Possibilities of the Use of Multicriterial Mathematical Methods in Building Customer Relations in the Area of Logistics and Transport Services

Miloš Poliak¹, Iwona Ewa Tomaszewska¹, Miroslava Mikušová¹

¹ Faculty of Operation and Economics of Transport and Communications, University of Žilina, Žilina, 010 26, Slovakia,

Abstract   Background: In actual world the ability to analyse multifaceted issues and interpret results is one of the most important competences for creating and evaluating decision-making variants. The increase in the importance of these competences is determined by many factors of socioeconomic life, including the development of the information society, with a particular focus on the dynamic generation and processing and analysis of large amounts of information (BigData) using, inter alia, cloud computing necessary to support processes e.g. in the implementation of transport services, virtual and augmented reality, the industrial Internet of things, the development of industry 4.0, which provides the basis for the creation and integration of conjugated information and operational technologies, creation of cyber physical systems, cybersecurity issues, implementation of artificial intelligence or block chain. Persons making decisions, assumptions and scenarios need to use techniques and tools that describe the facilities and phenomena studied in a comprehensive manner, while allowing for the rapid and practical preparation of development and decision-making plans. This is especially important in the area of logistics and transport services.

Objectives: This study aimed to explore possibilities of application of multi-criterial mathematical methods in the area of logistics and transport services.

Method: An analysis of multi-criteria decision methods’ algorithms was used to identify the most convenient methods.

Results: Practical examples of identified methods are provided in vehicle distribution systems.

Conclusion: This study revealed that the use of ELECTRE, AHP, PROMETHEE and UTA methods is the most convenient in the investigated area.

Keywords   decision making; multi-criteria analysis; logistics; transport services; algorithm.

JEL Classification:   R48; H40

1. Introduction

Decision-making practice focuses on weighing alternatives that meet a set of desired goals. Each decision includes the element of discovery, irrational randomness and economic, social, political, organizational, managerial and other effects. The decision is to choose one of them.

In any decision-making problem, there is at least one optimal decision, for which it can be objectively determined that there is no other better decision while remaining neutral with regard to the decision-making process. The problem is to choose the alternative that best meets the complete set of goals. Making choices and decisions is one of the basic human activities. The decisions that a person makes not only determine the shape of his personal and family life, but to some extent affect the history of certain environments and communities.

Mature decision-making is the art of making the right choices. No person can avoid making decisions, because everyday life constantly puts us in the face of facts and events that demand from us to take an attitude or make certain choices. Decision-making in the strict sense is only when such decisions are made by a man in a conscious, purposely and voluntary manner. This means that before making a decision, he or she can see alternative variants for action at any given time, and that decision-making is guided by a clearly defined objective. The majority of the population has been found to be accustomed to existing schemas of thinking and solving problems [1]. If we learn other ways of thinking, we will be able to find new solutions and better prepare for the constant change of conditions around us.

The initiators of the decision, solving the identified problems, try to express with a single aggregate criterion all the relevant consequences of the problem. We are then dealing with a single-criteria analysis in which each potential variant
is assessed against one selected a priori criterion, e.g. cost volume, profit, profitability, benefit.

In solving this problem, we use various ways, methods, e.g. linear programming, parametric programming, targeted programming, marginal analysis, stochastic programming, non-linear programming, econometric methods, game theory and others. This procedure is justified only in simple cases, as a single criterion is not fully reliable, acceptable and exhaustive, i.e. there is no property that a coherent family of criteria should have [2].

Multi-criteria decision-making (MCDM) is a development of single-criteria analysis. It allows for the formulation of a coherent family of criteria as an instrument for an understandable, acceptable and comprehensive set of arguments. The approach expressed should ensure that preferences are developed, justified and transformed into guidelines for the decision-making process.

Supporting multi-criteria decisions requires the participation of a number of adjudicators in the decision-making process. The assumption is based on observations of the behaviour and position of the various participants, which result from a different perception of reality and the processes taking place there [3]. They also result from the fact that each person represents a different world of values, and the positions of individual participants are built on different, sometimes conflicting, evaluation systems. Consequently, a multi-criteria approach to decision-making is formulated.

Classical multi-criteria methods are based on the assumption that the assessment of decision-making variants against criteria and the weighting of criteria are known precisely and expressed by real numbers. In practice, there are situations where it is difficult or even impossible to define precise assessments of decision-making variants. In such situations, the assessment of variants and/or the weighting of the criteria may be expressed by means of interval numbers [4], fuzzy numbers or ordered fuzzy numbers [5], among others.

The key elements of the practical application of MCDM methods are the determination of reliable weights of the criteria as they have a key impact on the choice of the final variant [6]. Many applications of MCDM methods use so-called subjective weights, defined by project promoters or experts, reflecting their subjective feelings and preferences.

In situations where it is not possible to determine reliable weights, one can turn to objective balances, which are determined on the basis of a decision matrix. One method for determining objective weights is the entropy-based method. As the assessment of decision-making variants against criteria is a range, the weights of the criteria should also be ranges. In the literature, methods can be found for determining the weighting of criteria using entropy, which is extended to compartmental entropy [7] and to entropy based on ordered fuzzy numbers [8].

2. Literature review

The ability to analyse multifaceted issues and interpret results is one of the most important competences in the complex process of creating and evaluating decision-making variants. The increase in the importance of these competences is determined by many factors of socio-economic life. Highlights include the development of the information society, with a particular focus on the dynamic generation and processing and analysis of large amounts of information (Big Data) using, inter alia, cloud computing necessary to support processes e.g. in the implementation of transport services, virtual and augmented reality, the industrial Internet of things, the development of industry 4.0, which provides the basis for the creation and integration of conjugated information and operational technologies, creation of cyberphysical systems, cybersecurity issues, implementation of artificial intelligence or blockchain.

Persons making decisions, assumptions and scenarios need to use techniques and tools that describe the facilities and phenomena studied in a comprehensive manner, while allowing for the rapid and practical preparation of development and decision-making plans in the areas analysed.

The issue of a multi-criteria approach concerns the following issues: choosing the best variants (alternatives) for the criteria considered, organizing objects from best practices to the worst, and sorting (classifying) variants according to pre-established criteria. Multi-criteria methods are mainly used to provide decision-makers with a tool that, in the event of a number of conflicting decision-making criteria, will enable a rational decision to be made.

