. The binary preference of A alternative over B alternative for specified levels of concordance p and discordance q is checked for conditions implementation:

$$C_{\mathrm{AB}} \geq p \text{ и } D_{\mathrm{AB}} \leq q. \qquad (4)$$

Route B is dominated and it can be excluded from the considered set by generating the new core of alternatives.

Table 7: Pairwise comparisons of routes

Pair of routes	Cost	Time	Reliability	Ecological impact
A-B	+	–	–	–
B-A	–	+	+	+
A-C	+	–	=	=
C-A	–	+	=	=
A-D	+	=	=	=
D-A	–	=	=	=
A-E	+	–	–	–
E-A	–	+	+	+
B-C	–	+	+	+
C-B	+	–	–	–
B-D	–	+	+	+
D-B	+	–	–	–
B-E	+	+	=	–
E-B	–	–	=	+
C-D	=	+	=	=
D-C	=	–	=	=
C-E	+	–	–	–
E-C	–	+	+	+
D-E	+	–	–	–
E-D	–	+	+	+

Table 8: Concordance matrix

Route	A	B	C	D	E
A	-	0,47	0,59	0,74	0,47
B	0,53	-	0,53	0,53	0,85
C	0,41	0,47	-	0,65	0,47
D	0,26	0,47	0,35	-	0,47
E	0,53	0,15	0,53	0,53	-

Table 9: Discordance matrix

Route	A	B	C	D	E
A	-	0,6	0,2	0	0,5
B	0,4	-	0,2	0,2	0,25
C	0,2	0,4	-	0	0,5
D	0,2	0,6	0,2	-	0,5
E	0,6	0,2	0,4	0,4	-

The first step specifies p=0,74 and q=0,25. As Tables 8 and 9 show, the condition (4) is performed for pair A-D and B-E. Then routes D and E are dominated and they can be excluded from the considered set of alternatives. Consequently, the core of considered alternatives now comprises three routes: A, B and C (shown by dotted line in Fig.1)

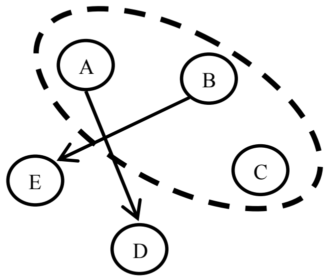

Figure 1: Core of alternatives A, B and C

Step 6. The level of concordance p is decreased by p=0,59, while the discordance is still q=0,25. The condition (4) is performed for pair A-C, and the route C is dominated and for p and q levels the new core of the best alternatives comprises two routes A and B (Fig. 2).

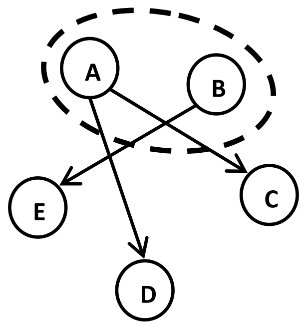

Figure 2: Core of alternatives A и B

7. EVALUATION OF THE EFFICIENCY OF SUGGESTED METHODS EMPLOYING

There is a consideration of the results of choosing the route and mode of freight transportation received by employing the methods AHP and ELECTRE (see Sections 5 and 6). The results of evaluation of freight transportation routes from Shanghai to Moscow, received by using methods AHP and ELECTRE, allow defining the most favourable routes and transportation modes. In general the obtained results are very similar to each other. So, choosing the alternative by AHP method, the route B is determined to be the best one, and the route A is the second in preference (see Table 3 above). Under implementing the ELECTRE method, the routes A and B are the best ones.

For *evaluation methods AHP and ELECTRE* the authors have formed the system of criteria including eleven indicators. These indicators were distributed in two groups: estimated by developers (programmers) and estimated by users (analytics) accordingly.

Group #1 "Users" estimated by users (analytics) includes eight indicators:

- simplicity of usage;
- visualization of results;
- control of estimates consistency;

- uncertainties in the analysis and calculations;
- flexibility of the analysis process;
- possibility of obtaining quantitative estimates for each alternative;
- possibility of separating assessment procedure for different experts;
- possibility of preferred alternatives changing.

