Multiple Criteria Evaluation of Global Transportation Systems - Analysis of Case Study

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Abstract. The paper presents the evaluation and selection of the most desired finished goods transportation corridor of delivery for the company which operates in the household appliances industry. To decrease the production costs, the company relocated manufacturing process to China. That is the reason why it is necessary to find a transportation and logistics solution how to supply finished goods from China to the warehouses in central Poland (Lodz) on the most preferable conditions for the company and its customers. The top management of this international company (acting as a Decision Maker DM) is responsible for finding the most suitable supply chain of manufactured goods. To solve the problem the author of this paper implements the Multi-Criteria Decision Making/Aiding methodology. The decision problem is formulated as a multiple criteria ranking problem. Thus, the author designs alternative global transportation corridors between China and Central Europe (Poland) based on a multimodal transportation process. On this basis she defines different alternatives of delivering goods and evaluates them by a consistent family of criteria. The author models the DM's preferences and carries out a series of computational experiments with the application of selected MCDM/A ranking methods, especially Electre III/IV and AHP methods. As a result it generates the final rankings of transportation options and gives the DM the most accurate transportation solution.

Keywords: Global transportation system · Supply chain · Logistics corridors · Transportation · Multi-criteria decision making/aiding · Electre III/IV method · AHP method

1 Introduction

Still changing economy and growing competition on the Polish market substantially influence the relevance of the delivery process in production companies. Enterprises strive for minimizing production costs of the components and shortening the flow of goods and information but at the same time trying to preserve the value of goods and services so important for the customers. The cooperation with the suppliers, who operate in developing countries, is one of the strategies to decrease manufacturing costs. That is the reason why more and more products offered on the European and United States markets come from China. However, decreased manufacturing costs,

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achieved by relocation of production to China, may lead not only to increase in the transportation and storage costs but also to the extension of delivery time. These are main purposes for dynamic development of the supply chains which has been observed for a couple of years. To reduce the number of goods frozen in the warehouses, it is necessary to analyze the duration of order, the time of delivery and the time of storage. Therefore, it is vital to improve the flow of goods delivered from China by implementation of the proper way of transportation, which would directly influence the decrease of costs and shorten the time of storage.

Herein, the author describes the process of construction and evaluation of the global transportation systems, which is a hot topic of the current transportation. The author considers the real world case study of global sourcing and presents a universal methodology of constructing and selecting the most desirable transportation – logistics corridors for global suppliers. The case study refers to the analysis of these corridors between China and Europe. Since China is a very active, global supplier, that delivers raw materials, components and finished goods on a large scale, worldwide, the analysis of the Chinese market makes, in the author's opinion, the presented results quite interesting.

The author analyzes and evaluates different transportation systems in the industry of household appliances. The delivered finished goods - small parts installed in household appliances - are manufactured in China and transferred to the central warehouses located in Central Europe (Poland/Lodz).

The author investigates different options of shipping the goods between China and Central Europe (Poland). She designs alternative, multi-modal transportation solutions that constitute the considered variants of delivering goods in industry. The transportation corridors are constructed heuristically, based on the author's intuition and expert knowledge. They may involve the transportation by road, by rail and by sea. The author simulates the behavior of generated solutions and evaluates major characteristics/parameters of their performance (costs, time, safety, reliability, timeliness). The evaluation of global transportation – logistics corridors is formulated as multiple criteria ranking problems. The author recognizes different stakeholders and their interests, defines consistent family of evaluation criteria, models the preferences of the decision makers (DMs) and stakeholders and finally performs a series of computational experiments. In the computational phase, she applies different MCDM/A methods, including Electre III/IV and AHP. As a result she generates final rankings of transportation options. Using the methods, the author compares the rankings generated by different computational algorithms and draws final conclusions regarding their stability. Finally, she recommends the best option of the transportation system.

The overall research goal of this paper is to develop a universal, generic methodology of evaluating global transportation systems and select the most desirable ones regarding the considered business environments, supply conditions and external circumstances. The author of this paper claims that the problem selection of transportation system has a multiple criteria character, and thus develops the proposed approach based on the principles of Multiple Criteria Decision Making/Aiding [1–4]. The challenge and the novelty of this work is to present the comparison of the multiple criteria evaluations of the alternative options - transportation systems and selection of the most desirable solution. The originality of this work consists also in the description and confrontation of all components of multiple criteria analysis of transportation variants. The presented approach can serve as a decision support tool for the logistic managers of companies performing the global sourcing. To the best of the author's knowledge such a contribution has not been reported in the literature, so far.

The paper is composed of 5 sections. In the first one the background of the analysis is presented. The second section includes the description of the methodological background of the research. It presents the principles of Multiple Criteria Decision Making/Aiding, the applied MCDM/A methods and the analysis of the transportation systems – with respect to transportation from China. Section 3 is focused on the description of decision making, especially on the characteristic of some ways of transportation and the criteria which are used for evaluation of those ways. Section 4 includes the results of computational experiments generated by the application of Electre III/IV and AHP methods. In Sect. 5 the final conclusions are presented. The paper is supplemented by a list of references.