Multi-criteria analysis is used to support decision-making in situations where the choice is made between multiple variants. It is important to select the assessment criteria accordingly and to assign the weights appropriately. This means that, depending on the issue, the criteria should reflect different aspects such as costs, time, inter-entity dependencies, market trends, closer and further environment requirements, implementation opportunities and others. The purpose of the analysis is to select an variant adapted from the point of view of the criteria adopted [13], [14]. When performing a multi-criteria analysis, one adopts a certain set of specific solutions:

\[ W = \{ W_i: i = 1, 2, 3, \ldots, n \} \]  \hspace{1cm} (2)

and a set of criteria:

\[ K = \{ K_j: j = 1, 2, 3, \ldots, m \} \]  \hspace{1cm} (3)

according to which the different variants will be assessed. Then, for each criterion, the value \( X_{ij} \) needs to be specified. The value of \( X_{ij} \) is a measure of variant \( W_i \) according to criterion \( K_j \).

All assigned values are placed in a structured data matrix:

\[ X_{ij} = \{ x_{ij}: i = 1, 2, 3, \ldots, n; j = 1, 2, 3, \ldots, m \} \]  \hspace{1cm} (4)
in which the \( i \)-th row shows the values of the variant and according to subsequent (all) criteria, and \( j \)-th column - the values of subsequent (all) variants according to the specified criterion \( j \) \[15\]:

\[
X = \begin{bmatrix}
X_{11} & \cdots & X_{1j} & \cdots & X_{1m} \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
X_{n1} & \cdots & X_{nj} & \cdots & X_{nm}
\end{bmatrix}
\] \[5\]

Each of the criteria needs to have weight assigned to it. When selecting evaluation criteria, one can use both measurable and non-measurable parameters, which will describe variants without their quantitative evaluation. In addition, both quantitative and qualitative criteria can be used using multi-criteria. When choosing qualitative criteria, they must be quantified in order to carry out the comparison. Publications \[15\], \[16\] described a number of ways of criteria standardising. The standardisation of Peldschus, Van Delft and Nijkamp \[15\], Weitendorf \[17\]. can be used.

Multi-criteria methods were developed in a distributed manner, what affects ambiguity in the classification of studies. The division of multi-criteria decision support methods pointed out by many specialists \[18\] distinguishes:

- methods of multi-attribute utility theory, called synthesis methods to a single criterion, disregarding incomparability \[19\]. A group of methods, derived from the American tradition and based on the multi-attribute utility theory \[20\], consists in aggregating different criteria (points of view) into a single utility function that is maximized \[18\]. Eventually, multiple criteria (attributes) are reduced to a single global criterion. The \( U \) usability function can therefore be saved as following \[21\]:

\[
U = U(f) = U(f_1, f_2, f_3, \ldots, f_n)
\] \[6\]

where: \( f_1, f_2, f_3, \ldots, f_n \) are individual criteria.

Multi-attribute utility theory is based on the assumption that all variants of a given problem are comparable. It follows from that thesis that, for each pair of variants, the decision-maker will always prefer one of them or consider them equivalent \[21\]:

\[
aPb, \text{ i.e. } a \text{ is preferred over } b, \\
bPa, \text{ i.e. } b \text{ is preferred over } a, \\
alb, \text{ i.e. } a \text{ and } b \text{ are equivalent}
\] \[7\]

Preference and equivalence relationships are formulated according to \[21\]:

\[
aPb \Rightarrow U(z_a) > U(z_b) \\
alb \Rightarrow U(z_a) = U(z_b)
\] \[8\]

where: \( z_a \) and \( z_b \) respectively are images of variants \( a \) and \( b \) in the criteria space, \( U(z_a) \) and \( U(z_b) \) are respectively usability values of variants \( a \) and \( b \).

The properties of preference relationship \( P \) and equivalence \( I \) \[21\] are defined:

\[
aPb-bPa, \text{ i.e. } P \text{ is asymmetric}, \Rightarrow \\
aIb-bIa, \text{ i.e. } I \text{ is symmetrical}, \Rightarrow \\
aPb \text{ and } bPc \Rightarrow \text{ P is transitive}, \Rightarrow \\
alb \text{ and } bIa \Rightarrow I \text{ is transitive}, \Rightarrow
\] \[9\]

The multi-attribute utility theory methods include UTA \[22\], \[23\], and AHP \[24\], \[25\], \[26\].

- methods based on the preference relations are called preference synthesis methods taking into account incomparability \( 27 \). Methods based on the preference relations were developed by B. Roy \[28\], \[29\], \[19\], \[30\], \[31\], \[32\], \[33\], \[34\], \[35\].

In the methods, the decision-maker's preferences are modeled by means of a preference relation, which allows for the incomparability of variants, i.e. a situation in which the decision-maker cannot indicate similarities and differences between variants. It is neither able to consider variations as equivalent nor indicate the better of the two variants.

The \( S \) preference relation is a binary relationship defined in variant set \( A \). Depending on the \( aSb \), the information on the decision-maker's preferences, the quality of the assessments of the different variants and the nature of the problem is available. It provides enough arguments to consider that variant \( a \) is at least as good as \( b \), while lacking significant information to reject this assumption.

The definition of the preference relation \( S \) is formulated as the sum of relationships of equivalence \( I \) and preference \( P \) i.e.:

\[
S = P \cup I
\]

On the basis of the \( S \) relation, it is possible to determine the decision-maker's preferences in accordance with \[36\]:

\[
aPb \Rightarrow aSa \\
alb \Rightarrow aSb \text{ and } bSa \\
arb \Rightarrow -aSa \text{ and } -bSa
\] \[10\]

where: \( aRb \) is the relationship of incomparability between variants \( a \) and \( b \).

The relation \( 10 \) results in the following characteristics of preference relationship \( P \) and equivalence \( I \) \[36\]:

\[
aPb \Rightarrow \neg bPa, \text{ i.e. } P \text{ is asymmetric}, \\
alb \Rightarrow \neg bIa, \text{ i.e. } I \text{ is callback}, \\
alb \Rightarrow bla, \text{ i.e. } I \text{ is symmetrical}
\] \[11\]

The preference feature has dependency-defined properties \[36\]:

\[
aSa, \text{ i.e. } S \text{ is callback}, \\
aSb \text{ and } bDc \Rightarrow aSc, \\
aDb \text{ and } bSc \Rightarrow aSc, \\
alb \forall \neq q a\overline{S}b \Rightarrow aSb \neq aSb, b
\] \[12\]

where: \( D \) – relationship of dominance, \( I_j \) – equivalence relation due to criterion \( j \), \( S_q \) – preference relation due to \( q \) criterion.