Group #2 "Developers" estimated by developers includes three indicators:

- simplicity of realization;
- simplicity of modification (when the set of criteria or/and the set of alternatives are changed);
- dependence of the realization complexity on number of criteria and alternatives.

To evaluate each indicator the authors have selected the numeric scale from 1 to 10, where 1 means unsatisfactory; 10 – excellent. The effectiveness of choice methods for the selected groups of criteria is characterized by the following criteria:

1) *the sum of scores* $S_j^{(i)}$, where $j=1$ for AHP method and $j=2$ for ELECTRE 1 method, where numbers of groups of criteria are $i=1,2$;
2) *the priority vector* (local criteria) $p_i=[p_{i,1},p_{i,2}]$, where the elements of the vector, respectively, define priorities (weights) of the methods AHP and ELECTRE 1 calculated for the *i*-th group of criteria as follows:

$$p_{i,j}=\frac{S_j^{(i)}}{S_1^{(i)}+S_2^{(i)}},\quad j=1,2. \tag{5}$$

It is easy to see that it is always $p_{i,1}+p_{i,2}=1$.

In the final step of the assessment process the vector $P=[P_1,P_2]$ of the *global criteria priorities* can be calculated:

$$P_j=\sum_{i=1}^{2}\beta_i p_{i,j},\quad j=1,2, \tag{6}$$

where $\beta_i, i=1,2$ are the weights of relative importance of the local (group); $\beta_i>0, i=1,2;\ \ \beta_1+\beta_2=1$.

In considered research the weights of local criteria suggested by experts are: $\beta_1=0,65$ and $\beta_2=0,35$.

A numerical weight or priority has been derived for each group of criteria (see Tables 10 – 11). Each group of criteria has been evaluated by four experts, and then average value of each indicator has been calculated. In both groups the criteria values of AHP method are greater (from 0,14 till 0,18) than the criteria values of ELECTRE, but each method has its own advantages.

Using formulas (5), (6) and the results of criteria assessment presented in Tables 10 and 11, we can calculate the global criteria priorities: p_1=0,58 for AHP method and p_2 =0,42 for ELECTRE method. So, the global criteria for AHP method is greater than the global criteria for ELECTRE 1 method by 0,16.

Table 10: Assessment of AHP and ELECTRE 1 methods for criteria group "Users"

Indicator	Method	
	AHP	ELECTRE
Simplicity of usage	3	5
Visualization of results	6	6
Control of consistency	8	2
Uncertainties	5	4
Quantitative estimates	8	2
Flexibility of the analysis	4	8
Separating assessment	8	4
Preferred alternatives changing	8	4
Sum of score	50	35
Criteria priorities	0,59	0,41

Table 11: Assessment of AHP and ELECTRE 1 methods for criteria group "Developers"

Indicator	Method	
	AHP	ELECTRE
Simplicity of realization	6	4
Simplicity of modification	4	6
Dependence of the realization complexity	6	2
Sum of score	16	12
Criteria priorities	0,57	0,43

The AHP seems to be the most attractive choice in this context since it allows structuring the choice procedure as a hierarchy of several levels. It allows distribution of criteria into several groups; consequently, the different groups of criteria can be evaluated by different experts. For instance, the economists have assessed the cost criteria; the transport technologists have evaluated the reliability and ecological criteria, while the managers have estimated the time criteria. The opportunity of the pairwise comparison of a smaller number of criteria in every group allows experts to determine better weighted values according to these criteria. The AHP method also allows the possibility of controlling the consistency of the experts' judgements, making it possible to increase the reliability of estimation. In summary, the multi-criteria analysis determined the AHP as the most suitable method for comparative evaluation of different alternatives of the cargo transportation.

When implementing the ELECTRE 1 method, the authors faced the problem of arranging the alternatives in the criteria table (assigning the weights). The use of a large number of criteria (Kopytov, E., Abramov, D., 2012) belonging to different professional knowledge areas resulted in an inadequate estimation of each criterion significance. With the help of invited experts, the authors were only able to competently evaluate certain criteria which they know well. The estimations of other criteria have been executed at by guess-work. Since the assigned weights of criteria have a great impact on the alternative choice, the authors have come to the conclusion that this method would result in largely inaccurate results.