2 Methodological Background of Research

2.1 Global Transportation System Considering the Chinese Market

Transportation is the set of activities connected with relocation of people and shipments in time and space with proper means [5, 6]. It is covering a distance or a change of place of goods/people using the transport facilities [7]. In another definition, the transportation is the technological process of each and every relocation in the distance, so the relocation of people, items and energy [8]. In economy, transportation is the service provision for consideration which results in relocation of people and shipments [9]. The general definition of the transportation defines it as a process which is the finite sequence of activities necessary to relocate people and shipments [10]. Its efficiency is determined by delivery of goods on time, to the right place, consistent with the decision of a person who assigns a transport service [11]. The set of transportation processes creates the transportation system. In this paper, the global transportation system is the main focus. The global transportation system is defined as the system which covers at least two national transportation systems. It has huge influence on functioning the international trade exchange where costs and time of transportation are very important. Costs and time of transportation depend on the branch and technologies of transportation used [12].

These days, when globalization and strong market competition shape functioning of companies, transportation system is the key issue. It is necessary to look for solutions which will increase competitive advantage of one company over another. Minimizing the prices for the goods by means of lowering the manufacturing costs is one of the ways to achieve the advantage [13]. It is often inevitable to transfer manufacturing to another countries or acquire materials from suppliers who come from countries where the labour force is low-priced [14].

China is the market which performs a vital role taking into account the migration of manufacturing to the developing countries (especially, keeping in mind those countries where the labour costs are lower). China, for the last thirty years, has recorded constant economic growth – on the average 10%. Such results are unprecedented in any other economy [15]. Besides, the forecasts present further development and economic growth of China caused by increasing trade activity between Asian and Pacific countries (the United States in particular) and number of investments in China and India. Still, the trade between the United States and the European Union will be the most important but the biggest growth in that respect will be designated to the trade with Asia [14]. China would be able to approximate or even catch up with the United States in the following decades according to the forecasts [15]. That is why China is the very interesting supply region which advantages are used more and more often by European (including Polish) manufacturers.

In China it is possible to purchase simple, mass products for very affordable prices [16, 17]. In that region is located the production of goods for which demand is constant and easy to predict and have long validity period. It is profitable solution for less innovative companies which manufacture the goods using common technologies [14].

Until recently, the transportation by sea has been exploited as the most preferable transportation system from China. However, this mean of transportation poses a lot of difficulties for companies, especially with respect to placing orders and planning the supplies. Another disadvantage of this way of transportation is the long term of delivery which is more than thirty days. Therefore, companies need to place orders a couple of weeks earlier which may cause planning stocks on the basis of forecasts and result in increase of stocks stored in the warehouses with the simultaneous lack of flexibility in case of changing demand [18]. Such a rationale is the ground for seeking the alternative ways of transportation in the case study described in this paper.

2.2 Characteristics of the MCDM/A Methodology: Major Features of the Applied MCDM/A Methods

Multiple Criteria Decision Making/Aiding (MCDM/A) is a field of study that develops rules, tools and methods supporting the DM in solving complex decision problems, in which several – often contradictory – points of view must be taken into account [1–4]. According to B. Roy [19, 20] Multiple Criteria Decision Making/Aiding is the activity of an analyst who helps to a DM, during a decision making process, to find answers for questions asked to find the most desired solutions, taking into consideration multiple aims (criteria) which are formulated by the DM. The methodology of MCDM/A has a universal character and can be applied in various cases when a DM solves a so called multiple criteria decision problem (MCDP). MCDM/A simplifies the process of carrying out most of the stages of the decision process, starting from formulation of decision aims, through creation of options and finally choosing the best of them [21].

MCDP is a situation in which, having defined a set of actions/variants/solutions (A) and a consistent family of criteria (F) the DM tends to: [1–3, 22]

- determine the best subset of actions/variants/solutions in A according to F (choosing problem),
- divide A into subsets representing specific classes of actions/variants/solutions, according to concrete classification rules (sorting problem),

- rank actions/variants/solutions in A from the best to the worst, according to F (ranking problem).

The set of A can be defined directly in the form of a complete list or indirectly in the form of certain rules and formulas that determine feasible actions/variants/solutions, e.g. in the form of constraints [3, 4]. The consistent family of criteria F should be characterized by the following features: [2, 19, 23, 24]

- it should provide a comprehensive and complete evaluation of A,
- each criterion in A should have a specific direction of preferences (minimized – min or maximized – max) and should not be related with other criteria in F,
- the domain of each criterion in F should be disjoint with the domains of other criteria.

In this paper the multiple criteria evaluation of transportation systems is defined as a multiple criteria ranking problem. The transportation options constitute the considered variants A. They are evaluated by a standardized, consistent family of criteria F and finally ranked from the best to the worst. The criteria evaluate various aspects of the considered variants, which are believed to be important from the perspective of different stakeholders, including the DM.

To solve MCDPs multiple methods can be used. Those methods can be generally divided into:

- The methods of American inspiration [25] based on the utility function; e.g. AHP [26, 27] or UTA [1].
- The methods of the European/French origin, based on the outranking relation (e.g. Electre methods [19, 23], Promethee I and II [1].