Among the methods based on preference relation we distinguish: Electre I – IV [], [27], [28], [38], [39], Promethee I
and II [37], [40], [41], [42], and Oreste [43] [44]. A separate group consists of methods that are a combination of a methodology based on the preference relation, as well as a multi-attribute theory of usability. The methods Idra [45], Mappac [46], Pragma [47] are included in the group.

- interactive methods, called local assessment dialogue methods based on the trial and error approach of individual iterations [30], [31]. A common feature of methods based on the trial and error approach in individual iterations is the interlacing of the computational and the decision-making phase. As a first step, the decision maker obtains pareto-optimised solutions or sample solutions. In the second, the replies received are verified on the basis of preferential information [48], [49], [51]. One can highlight the following methods in this group:

  - search-oriented, e.g. LBS [52], [53], [54], STEM [55],
  - learning-oriented [56].

Among the methods which correspond to the classification criterion of the purpose of the decision-making process one can distinguish [57], [58]:

- multi-criteria selection methods (optimising),
- multi-criteria classification (sorting) methods,
- multi-criteria serial (ranked) methods.

In view of the wide variety of multi-criteria decision support methods available, each with specific advantages, disadvantages and limitations, for each of the issues considered, it is necessary to carry out a detailed qualitative analysis in order to select a technique that is appropriate to the decision-making problem in question. We focussed our investigation on the convenience of these methods for their use on the area of logistics and transport services. The basic overview of the main findings is presented in the following text.

MCDMs are used in many areas and segments of the economy. Depending on formulating the problem and the nature of the issues addressed, there are, identifiable in particular in scientific reports and experimental reports, preferences for the use of different multi-criteria methods. There are analyses on environmental [88], design [81], [89], and industrial [90] issues. The issue of multi-criteria decisions covering sales and marketing is reflected in [91], human resources management, inter alia, in [92], [93], production management [94], and transport and logistics [95], [58], [96], [97].

An analysis of the problems in publications compared to the preferences of authors and users revealed trends in the use of groups of multi-criteria methods. Mr Saaty described the use of the AHP method to address multi-criteria transport decision-making problems, including m.in. choice: the route for commuters, the most advantageous combination of routes to Pittsburgh’s new international airport, and the most advantageous mode of transport taking into account the cost-benefit analysis [24]. Article [25] characterises the use of the AHP method to address the multi-criteria decision-making problem of transport investment for the transport system in the Bosphorus Strait. The AHP method and ELECTRE III method were used to determine variant weights and calculate the parameters of the multi-secretarial objective function and to solve the decision-making problem related to the transport investment for the transport system in Poznań [98]. J. Żak used ELECTRE III as a decision support tool to solve the problem of decision-making allocation of vehicles to the tasks of the transport company [99]. An assessment of the environmental impact of transport using the ELECTRE III method is described in the article [85]. Source [100] presents a solution to the decision-making problem of the rank of transport service providers for a company operating in public road and rail transport using the multi-criteria PROMETHEE method. The PROMETHEE method was used to solve the multi-criteria problem of choosing the route between Belgrade and Birmingham [101]. E. Jacquet-Lagreze and J. Siskos used the UTA method to solve the multi-criteria problem of car serialing decision-making [102]. At work [103] the decision-making problems in transport systems are described.

3. Research design and methodology

Based on the analysis of the literature, no research results focused on CRM were found. When implementing CRM, it is important to identify customer expectations and to achieve the best possible customer satisfaction. It is important to note that there are differences in the provision of services and in the supply of tangible goods. The aim of this research is to identify which methods of multicriteria evaluation can be used in the implementation of CRM in the conditions of companies providing transport services. The research methodology is based on the evaluation of individual methods of multicriteria evaluation in terms of usability in the evaluation of customer care in the provision of transport services.

Given the different uses of MCDMs to solve multi-criteria decision-making problems, it is important to choose a tailored method of supporting decisions. The concept of choosing the MCDM method for the specificity of the multi-criteria decision-making problem involves carrying out a step-by-step approach to the solution by performing the following (in order):

- identification of the decision-making situation – the current decision-making situation is assessed, including both an informal and a formal assessment of the functioning of the system, e.g. SWOT analysis,
- detailed MCDM analysis – axiomatic analysis allows you to assess the specificity of the methods, identify their weaknesses and strengths. The arrangement of methods supports the process of adapting the method to the specificities of the analyzed decision-making problem. The indication of the MCDM method shall affect the correct modelling of the decision-making situation and the appropriate interpretation of the results obtained,
- analysis of aspects of method selection – analysis of aspects of matching decision-making problem and MCDM method and between the method and preferences of the decision-maker,
- comparison of the results of the analysis – the assessment of the matching of the MCDM method with the
specificity of the decision-making problem and to the
decision-maker’s preferences are compared with each other. The conclusions resulting from the comparative
analysis of the information obtained are the basis for
recommending the use of the method in the decision-
making situation under analysis,

– method selection.

Based on the performed research the most convenient
methods for identification and description of the specificities
of logistics and transport services are ELECTRE III, AHP,
PROMETHEE I and UTA.

This section is providing detailed description of previously
identified methods, that make possible their effective application
in the area of logistics and transport services.

The ELECTRE III calculation algorithm includes three steps:

I. the design of the evaluation matrix and the definition of
   the adjudicator’s preference model – defining a set of variants
   A and defining a coherent family of criteria F. For all the
   variants the values of subsequent criteria functions \( f_j \) are
determined. With the equivalence \( q_j \), preferences \( p_j \) and veto \( v_j \)
thresholds and coefficients of importance \( w_j \), for each crite-

rion \( j \), the adjudicator’s preference model is defined. This is
subject to the condition,

\[
q_j < p_j < v_j
\]  

(13)

II. design of the preference relation – for each pair of var-
   iants \( (a, b) \) the following shall be determined:
   a. conformity factors \( c_j (a, b) \) which determine to what
      extent, according to criterion \( j \), variant \( a \) is at least
      as good as \( b \), as described by the dependency:

\[
c_j (a, b) = \begin{cases} 
1 & \text{if } f_j(a) + q_j(f_j(a)) \geq f_j(b), \\
0 & \text{if } f_j(a) + p_j(f_j(a)) \geq f_j(b) 
\end{cases}
\]  

(14)

b. conformity index:

\[
C(a, b) = \frac{1}{W} \sum_{j=1}^{n} w_j c_j (a, b) \quad \text{gdzie } W = \sum_{j=1}^{n} w_j
\]  

(15)

c. non-conformity factors \( D_j (a, b) \) which determine to
what extent, according to criterion \( j \), variant \( a \) is at least
as good as \( b \), as described by the dependency:

\[
D_j (a, b) = \begin{cases} 
C(a, b) & \text{jeżeli } D_j (a, b) \leq c_j (a, b), \\
\frac{1 - D_j (a, b)}{1 - c_j (a, b)} & \text{inaczej}
\end{cases}
\]  

(16)

where: \( J(a, b) \) is a set of criteria for which \( D_j (a, b) > C(a, b) \).