But ELECTRE methods have some advantages too. The main advantages of ELECTRE 1 method are flexibility of the analysis process and possibility of preferred alternatives changing. The important merit of ELECTRE methods is staging of preferences detection for the decision maker taking the procedure of specifying the levels of concordance and discordance and cores examination. The analyst offers the whole range of possible solutions of the problem in the form of different cores to the decision maker. The concept of incomparableness employed in ELECTRE methods, is exceptionally significant from the practical point of view. It allows detecting the routes with "contrast" estimates for special examination.

CONCLUSIONS

The presented study has demonstrated that the AHP and ELECTRE methods can be used to solve the problem of choosing the best cargo transportation route and mode. In general the results obtained by AHP and ELECTRE methods are similar to each other.

In the judgment of the authors, AHP method is the most efficient for choosing the optimal logistic system. The method allows arranging the alternatives of trasportation in the order of their efficiency and showing their difference in the given set of criteria.

REFERENCES

Bouyssou, D., Marchant T., Pirlot M., Tsoukias A., Vincke P., 2006. *Evaluation and Decision Models with Multiple Criteria: Stepping stones for the analyst*. Springer Science & Business Media, Inc.

Cherkassky, B.V., Goldberg, A.V., Radzik, T., 1996. Shortest paths algorithms: theory and experimental evaluation. *Mathematical Programming*. Ser. A 73 (2), 129–174.

Figueira, J., Mousseau, V., Roy, B., 2005. ELECTRE Methods. In: J. Figueira, S. Greco, M. Ehrgott, ed. *Multiple criteria decision analysis: state of the art surveys*. Springer's International Series, Springer Science & Business Media, Inc., 133–162.

Ghiani, G., Laporte G. and Musmanno R., 2004. *Introduction of Logistic Systems Planning and Control*. John Wiley and Sons. England.

Gursoy, M., 2010. A method for transportation mode choice. *Scientific Research and Essays*, 5(7), 613–624.

Ivanova, O., Toikka T. and Hilmola O., 2006. *Eurasian Container Transportation Market: Current status and future development trends with consideration of different transportation modes*. Finland, Lappeenranta: Lappeenranta University of Technology. Research Report No 179.

Hansen, P., 1980. Bicriteria Path Problems. In: G. Fandel and T. Gal, ed. *Multiple Criteria Decision Making Theory and Applications*. *Lecture Notes in Economics and Mathematical Systems*, 177, Springer Heidelberg 1980, 109–127.

Henig, M. I., 1985. The shortest path problem with two objective functions. *European Journal of Operation Research,* 25, 281-291.

Köksalan, M., Wallenius, J., Zionts, S., 2011. *Multiple Criteria Decision Making: From Early History to the 21st Century*. Singapore: World Scientific.

Kopytov, E., Abramov, D., 2011. Modelling of multimodal freight transportation system using process approach. *Proceedings of the 13th International Conference on Harbour Maritime Multimodal Logistics Modelling and Simulation (HMS 2011)*, pp. 46-51, Sept. 12-14, Rome, Italy.

Kopytov, E., Abramov, D., 2012. Multiple-criteria analysis and choice of transportation alternatives in multimodal freight transport system. *Transport and Telecommunication*, 13 (2), Versita, 148-158.

Lukinsky V., 2008. *Models and methods of the theory of logistic: the Manual*. St. Petersburg: Piter.

Martins, E.Q.V., 1984. On a multicriteria shortest path problem. *European Journal of Operation Research*, 16, 236-237.

Müller-Hannemann, M., Weihe, K., 2001. Pareto Shortest Paths is Often Feasible in Practice. In: G. Brodal, D. Frigioni, A. Marchetti-Spaccamela, ed. *WAE 2001*. *LNCS*, 2141. Springer, Heidelberg, 185–197.

Ravindra, K. A., Magnanti, T. L., Orlin, J. B., 1993. *Network Flows: Theory, Algorithms and Applications*. Prentice Hall.

Saaty, T.L., 2001. *Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World*, New Edition (Analytic Hierarchy Process Series, Vol. 2), RWS Publications.

Triantaphyllou, E., 2000. *Multi-criteria decision making methods: A comparative study*. London: Kluwer Academic Publishers.

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