In this paper – in the case study described – the Electre III/IV method and AHP method are applied to rank the global transportation systems.

Major Features of Electre III/IV Method
The Electre III/IV method belongs to a family of multiple criteria ranking procedures based on the outranking relation. It is based upon building the preference model by comparing in pairs all decision variants considering thresholds which define the relation between those variants [28]. It generates the final rankings of a definite set of variants and orders them from the best to the worst, taking into account the following relationships between variants: indifference (I), preference (P) and incomparability (R). The calculation algorithm comprises following stages:

- I – creation of the evaluation matrix and definition of the DM's preferences model, (matrix of performances comprises the evaluation of each variant by each criterion; the DM's preference model is constructed with the application of indifference (qj), preference (pj) and veto (vj) thresholds as well as the weight (wj), defined for each criterion. The thresholds define the sensitivity of the DM to the changes of the criteria values and the weight (wj), expresses the importance of each criterion).

- II – creation of the outranking relation.
- III – usage (operation) of the outranking relation.

The final ranking is made on the basis of preorders: a descending and an ascending, in compliance with the following rules:

- The a variant is considered to be better than the b variant (aPb), if at least in one finite preorder a is placed before b, and in the other one a is at least as well classified as b is.
- The a variant is evaluated equally to the b variant (aIb), if both variants belong to the same class in each of two rankings.
- Variants a and b are incomparable (aRb), if in one of two rankings the a variant is placed higher than b and the b variant is placed over the a variant in the other ranking.

In the descending distillation the variants are ranked from the best to the worst, while in the ascending distillation they are ranked in the inverse order. The intersection of two preorders gives the final ranking, which is usually presented in a graphical form. It corresponds to a relation matrix that includes final relations between variants, expressed in the following form: indifference (I); preference (greater than ">"); non-preference or inverse of preference (less than "<") and incomparability (R) [22, 29].

Major Features of Analytic Hierarchy Process (AHP) Method

The AHP method was formulated by Saaty [26, 30], who claimed that human judgments are always relative and depend on characteristic of a DM, his role and the system of values that the DM upheld. As the result one may observe various approaches to the decision problem (the object of evaluation) and manifest itself in different importance wages of partial utilities of specific variants which are the same with the evaluation criteria. The above statement points to consistency of AHP method with utility theory [31].

Similarly to Electre III/IV method the AHP is also a multiple criteria ranking procedure that ranks a finite set of variants from the best to the worst. It is focused on the hierarchical analysis of the decision problem. Through the definition of the overall objective, evaluation criteria, sub-criteria and variants the method constructs the hierarchy of the decision problem. As opposed to Electre III/IV method the AHP is based on a multi-attribute utility theory [25] and generates final rankings of variants based on their aggregated evaluations represented by a utility function. In the final rankings generated by the AHP method the possible relationships between variants are limited to: indifference (I) and preference (P). All variants evaluated by the AHP method are comparable [22].

The AHP method consists of following stages: [32, 33]

- making of hierarchical structure,
- evaluation of the structure.

The procedure of the AHP method is based on the pair-wise comparisons of criteria, sub-criteria and variants. This model of preferences is expressed in the form of relative weights (wr), which represent relative strength of the compared element against another, expressed on the 1 to 9 point scale [26].

The result of the AHP method is a set of vectors containing normalized, absolute values of weights (wa) for criteria, sub-criteria and variants. The sum of the elements of the vector is 1 (100%). The absolute weights (wa) are aggregated by an additive utility function. The utility of each variant (i) – Ui is calculated as a sum of products of absolute weights (wa) on the path in the hierarchy tree (from the overall goal, through criteria and sub-criteria) the variant is associated with. The utility (Ui) represents the contribution of variant (i) in reaching an overall goal and constitutes its aggregated evaluation that defines its position in the final ranking [22].

In Sect. 4 one can find more specific description of each stage in both methods and the results of computational experiments which have been carried out.

The author of this paper has chosen these two methods, as suitable for solving the multiple criteria ranking problem but at the same time handling it in a different manner. She wants to demonstrate how the representatives of two alternative schools of MCDM/A can deal with the global transportation systems evaluation and selection problem. The choice of Electre III/IV and AHP methods allows the author to compare the computational results generated by two methods based on different methodological (axiomatic) principles, alternative ways of defining and structuring criteria and different techniques of modeling the DM's preferences.

3 Characteristic of the Decision Situation

3.1 Verbal Description and Definition of Variants

The object of considerations is evaluation and selection of the most suitable transportation and logistics variant for the company operating in the household appliances industry. The entity is a part of the international corporation which is the leading producer of such appliances. At present, the group comprises of 42 manufactures in 13 countries in Europe, the United States and Asia. Altogether, the sale and customer service network involves 80 companies in 47 countries. The corporation employs about 50,000 people 70% of whom work in Europe. The entity specializes in sale of fridges, ovens, cookers, hoods, washing machines, clothes dryers, dishwashers and small kitchen appliances.