III. use of the preference relation – ordering variants on the
basis of the preference degrees obtained \( S(a, b) \) according to
the condition:

\[
\lambda = \max S(a, b)
\]  

(17)

Only those pairs of variants \( (a, b) \) for which \( S(a, b) \) is
located in close proximity to \( \lambda \) undergo the analysis. Position
is determined by the difference \( \lambda - s(\lambda) \), where \( s(\lambda) \) is the
so-called cut-off level. The so-called qualification factor of
each variant \( Q(a) \), i.e. the difference between the number of variants that the variant is superior to and the number of var-

iants in respect of which case \( (a) \) is classified below, is cal-
culated on the basis of the \( \lambda \) value.

On the basis of the descending and ascending preorder,
a final ranking of solutions is prepared, based on the follow-
ing principles:

• variant \( a \) is considered superior to variant \( b \) \((aPb)\) if at
least one of the complete preorders \( a \) is placed before \( b \)
and in the other \( a \) is at least as well classified as \( b \),

• variant \( a \) is evaluated equally against \( b \) \((aHb)\) if both var-
iants belong to the same class in each of the two ranks,

• variants \( a \) and \( b \) are incomparable \((aRb)\) if variant \( a \) is in
a better position in one of the two series than \( b \) in the
ascending preorder, while variant \( b \) is in a better position
than \( a \) in the second rank.

Between the variants there may be situations: equiva-

lence – \( I \), preference – \( P \) and incomparability \( R \) [99]. In the
ranking matrix, the relations are shown between pairs of var-

iants and written in the form of symbols: equivalence – \( I \),
preference – \( P \), inverse of preferences – \( (P) \) andincompara-

bility – \( R \).

The AHP algorithm assumes that actions are carried out involving:

a. constructing a hierarchical structure of the decision-mak-

ing process, by setting levels: the objective of the deci-
sion-making process, which may be, for example, to or-

ganize decision-making variants from best to worst and to
choose the preferred variant (level 0) – criteria and eval-

uation sub-criteria (level 1), decision-making vari-

ants (level 2).

b. defining the decision-maker’s preferences – at each level of
the hierarchy, decision-making participants grant relative
assessments of importance (on a scale of 1 to 9
points) for pairs of criteria and decision-making variants,
indicating individual preferences of the solution. The
more preferred (more important) an element is, the higher
its score. All factors are compensatory, i.e. the rating
value for a less important (less preferred) element in a
given pair is the inverse of the value assigned to the more
important (more preferred) element. The resulting sets of
comparisons are presented in pairs in evaluation matrices,
where rows and columns have further criteria, sub-crite-

ria (specified for each criterion) and variants (specified
for criteria and sub-criteria). The direction in which pre-
ference information is written in matrices is always the
same, i.e. the relation of the element in the row to the el-

ement in the column is presented.

c. calculation of standardized evaluations of the validity of
hierarchy elements – based on the evaluation matrix, an
estimate of the validity ratings of individual elements of
the hierarchy is used. To this end, the so-called problem
of seeking the value of the matrix’s own value is solved.
The validity ratings are then normalized, i.e. their sum at each level of the hierarchy is 1.

d. study of global matrix consistency – checking the logic and homogeneity of preferential information provided by the decision-maker. For this purpose, a consistency ratio (CR) shall be used, the value of which shall not exceed 0.1. If the value of the cohesion index exceeds 0.1, then it is necessary to verify the preferential information provided by decision-makers, as it is too inconsistent or a mistake has been made e.g. when entering data. In such a situation, the decision-maker’s preferences are redefined.

e. variant final rank – standardised weights of variants, sub-criteria and criteria are aggregated using an additive utility function that synthesizes the weight shares of elements from each level. Scales represent an element’s share of the global decision-making goal. The utility of this variant $U_{(t-2)}$ appearing in the hierarchy at level $t - 2$, is calculated as the sum of the product weights of the individual elements occurring on the road from each branch of the hierarchy to which the variant is associated and (level $t - 2$), through sub-criteria (level $t - 1$) and criteria (level $t$). Utility $U_{(t-2)}$ is an aggregated assessment, the value of which should be determined from dependencies:

$$U_{(t-2)} = \sum_{j=1}^{n_t} \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{l} w_{k(t-2)} \cdot w_{f(t-2)} \cdot w_{j(t)}$$

(18)

where:

- $w_{k(t-2)}$ – standardised assessment of the validity (weight) of the hierarchy element and (variant) at level $t - 2$ relative to the hierarchy element $k$ (sub-criterion) at level $t - 1$ and the hierarchy element $j$ (criterion) at level $t$,

- $w_{f(t-2)}$ – standardised assessment of the importance (weight) of hierarchy element $k$ (sub-criterion) at level $t - 1$, relative to the element of hierarchy $j$ (criterion),

- $w_{j(t)}$ – a standardised assessment of the importance (weight) of hierarchy element $j$ at level $t$ relative to the level $0$ hierarchy element (decision-making objective).