The case study refers to the company located in central Poland – Lodz. The enterprise specializes in the sale of household appliances and its annual production in 2015 was 1.5 pieces and keeps increasing every next year. The company's customers are the so called local warehouses which distribute appliances to the particular stores. Products are sold all over the world, especially on the European markets (Germany, France, Italy, Spain, Great Britain in particular, less frequently in Scandinavia and East Europe), as well as in the United States, Australia and Asia.

Most of the company's suppliers are located in Europe, nevertheless, some of the components are delivered from the Far East. Materials purchased from the supplier whose manufacture is located in China constitute the highest share. It is one type of materials which stands for five different goods (which differ in specification and technical parameters). These components are used in about 67% of manufactured appliances, one item per one appliance.

The process of materials delivery from China is connected with some obstacles caused by distance what results in high delivery time. It influences the quantity of materials stored in the warehouses. The company aims to minimize the stocks by looking for solutions which will make it possible. Therefore, 5 Why analyses were carried out to find the reason why the share of materials delivered from China is so high in the overall quantity of stocks. The analyses have shown that such situation is caused by usage by the company only one transportation solution that is combined variant of two branches: sea and road transportation (V2 variant described in the Table 1). Such model of delivery process was suggested by the shipping agency that cooperated with the company. Director of logistics, acting as the DM, selected the above delivery variant in compliance with the agreement with the shipping agency whereby the agency was responsible for delivery. Besides, the company has never before analysed various transportation variants, taking into account such criteria as costs, duration, timeliness, reliability, flexibility, safety or value-added services offered by the suppliers.

The DM is determined to rationalize the supply chain of purchased goods due to growing, strong competition so that it would be possible to reduce costs and time of delivery as well as improve such crucial parameters as safety and timeliness. To achieve the above mentioned added value of services, the DM finds it necessary to reassess the transportation system used so far and evaluate other options of delivery. After first analyses, the DM considers reduction of sea-road combination chain of delivery and implementation of transportation variant which employs other transportation branches

Table 1. Variants – global transportation systems – verbal description of decision problem.

Variant	Type	Verbal description
V1	Sea transport+sea transport+road - rail transport	Stages: • sea transport from port in Qingdao to Hamburg port • sea transport from Hamburg to Gdynia port • rail transport from Gdynia to container terminal in Strykow • road transport from Strykow to company's central warehouse
V2	Sea transport+sea transport+road transport	Stages: • sea transport from Qingdao to Hamburg port • sea transport from Hamburg to Gdynia port • road transport from Gdynia to company's central warehouse
V3	Sea transport+road transport	Stages: • sea transport from Qingdao to Hamburg port • road transport from Hamburg to company's central warehouse
V4	Road-rail transport	Stages: rail transport from Chengdu to Lodz railway station road transport from Lodz railway station to company's central warehouse
V5	Rail transport+rail transport	Stages: • rail transport from Chengdu to reloading terminal in Lodz • rail transport from Lodz railway station to company's central warehouse (the company owns its siding)

or different combination of them. In the times of strong competition, the DM needs to find better transportation variant having regard to price and duration of delivery. At the same time the DM would like to carry out comprehensive and objective evaluation of transportation options.

Decision problem of choosing the global transportation systems is defined as multicriteria variant ranking task. The variants taken into consideration indicate the ways of covering the distance between China/Qingdao or Chengdu and Poland/Lodz V1–V5 (Table 1).

The above mentioned variants entail the supplier's responsibility for delivery either to Qingdao sea port or to Chengdu railway station. The air transport is intentionally omitted, as it implies too high costs for the investigated company. Since the DM has not used any other transportation systems so far, thus the selection of the new system shall be well-thought and based on the detailed analysis. The following criteria will apply in the selection of the system: time, cost, transportation timeliness and reliability. They are believed to be the most crucial from the DM's perspective.

3.2 Evaluation Criteria for Variants

The decision process of selecting the most desired transportation system is based on 5 variants. Thus, on the basis of the interview and DM's preferences and aspirations the adequate criteria have been formulated. Finally, criteria K1–K7 have been specifically described in Table 2.

Table 2. Evaluation criteria for variants – global transportation systems – decision problem presentation.

Criteria	Verbal description
K1: Transportation cost	It is one of the fundamental criterion for variants evaluation, which defines overall costs of transportation operations of container 40′ from China to the warehouse of the company, expressed in monetary units [PLN]. The criterion has been formulated on the basis of data provided by the company and the shippers' offers. This criterion is minimized
K2: Transportation time	It is the second fundamental criterion for transportation variant evaluation. The criterion is expressed in days and it represents the duration from the release of materials by the supplier to the delivery to the company's warehouse. This criterion is minimized
K3: Transportation timeliness	The criterion defines the variance between actual and pre-defined delivery due date. It resulted from the statistical data provided by the potential carriers. It is a maximized criterion defined as a percentage [%] of deliveries carried out on time
K4: Transportation reliability	This criterion measures the number of damaged packages in delivery process, in a month period. It is a minimized criterion defined as a percentage of damaged shipments

(*continued*)

Table 2. (*continued*)

Criteria	Verbal description
K5:Transportation flexibility	The criterion measures the variant's reaction time (including: operating carrier) to unexpected events. It represents several aspects including: K5.1 – frequency of delivery (defined as a number of potential deliveries in a month period), K5.2 – minimal size of shipping quantity (expressed on the 1 to 10 point scale) and K5.3 – packaging ability (percentage of held container capacity). It is a maximized criterion
K6: Transportation safety	The criterion involves aspects such as: possibility of loss or damage of the goods comprising transshipment or temporary storage. It is pressumed that safety of the delivery decreases not only with the increasing number of transshipments during the transportation process (K6.1 – number of indirect operations) but also with the extension of the storage period in the transshipment terminals (K6.2 – total period of the storage in the transshipment terminals, expressed in days). It is a minimalized criterion
K7: Customer's comfort	The criterion includes such transportation aspects as ability to monitor the package and its status information (K7.1 – expressed on the 1 to 10 point scale). It also includes K7.2 – additional service: number of free of charge storage in port and due date of the payment (K7.3). It is a maximized criterion

The selection of the desired transportation system shall be thoughtful and established on the basis of various criteria, crucial for the DM's perspective. The most important (the highest value) are cost, time and timeliness. On the basis of the seven abovementioned evaluation criteria of the variants and original raw data, the evaluation matrix has been constructed (Table 3).

In the described case study the raw data has been properly processed. Due to the fact that the selection of global transportation systems has been based on the application of two alternative multiple criteria ranking methods (Electre III/IV and AHP) the presented raw data has been handled and adjusted to the requirements of these methods. In all computational experiments based on the application of AHP method the raw data, including the evaluations of variants/transportation systems on all criteria and sub-criteria has remained unchanged. At the same time the raw data for the computational experiments with the application of Electre III/IV method required certain adjustments. For all instances in which single, separate criteria have been applied to evaluate variants (criteria K1, K2, K3 and K4) all the evaluations remained unchanged. For all the remaining criteria (K5, K6 and K7), structured as quantities composed of sub-criteria, the sub-criterion evaluations have been normalized, i.e. transformed into 0–1 intervals and then aggregated (arithmetically or weighted averaged) within each criterion. As a result for all criteria composed of sub-criteria standardized and normalized evaluations have been computed [22]. The detailed computational experiments are presented in the next section of this paper.

Table 3. The Evaluation Matrix based on raw data in described case study (selection of global transportation systems).

Criteria	Variants				
	V1	V2	V3	V4	V5
K1 [PLN]	5650	6250	6550	28400	29100
K2 [Days]	56	51	45	21	23
K3 [%]	0.70	0.80	0.85	0.90	0.85
K4 [%]	0.05	0.04	0.03	0.02	0.03
K5					
K5.1 [Points]	3	4	5	5	4
K5.2 [Points]	3	6	6	3	3
K5.3 [%]	0.45	0.90	0.95	0.50	0.50
K6					
K6.1 [Points]	3	2	1	1	1
K6.2 [Days]	12	8	8	7	10
K7					
K7.1 [Points]	3	5	5	8	8
K7.2 [Days]	12	10	8	2	5
K7.3 [Days]	60	45	45	30	30

4 Computational Experiments

4.1 Ranking of Variants with the Application of Electre III/IV Method

The ranking of the variants has been performed with the application of the MCDM ToolKit programme, which is the implementation of Electre III/IV method, presented in the second section of this paper. In accordance with the algorithm of the applied method, the evaluation matrix (Table 4) of each variants (V1, V2, … V5) of global transportation systems has been constructed. Matrix of performances have been aggregated in accordance with the abovementioned computational procedure.

Table 4. The Evaluation Matrix based on transformed data, used in computational experiments with the application of Electre III/IV.

Criteria	Variants				
	V1	V2	V3	V4	V5
K1 [PLN]	5650	6250	6550	28400	29100
K2 [Days]	56	51	45	21	23
K3 [%]	0.70	0.80	0.85	0.90	0.85
K4 [%]	0.05	0.04	0.03	0.02	0.03
K5 [0–1]	0	0.80	1	0.37	0.20
K6 [0–1]	0	0.65	0.90	1	0.70
K7 [0–1]	0.67	0.57	0.50	0.33	0.43

Then DM's preference model has been constructed including weights of criteria and indifference (qj), preference (pj) and veto (vj) thresholds which define the sensitivity of the DM to the changes of the criteria values. The model has been presented in Table 5. It presents subsequent criteria, preferences direction (including maximalized criterion – increasing (gain) and minimalized criterion – decreasing (cost), weights of the criteria (expressed on the 1 to 10 point scale, where 1 is the lowest value of criterion and 10 is the highest value of criterion) and indifference, preference and veto thresholds.

Table 5. The final model of preferences characteristic for the Electre III/IV method applied in case study.