As a result of the actions carried out, it prepares a summary of variants from best to worst, according to the calculated values of their usefulness, from the largest to the smallest. Relationships that may occur between variants in the end hierarchy can be indexed as: equivalent to $\equiv$ and preferred $\succ$. The preference relation is used to draw up a list of decision-making variants (partial ordering). To check whether there is a resilient relation of domination:

$$\forall a, b \forall x \in A \text{ if } \varphi^+(a) \geq \varphi^+(b) \land \varphi^-(a) \leq \varphi^-(b)$$

(22)

If variant $a$ is not preferred by variant $b$ and at the same time variant $b$ is not preferred by variant $a$, then $a$ is equivalent to $b$ as is left:

$$a \equiv b \land a \equiv b \Rightarrow a \approx b$$

(23)

The preference relation is carried out by organizing a set of decision variants using a preference relation. In the case where variant $a$ is not preferred by variant $b$, shall be written according to:

$$a \approx b \text{ if } \varphi^+(a) \geq \varphi^+(b) \land \varphi^-(a) \leq \varphi^-(b)$$

(24)

The scheme of multi-criteria analysis in the PROMETHEE method is carried out according to the procedure:

- comparing variants according to individual criteria using the preference functions reflected in the equation:

$$D_{i}(a, b) = \begin{cases} H(x) \text{ if } f_k(a) > f_k(b), \\ 0 \text{ if } f_k(a) \leq f_k(b) \end{cases}$$

(19)

where:

$$x = f(a) - f(b), \ 0 \leq H(x) \leq 1$$

- preference aggregation in the form of preference $\pi(a, b)$ is expressed by a dependency:

$$\pi = \sum_{x \in A} \varphi^-(a, x)$$

(20)

- ordering variants based on preference flows $\varphi^+$ and $\varphi^-$:

$$\varphi^+(a) = \sum_{x \in A} \varphi^+(a, x)$$

$$\varphi^-(a) = \sum_{x \in A} \varphi^- (a, x)$$

(21)
For all \( i = 1, \ldots, m, j = 1, \ldots, m \) designate \( \min_2(i,j) \) according to

\[
\min_2(i,j) = \arg\min \left( \varphi^+(a_i) - \varphi^+(a_j) \right) \quad \text{for } w \in W
\]

For all \( i = 1, \ldots, m, j = 1, \ldots, m \) check if there is a relation \( a_i \not\leq w_{ij} a_j \) with

\[
a_i \not\leq w_{ij} a_j \quad \text{if } \min_1(i,j) \geq 0 \quad \text{and} \quad \min_{1,2}(i,j) > 0 \text{ or there is no } i \text{ } \min_2(i,j) \leq 0
\]

Utilities Additives type (UTA) methods are based on minimizing utility error using a linear programming model. The UTASTAR method assumes the objective to minimize the distribution (dispersion) of errors, the UTADIS method determines two error values: indicating, respectively, a violation of the lower and upper end of the utility function of the alternative group by the \( k \)-th decision-making variant. UTADIS I assumes equal optimality criteria when creating an additive value classification model, UTADIS II is based on minimizing the number of poorly classified alternatives, UTADIS III simultaneously minimizes misclassified alternatives and maximizes the measure of good classification (distance of alternatives from value thresholds). The UTA method procedure includes:

a. identification of input data – the input data necessary for the calculation procedure is prepared, i.e.: a finite set of variants \( A \), a coherent family of criteria \( F \), the arrangement of parts of the set \( A \rightarrow A' \), which is at the same time the definition of the preference model. The preference model uses relations of preference \( P \) and equivalence \( I \).

b. constructing usability functions – a usability function is built on the basis of input:

\[
U(a) = \sum_{j} u_j \left( f_j(a) \right)
\]

where: \( w_{ij} \) the weight (conversion or compensation factors) of criterion \( j \) determining how many units of a given criterion \( j \) compensates the unit of another criterion. The values of the criterion functions \( U_j(u_j) \) are defined in order and, in points \( u_j \). Then linear interpolation \( U_j \) between these points is carried out on the basis of dependencies (30):

\[
U_j(z_j) = U_j(u_j^+) + \frac{z_j-u_j}{u_j^{++}-u_j} \left[ U_j(u_j^{++}) - U_j(u_j^+) \right]
\]

If the number of elements in the set is relatively small, then these elements take the value \( u_j \), which allows after the transformation to save the dependency (30) as:

\[
U(a) = \sum_{j} u_j \left( x_j^a + \delta(a) \right)
\]

where: \( x_j^a = f_j(a) \) and \( \delta(a) \) is an error related to estimation of value \( U(a) \).

c. final variants’ ranking – all variants are eventually ranked from best to worst according to the obtained partial values of utility function \( U(a) \). The measure of conformity of the summary statement, generated from the \( U \) utility function obtained, with the order set by the decision maker (standard order \( A' \)) is the amount called the Kendall coefficient \( \tau \) determined by the following formula:

\[
\tau = 1 - 4 \cdot \frac{d_{hk}(R,R')}{{m(m-1)}}
\]

where:

\( R \) – matrix of size \([mm]\), associated with the order set by the adjudicator,
\( R' \) – matrix of size \([mm]\), associated with the order specified by the utility function,
\( d_{hk}(R,R') \) – Kendall's distance, which determines the differences between the different elements \( R \) and \( R' \).

4. Discussion of Result

The issue of the vehicle distribution system is based on the functioning of car companies cooperating with subcontractors, e.g., car dealers. Regardless of the location of the production facilities, the automotive industry has a characteristic of the need to distribute and transport manufactured vehicles from manufacturer to recipient. The reality of the industry and the market demand that there must be an indirect entity between the first and the last entity, without which the process could not be properly implemented. Therefore, the main links identified in the vehicle distribution system are the manufacturer, importer, dealer, and consignee.

For the purpose of completing this task, the following assumptions were formulated:

- the movement of vehicles in the distribution system takes place in exactly the following order:
  manufacturer → importer → dealer → user;
- the movement of vehicles in the system is known and predetermined;
- the number of vehicle manufacturers is known and production facilities may be located in different locations (e.g., countries or continents);
- manufacturers receive orders for individual vehicles directly from importers, in a specific technical specification;
the customer cannot order the vehicle directly from the manufacturer, bypassing the other links in the chain.

The issue for the recipient is the selection of a suitable vehicle (means of transport) to carry out certain transport tasks. The customer has the opportunity to order any vehicle on sale on a given market (which is offered by a local importer). Before choosing the right means of transport, the user must also make certain assumptions:

a. specify the type of transport task to be carried out,
b. specify the time for which they intend to use the vehicle,
c. determine the degree of wear of the vehicle concerned, i.e. determine the average annual mileage of the vehicle to be carried out during the performance of the transport tasks.

For the purposes of presented investigation, it is assumed that the customer reports to the dealer, who has the means of transport on offer to all importers operating on the market concerned and sets out the requirements which, in their opinion should be met by the means of transport. When configuring the means of transport, the user will determine its technical and technological parameters, inter alia: volume of cargo space, payload, permissible total weight, type of fuel supply, emission standard, expected fuel consumption per 100 km.