Preference information					
Criteria	Preference direction	Weight	Indifference threshold	Preference threshold	Veto threshold
K1	Decreasing (Cost)	9	1000	20000	50000
K2	Decreasing (Cost)	8	5	20	50
K3	Increasing (Gain)	7	0.05	0.10	0.50
K4	Decreasing (Cost)	6	0	0.03	0.05
K5	Increasing (Gain)	5	0.20	0.50	1
K6	Decreasing (Cost)	3	0.20	0.50	1
K7	Increasing (Gain)	4	0.20	0.50	1

In the second stage of algorithm the outranking relation has been constructed. The computational procedure starts with the concordance and discordance matrix. On this basis the credibility matrix is acquired (Table 6). Matrix is expressed by the degree of outranking and credibility d(a, b) which are the aggregated evaluations of variants and outranking relation S(a, b) representation. Each degree of credibility defines the degree where 'a substantially outranks b'. For instance, as presented in the table, degree of credibility d(V4, V3) = 0.463 means that variant V4 is likely to outrank variant V3, whereas d(V1, V3) = 0 means that variant V1 will not outrank variant V3.

Table 6. Credibility matrix generated in the computational procedure based on the application of Electre III/IV method in case study.

Credibility matrix					
Alternative	V1	V2	V3	V4	V5
V1	1	0.267	0	0.162	0.272
V2	0.650	1	0.940	0.365	0.559
V3	0.186	0.988	1	0.660	0.756
V4	0	0.600	0.463	1	0.976
V5	0.373	0.483	0.244	0.952	1

In the final stage of the algorithm the outranking relation S(a, b) has been applied and on the basis of qualitative characteristics of each variant, both ascending and descending distillations have been performed. It resulted in complete preorders of the variants. Then, they have been averaged in the median ranking and the intersection of preorders resulted in the final ranking. The results of these calculations are presented in Fig. 1.

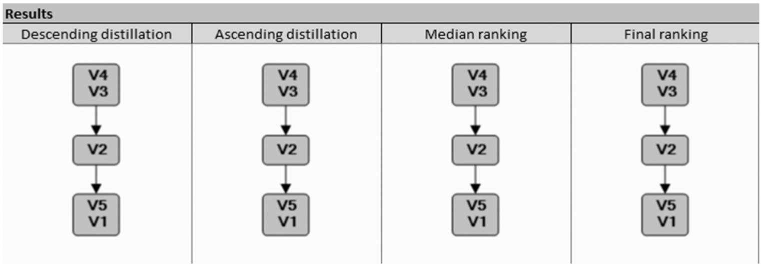

Fig. 1. The results of case study – analysis of global transportation systems – generated by a computational procedure based on the application of Electre III/IV method

The tabular form of the final ranking is outranking matrix also known as relation matrix, presented in Table 7 of this paper. The matrix includes final relations of the variants, expressed in the following form: indifference (I), preference (>), inverse of preference (<) and incomparability (R).

Table 7. Relation matrix generated in the computational procedure based on the application of Electre III/IV method in case study.

Relation matrix					
Alternative	V1	V2	V3	V4	V5
V1	I	<	<	<	I
V2	>	I	<	<	>
V3	>	>	I	I	>
V4	>	>	I	I	>
V5	I	<	<	<	I

Final ranking and relation matrix clearly indicate that equally V3 and V4 are the most desired variants and they outperform the others. The high value of system V3 is created by: low cost (K1), accurate timeliness (K3), flexibility (K5) and high ranking of criterion K7 – comfort for the customer. The major strengths of variant V4 are low delivery time (K2), excellent timeliness (K3) and reliability (K4) as well as safety of delivery (K6). It is worth pointing out that both variants V3 and V4 offer the average but not the cheapest price of transportation, which means that this aspect is compensated by other values.

The least desired systems are variants V1 and V5. Although the variant V1 offers the lowest costs of delivery, the other aspects of this variant have poorer performance than the winners of the ranking. The similar situation is with variant V5, which in addition offers the highest price of transportation.

4.2 Ranking of Variants with the Application of AHP Method

In the AHP method the pair-wise comparisons of criteria, sub-criteria and variants/global transportation systems have been applied to generate the preference model. This model of preferences is expressed in the form of relative weights (wr) on the 1 to 9 point scale. Each evaluation represents relative strength of the compared element against another. All weights have a compensatory character, i.e.: the value that characterizes the less important element (1/2, 1/4, 1/9) is the inverse of the value assigned to the more important element in the compared pair (2, 4, 9) [22].

Based on the AHP method algorithm the consistency indexes CI for each matrix of relative weights (wr) at each level of the hierarchy (criteria, sub-criteria and variants) have been generated. In the analyzed case study 16 CI-s have been computed, including 1 for criteria level, 3 for the sub-criteria levels and 12 for variants compared against each criterion.

In the next step of the AHP method computational algorithm 16 normalized, absolute values of weights (wa) for criteria, sub-criteria and variants have been produced. Due to space limitation the results of these calculations are not presented in this paper.

Table 8. The values of utility of each variant generated in the computational procedure based on the application of AHP method in case study.