The purpose of the vehicle distribution system is to provide potential customers with transport vehicles enabling the defined transport tasks to be carried out. It is required that the vehicle distribution system has a defined structure and operates on the basis of known organisational assumptions subordinated to the provision of vehicles to users.

4.1. Guidelines for multi-criteria assessment

For the purpose of the analysis, partial evaluation indicators were identified: the duration of the transport service, expenditure on the use of the vehicle e.g. depreciation resulting from the loss of value of the means of transport during the execution of transport tasks, related to the projected annual mileage of the car, maximizing the average daily working time of the means of transport, maximizing the use of means of transport. Depreciation cost is calculated according to dependency:

\[
K_{dp}(m(s), t(a)) = \frac{(2s - k_{dp}(a) + l_{d}(b) \cdot (o_{a}(a) + o_{d}(a)) + k_{dp}(b, i) \cdot n_{a})}{2m(i)}
\]

where:
\[o_{d}(a)\] – the cost of purchasing a summer tyre in size \(a\),
\[o_{d}(a)\] – the cost of purchasing a summer tyre in size \(a\),
\[k_{dp}(a)\] – the cost of replacing one tyre in size \(a\),
\[l_{d}(b)\] – number of tyres,
\[k_{dp}(b, i)\] – the cost of storing one set of tyres for one season,
\[s_{c}\] – number of tyres operated simultaneously in service,
\[n_{c}\] – fixed number of tire replacement periods,
\[m(s)\] – the total mileage of the \(s\)-th means of transport.

The average daily working time indicator \(L(i)\) was formulated as (35). The high value of the indicator \(L(i)\) can compensate for losses resulting from the low rate of use of means of transport.

\[
L(i) = \frac{t_{dp}(i)}{d_{dp}(i)}
\]

where:
\[t_{dp}(i)\] – working time in hours of \(i\)-th means of transport,
\[d_{dp}(i)\] – number of working days of \(i\)-th means of transport,

The rate of maximisation of the use of means of transport is calculated as the quotient of the working days of the means of transport (involvement in the performance of transport tasks) and the days at our disposal:

\[
L_{max}(i) = \frac{d_{dp}(i)}{30 t(i)}
\]

where:
\[d_{dp}(i)\] – number of working days of \(i\)-th means of transport,
\[t(i)\] – the time of disposal of \(i\)-th means of transport in months.

4.2. Local distribution model is the operational problem

Attention was also drawn to the issue of route planning as part of the strategic arrangements described in [107]. The issues raised concern in particular the issue of determining the shortest route and/or minimum journey time in order to reduce the total cost of forwarding. Assuming that the total cost is derived from the length of each route, the calculation of the total cost of transporting...
consignments on the route marked with starting and destination points may be expressed by means of dependencies:

\[ K = \sum K_{k,d} \cdot d_k \]  

(37)

where:

- \( K \) – total cost of local distribution,
- \( K_{k,d} \) – cost of transport (transport to or from) of consignments on route \( k \) [Eur/km],
- \( d_k \) – distance of \( k \) route,
- \( n \) – number of routes.

In practice, the problem is more complicated, because the cost of driving of 1 km of the route is not fixed. It is directly related to the peculiarities of the route on which the ride is to take place, i.e. the quality of the infrastructure, location, accessibility, repeatedly also with the time of day. Even more complicated is the relationship between cost and distance. The task shall become additionally complex after taking into account the conditions required to meet the conditions indicating that the longer the route, the more consignments must be delivered during the journey. As a consequence of the conditions, it is necessary to increase the payload of the vehicle used for transport, which directly translates into the unit cost of delivery.

It would therefore be appropriate to take into account in the relationship analyses that the distance of the journey is determined by the payload of the van used and that the payload may be a function of the length of the route. Reasoning results from multithreaded relationships between function arguments, their effectiveness and impact.

When preparing a description of the criteria, it should be remembered that the efficiency of processes in local distribution depends on the size of the network, and the format of the network operation affects the distribution costs. It should also be borne in mind that the route selection algorithm being developed must be consistent and enable implementation in a functioning consignments distribution system.

After analysing the aspects of the issue discussed, it was concluded that it was appropriate to design the distribution system first and, at taking into account the forwarding structure, to undertake work on adapting the transport process. The efficiency of the implementation of processes, at the operational level, will depend on the structure of distribution built, which may prove to be a fundamental constraint during the implementation of the adaptation processes. In this case, adjustments will have to be made, e.g. in the functioning of the location system, the equipment of terminals, the payload of means of transport. The procedure results from the nature of the coupled relations between processes and levels of management.

5. Conclusions

The study was devoted to analysing multi-criteria decision-making methods with a view to using solutions in the process of developing methodologies for building customer relations in the field of transport services.

Literature broadly addressing the decision-making issues of MCDM multi-criteria has been reviewed and analysed. Research models and the use of decision-making processes used in each method to achieve the goal set in the work have been identified.

The practical use of multi-criteria methods in logistics and transport analyses has been verified. The strengths and weaknesses of the ways proposed in the work were presented. The solved and addressed research aspects have been reviewed and, within the transport area, examples of decision-making problems that use the specificities of specific methods have been reviewed. Methods such as ELECTE III, AHP, PROMETHEE I and UTA were selected to describe the specifics of the issues in logistics and transport.

For those selected, the issues of conduct and analytical procedures are discussed in detail. Examples discuss the practical use of multi-criteria methods to solve complex vehicle distribution tasks and aspects of vehicle use for local shipment distribution. The aim of the work was not to mark process parameters, but to combine the critical points of the solution in order to guarantee the stability and development of the processes resulting from the transport plan. The results confirmed the complexity of the issue of the productivisation of proceedings in complex transport systems.

It was found that using the total cost model, simulations of different combinations of direct and indirect services could be carried out, the costs of different transport variants could be calculated and a solution which meets the criterion of e.g. minimum costs could be chosen. Price, time and reliability, punctuality and flexibility are currently not the only elements of competition from transport companies. In order to achieve a high position in the market, it is necessary to combine supply chain management, customer relations and transport process. In the era of creating partnerships with customers, it is necessary to develop links with the systems of individual partners. It would be appropriate for the methods to be adaptable, i.e. to support information distribution processes in areas such as co-operators, suppliers, producers, distributors and customers. It is necessary to adapt to the needs of the final customer, who in a highly competitive consumer goods market can make a fully informed choice of products and services according to individual needs.