Alternative	Score
V3	0.726
V4	0.720
V2	0.632
V5	0.614
V1	0.512

Table 8 presents the computed utilities (Ui) of each variant – transportation system with its absolute and normalized values. Figure 2 shows the classification of variants based on their generated utilities in the graphical form. Each variant – transportation system, presented in the graph, is featured by the level of computed utility (from 0.512 – V1 to 0.726 – V3 in the absolute values). The winner of the ranking generated with the application of AHP method is variant – global transportation system V3, followed by variants V4 and V2 (current system). The weakest variant V1 occupies the bottom position of the ranking.

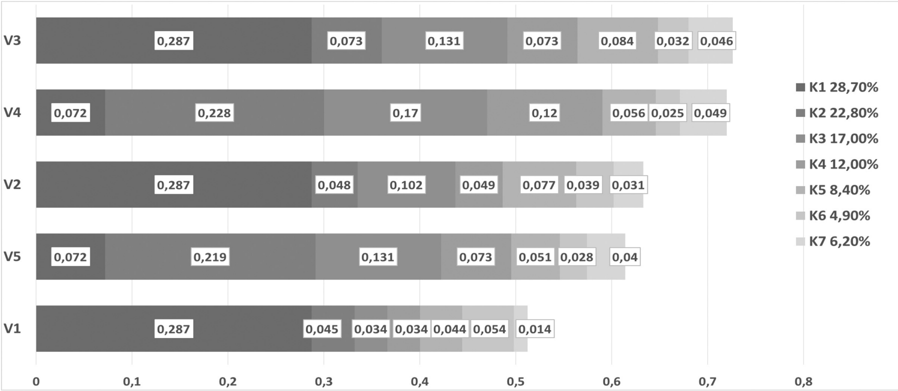

Fig. 2. Graphical representation of the final ranking generated with the application of AHP method in case study

Based on the ranking generated by the AHP method algorithm one can also conclude about the distance between the variants – global transportation systems (Table 8 or Fig. 2). The utility (Ui) of variant V3 is 0.726 and is not much larger than (Ui) of variant V4 (which makes these two variants comparable). But, what is transparent, the utility (Ui) of variant V3 is substantially larger than utilities of the remaining variants. For example the difference between V3 and V2 is 0.094 and between V3 and V1 is 0.214 (in the absolute values). The important feature of the ranking is its ability to demonstrate the contribution of each criterion to the final score and position of each variant – transportation system. Each distinctive colour on the graph represents the share of each criterion contribution in the utility (Ui) of each global transportation system.

The results generated with the application of AHP method are identical to those produced by the application of Electre III/IV method. Electre III/IV method indicates the equal importance of variants V3 and V4. Calculation results of AHP indicate slight difference of utility (Ui) between variants (0.006) so it can be assumed that they are comparable. Thus, the author of this paper recommends the transportation system V3 as the most universal and desired. For the DM of lower sensitivity on cost criterion, system V4 can be also taken into consideration, as it is characterized by a very low delivery time.

5 Summary

The presented paper is a comprehensive study concerning the evaluation and selection of global transportation systems for the company in the industry of household appliances. It proposes universal methodology based on the selection of global transportation system with application of the principles of Multiple Criteria Decision Making/Aiding (MCDM/A) and algorithm of solving the multiple criteria decision problem. Decision problem is defined as a multiple criteria ranking problem. The Electre III/IV and AHP methods have been applied in order to obtain the final ranking of global transportation systems. This research is an extension of the author's previous works [6, 22, 29].

The paper has both methodological and utilitarian character. It indicates the way of analysis and assessment of global transportation systems in order to rank solutions from the best to the worst, in compliance with the multiple criteria methodology. The methodological approach is based on the presentation of multiple criteria decision making procedure (ranking of the variants) in order to enable the optimum selection of global transportation systems. The author demonstrates the process of selecting and defining the variants (global transportations systems), specifies DM's model of preferences and finally carries out a series of computational experiments with the application of selected multiple criteria ranking methods. Based on the generated rankings, the author recommends the selection of the most desired transportation system.

In practical terms the author demonstrates the best variants which appear to be V3 and V4. They are both variants characterized by a lot of values, even though they do not provide the lowest cost of transportation. Variant V3 presumes to be favourable in aspect of costs, timeliness, flexibility and reliability of delivery. It is also featured by a high rank in aspect of comfort for the customer, ensuring the option of monitoring the package during transportation process, eight days of free of charge storage in port and convenient 45-days payment period for transportation service. Variant V4 is advisable in situation where DM expects low delivery time (this variant offers the lowest delivery period) regardless of the costs, which in this case is not the cheapest option. Nevertheless, it is also valuable for accurate timeliness, reliability and safety of delivery.

In conclusion, the author of this paper recommends the selection of V3 global transportation system as the most universal and desired. At the same time for the customer of lower sensitivity on costs but aimed at the short period of delivery, the author indicates variant V4 as considerable.