Optimization problems require the development of customized optimization models in each case. Although a single, holistic model describing the functioning of the whole system can be developed, there should be as many optimisation models as there are decision-making problems. Only in this case is it possible to distinguish the functions of the purpose and consider the different relationships of the analyzed processes.

ACKNOWLEDGEMENTS

This work was supported by the Slovak Research and Development Agency under the Contract no. APVV-19-0444.
REFERENCES

[1] Dyer, J., Maut, Multiattribute Utility Theory, 2005.
[2] Roy B., Multi-criteria Decision Support, Scientific and Technical Publishing House, Warsaw, 1990.
[3] Roy B., Paradigms and challenges, 2005.
[4] Jahanshahloo G. R., Lotfi F.H., Izadikhah M., An Algorithmic Method to Extend TOPSIS for Decision-making Problems with Interval Data, "Applied Mathematics and Computation", 175, s. 1375-1384, 2006.
[5] Roszkowska E., Kacprzak D., The Fuzzy SAW and Fuzzy TOPSIS Procedures Based on Ordered Fuzzy Numbers, Information Sciences, 369, s. 564-584, 2016.
[6] Trzaskalik T., Multiple Criteria Decision Making (MCDM), Publishing House of the University of Economics in Katowice, 2006.
[7] Lotfi F. H., Fallahnejad R., Imprecise Shannon's Entropy and Multi Attribute Decision Making, Entropy, 12, s. 53-62, 2010.
[8] Kacprzak D., Objective Weights Based on Ordered Fuzzy Numbers for Fuzzy Multiple Criteria Decision Making Methods, Entropy, 19, s. 373, 2017.
[9] Kiksalan M., Wallenius J., Zionts S., Multiple Criteria Decision Making, From Early History to the 21st Century, World Scientific, New Jersey, London, Singapore, Beijing, Shanghai, Hong Kong, Taipei, Chennai, 2011.
[10] Banayoun R., Roy B., Sussman N., Electre Program Reference Manual, Synth Note and Formation 25. Scientific Directorate SEMA, (1966).
[11] Slama T., Multi-criteria decision support. Methods and applications, EuP 2014.
[12] Zalewski W., Application of the TOPSIS method for assessing the financial condition of electricity distribution companies, Economics and Management4(4), 138-145, 2012.
[13] Szwabowski J., Rain J., Methods of multi-criteria comparative analysis, Silesian University of Technology Publishing House, Gliwice, 2001.
[14] Žabicki P., Gardzieczyk W., Selected aspects of multi-criteria analysis in roads design, Construction and Architecture, 13, 1, 2014, 213-222.
[15] Geneletti D., Multicriteria analysis to compare the impact of alternative road corridors: a case study in northern Italy, Impact Assessment and Project Appraisal, 23, 2, p. 135-146, 2005.
[16] Brauers W. K. M., Zavadskas E. K., Peldschus F., Turskis Z., Multi-objective decision-making for road design, Transport, 23, 3, 2008, 183-193.
[17] Afshari A., Mojahed M., Yusuff R., Simple Additive Weighting approach to Personnel Selection problem, International Journal of Innovation, Management and Technology, 1, 5, p. 511-515, 2010.
[18] Vincke P., Multicriteria Decision Aid, John Wiley & Sons, Chichester, 1992.
[19] Roy B., Multi-criteria Decision Support, Scientific Technical Publishing House, Warsaw, 1990.
[20] Keeney R., Raiffa H., Decision Analysis with Multiple Objectives, Preferences and Value Tradeoffs, Cambridge University Press, Cambridge, 1993.
[21] Žak J., Multi-criteria decision support in road transport, Poznań University of Technology, Poznan, 2005.
[22] Jacquet-Lagreze E., Siskos J., Assessing a Set of Additive Utility Functions for Multicriteria Decision-making, the UTA Method, European journal of Operational Research, Vol. 10, s. 151-164, 1982.
[23] Siskos Y., Grigoroudis E., Matsatsinis F., UTA Methods. W: Figueira J., Greco S., Ehrgott M. (red.): Multiple Criteria Decision Analysis. State of the Art Surveys, Springer, New York, 2005.
[24] Saaty T., The Analytic Hierarchy Process, McGraw-Hill, New York, 1980.
[25] Saaty T., Transport Planning with Multiple Criteria: The Analytic Hierarchy Process Applications and Progress Review, Journal of Advanced Transportation, Vol. 29, Nr 1, s. 81-126, 1995.
[26] Figueira J., Greco S., Ehrgott M., Multiple Criteria Decision Analysis, State of the Art Surveys, Springer, New York, 2005.
[27] Roy B., The Outranking Approach and the Founddations of ELECTRE Methods. W: Bana-Costa C. (red.): Readings in Multiple Criteria Decision Aid, SpringerVerlag, Berlin, 1990.
[28] Roy B., ELECTRE III: A ranking algorithm based on a fuzzy representation of preferences in the presence of multiple criteria, Cahiers du Centre d'Etudes de Recherche Operationnelle, Vol. 20, Nr 1, s. 3-24, 1978.
[29] Roy B., Main Sources of Inaccurate Determination, Uncertainty and Imprecision in Decision Model, Mathematical and Computer Modeling, Vol. 12, Nr 10/11, s. 1245-1254, 1989.
[30] Roy B., Bertier P., La methode ELECTRE II - Une application au media-planning, Operational Research'72, North-Holland Publishing, Amsterdam, 1973.
[31] Roy B., Hugonnard J., Ranking of urban line extension projects on the Paris metro system by a multi-criteria method, Transportation Research, Vol. 16A, Nr 4, s. 301-312, 1982.
[32] Roy B., Present M., Sifol D., A programming method for determining which Paris metro stations should be renovated, European Journal of Operational Research, Vol. 24, s. 318-334, 1986.
[33] Roy B., Vanderpooten D., An Overview on "The European School of MCDA: Emergence, Basic Features and Current Works". European Journal of Operational Research, Vol. 99, Nr 1, s. 26-27, 1997.
[34] Roy B., Vanderpooten D., The European School of MCDA: A Historical Review. Journal of Multi-Criteria Decision Analysis, Vol. 5, s. 22-38, 1996.
[36] Vincke P., Multicriteria Decision Aid, John Wiley & Sons, Chichester, 1992.

[37] Brans J., Mareschal B., PROMETHEE Methods. W: Figueira J., Greco S., Ehrgott M. (red.): Multiple Criteria Decision Analysis. State of the Art Surveys, Springer, New York, 2005.

[38] Vuchic V. R., Urban Public Transportation Systems, Prentice-Hall, s. 673 1981.