References

1. Figueira, J., Greco, S., Ehrgott, M.: Multiple Criteria Decision Analysis. State of the Art Surveys. Springer, Berlin (2005)
2. Vincke, P.: Multicriteria Decision-Aid. Wiley, New York (1992)
3. Żak, J.: Multiple Criteria Decision Aiding in Road Transportation. Poznan University of Technology Publishers, Poznan (2005)
4. Żak, J.: The methodology of multiple criteria decision making/aiding in public transportation. J. Adv. Transp. **45**(1), 1–20 (2011)
5. Cavinato, J.L.: Transportation-Logistics Dictionary. Springer, Berlin (1989)
6. Galińska, B.: Koncepcja Global Sourcing. Teoria i Praktyka. Difin S.A, Warszawa (2015)
7. Pfohl, H.C.: Logistiksysteme. Betriebswirtschaftliche Grundlagen. Springer, Berlin (2010)
8. Waters, D.: Global Logistics and Distribution Planning. Strategies for Management. Kogan Page, London (2003)
9. Hall, R.: Handbook of Transportation Science. Springer, Berlin (2003)
10. Borkowski, P., Koźlak, A.: Global competitiveness of Baltic Sea region in view of transport infrastructure development challenges. In: Globalizácia a jej sociálno-ekonomické dôsledky '09: elektronický zborník príspevkov z medzinárodnej vedeckej konferencie, pp. 54–65. Rajecké Teplice: Žilinská Univerzita v Žiline (2009)

11. Gleissner, H., Femerling, J.C.: Logistics. Basics-Exercises-Case Studies. Springer, Berlin (2013)
12. Gołembska, E.: Conditions of global logistics development. In: Żołądkiewicz, K., Michałowski, T. (eds.) Meeting Global Challenges. Working Papers Institute of International Business University of Gdańsk, Gdańsk (2008)
13. http://www.montana.edu
14. Oum, T.H., Park, J.H.: Multinational firms location preference for regional distribution centers: focus on the Northeast Asian region. Transp. Res. **2**, 101–121 (2004)
15. Aggarwal, V.K., Newland, S.A.: Responding to China's Rise. US and EU Strategies. Springer, Berlin (2015)
16. http://www.pgmc-company.com
17. Kerkhoff, G.: Zukunftschance Global Sourcing. Wiley-VCH, Weinheim (2005)
18. Guszczak, B., Jeleń, I.: Rozwój transportu kolejowego na rynkach wschodnich. Logistyka **6**, 4373 (2014)
19. Roy, B.: Decision-aid and decision making. Eur. J. Oper. Res. **45**, 324–331 (1990)
20. Roy, B.: Wielokryterialne wspomaganie decyzji. Wydawnictwo Naukowo Techniczne, Warszawa (1990)
21. Walentynowicz, P., Jankowska-Mihułowicz, M.: Wykorzystanie analizy wielokryterialnej w podejmowaniu decyzji kierowniczych, w przedsiębiorstwach województwa pomorskiego. Zarządzanie i Finanse **2**, 207 (2012)
22. Żak, J., Galińska, B.: Multiple criteria evaluation of suppliers in different industries—comparative analysis of three case studies. In: Żak, J., Hadas, Y., Rossi, R. (eds.) Advances in Intelligent Systems and Computing. Vol. 572: Advanced Concepts, Methodologies and Technologies for Transportation and Logistics, pp. 121–155. Springer, Berlin (2017)
23. Roy, B.: The outranking approach and the foundations of ELECTRE methods. In: Bana e Costa, C. (ed.) Readings in Multiple Criteria Decision Aid. Springer, Berlin (1990)
24. Żak, J.: Metodyka wielokryterialnego wspomagania decyzji w transporcie i logistyce. Logistyka **3**, 7141–7153 (2014). (ILiM, Poznań)
25. Keeney, R., Raiffa, H.: Decisions with Multiple Objectives. Preferences and Value Tradeoffs. Cambridge University Press, Cambridge (1993)
26. Saaty, T.: The Analytic Hierarchy Process: Planning. Priority Setting. Resource Allocation. McGraw-Hill, New York (1980)
27. Saaty, T.: Transport planning with multiple criteria: the analytic hierarchy process applications and progress review. J. Adv. Transp. **29**(1), 81–126 (1995)
28. Zopounidis, C., Pardalos, P.M.: Handbook of Multicriteria Analysis. Springer, Berlin (2010)
29. Galińska, B., Rybińska, K., Żak, J.: Multiple criteria evaluation of suppliers in food industry. Logistyka **2**, 140–144 (2015). (ILiM, Poznań)
30. Saaty, T.: How to make a decision: the analytic hierarchy process. Eur. J. Oper. Res. **48**, 9–26 (1990)
31. Mani, V., Agrawal, R., Sharma, V.: Supplier selection using social sustainability: AHP based approach in India. Int. Strateg. Manag. Rev. **2**, 98–112 (2014)
32. Jurek, A.: Description and possibilities of the usage multicriterial methods of the analytic hierarchy process. Folia Univ. Agric. Stetin. **49**, 68–78 (2007)
33. Rogowski, G.: Metody analizy i oceny działalności banku na potrzeby zarządzania strategicznego. Wydawnictwo Wyższej Szkoły Bankowej, Poznań (1998)