[39] Vuchic V., Urban Transit: Operations, Planning and Economics. J. Wiley and Sons, New York, 2005.

[40] Brans J., Vincke P., A Preference Renking Organization Method, Management Science, Vol. 31, s. 647-656, 1985.

[41] Brans J., Mareschal B. i Vincke P., PROMETHEE: A New Family of Outranking Methods in Multicriteria Analysis, W: Brans J. (red.): Operational Research'84, Amsterdam, North-Holland Publishing, Amsterdam, s. 408-421, 1984.

[42] Brans J., Vincke P. i Mareschal B., How to Select and How to Rank Projects: The PROMETHEE Method. European Journal of Operational Research, Vol. 24, 1986, s. 228-238.

[43] Pastijn H., Leysen J., Constructing an Outranking Relation with OREST, Mathematical and Computer Modelling, Vol. 12, Nr 10/11, s. 576-587, 1989.

[44] Roubens M., Preference Relations on Actions and Criteria in Multicriteria Decision Making, European Journal of Operational Research, Vol. 10, s. 51-55, 1982.

[45] Greco S., A New PCCA Method: IDRA, European Journal of Operational Research, Vol. 98, Nr 3, s. 587-601, 1997.

[46] Matarazzo B., MAPPAC as a Compromise Between Outranking Methods and MAUT, European Journal of Operational Research, Vol. 54, Nr 1, s. 48-65, 1991.

[47] Matarazzo B., Preference Ranking Global Frequencies in Multicriteria Analysis (PRAGMA), European Journal of Operational Research, Vol. 36, Nr 1, s. 36-49, 1988.

[48] Greco S., Matarazzo B., Slowiński R., Multicriteria Classification by Dominance Based Rough Set Approach, Methodological Basis of the 4eMka System. W: Klossegen W., Zytkowski J. (red.): Handbook of Data Mining and Knowledge Discovery, Oxford University Press, New York, 2002.

[49] Vuchic V. R., Urban Public Transportation Systems. Prentice-Hall, s. 673, 1981.

[50] Żak J., The Methodology of Multiple-Criteria Decision Making in the Optimization of an Urban Transportation System: Case Study of Poznan City in Poland, International Transactions in Operational Research, Vol. 6, Nr 3, s. 571-590, 1999.

[51] Vanderpooten D., The Use of Preference Information in Multiple Criteria Interactive Procedures, W: Locket A., Islei G. (red.): Improving Decision Making in Organizations, Springer-Verlag, Berlin, 1989.

[52] Jaszkiewicz A., Slowiński R., The „Light Beam Search” Approach - an Overview of Methodology and Applications, European Journal of Operational Research, Vol. 113, Nr 2, s. 300-314, 1999.

[53] Jaszkiewicz A., Slowiński R., The LBS - Discrete Interactive Procedure for Multiple-Criteria Analysis of Decision Problems, W: Climaco J. (red.): Multicriteria Analysis. Proceedings of the 11th International Conference on MCDM, August 1-6, 1994, Coimbra, Springer-Verlag, Berlin-Heidelberg, s. 320-330, 1997.

[54] Jaszkiewicz A., Slowiński R., The Light beam Search - Out-ranking Based Interactive Procedure for Multiple-Objective Mathematical Programming, W: Pardalos P., Siskos Y. i Zopounidis C.: Advances in Multicriteria Analysis, Kluwer Academic Publishers, Dordrecht, 1995.

[55] Korhonen P., Wallenius J., A Modification of the Zionts-Wallenius Multiple Criteria Method for Nonlinear Utility Functions, Helsinki School of Economics Press, Helsinki, 1985.

[56] Wierzbicki A., The Use of Reference Objectives in Multi-objective Optimization, (red.): Fandel G., Gal T.: Multiple Criteria Decision Making. Theory and Applications. Lecture Notes in Economics and Mathematical Systems, Springer-Verlag, Berlin, Vol. 177, 1980.

[57] Korhonen P., Wallenius J., A Modification of the Zionts-Wallenius Multiple Criteria Method for Nonlinear Utility Functions, Helsinki School of Economics Press, Helsinki, 1985.

[58] Żak J., Fierek S., Desing and Evaluation of Alternative Solutions for an Integrated Urban Transportation System, Proceedings of the World Conference on Transport Research, Berkeley 2007.

[59] Churchman C.W., Ackoff R.L., An approximate measure of value, Journal of Operations Research Society of America, 2, 1, 172-187, 1954.

[60] Afshari A., Mojahed M., Yusuff R., Simple Additive Weightingapproach to Personnel Selection problem, International Journal of Innovation, Management and Technology, 1, 5, 511-515, 2010.

[61] Tzeng G. H., Huang J. J., Multiple Attribute Decision Making. Methods and Applications, CRC Press, London, 2011.

[62] Lootsma F.A., The REMBRANDT system for multi-criteria decision analysis via pairwise comparisons or direct rating, Report 92-05, Faculty of Technical Mathematics and Informatics, Delf University of Technology, Delft 1992.

[63] Saaty T. L., Decision making with dependence and feedback, The analytic network process. RWS Publications, 4922 Ellsworth Ave., Pittsburgh, 1996.

[64] Mikhailov, L., Tzvetinov P., Evaluation of services using a fuzzy analytic hierarchy proces, Applied Soft Computing Journal", 5, p. 23-33, 2004.

[65] Larichev O. I., Moskovich H. M., ZAPROS-LM - a method and system for ordering multiattribute alternatives, European Journal of Operational Research, 82(3), p. 503-521, 1995.

[66] Larichev O., Ranking multicriteria alternatives: The method ZAPROS III, European Journal of Operational Research, 131, p. 550-558, 2001.

[67] Konarzewska-Gubala E., Bipolar: Multiple Criteria Decision Aid Using Bipolar Reference System, LAMSADE, Cashier et Documents, 56, 2009.

[68] Roy B., Vincke P., Relational Systems of Preference with One or More Pseudo-Criteria: Some New Concepts and Results, Management Science, Vol. 30, Nr 11, s. 1323-1335, 1984.

[69] Roy B., Bouyssou D., Aide Multicritere a la Decision: Methods at Cas, Economica. Paris 1993.
[70] Zaras K., Martel J. M., Multiattribute Analysis Based on Stochastic Dominance, [in:] B. Munier B., Machina M. J. (eds.): Models and Experiments in Risk and Rationality, Kluwer Academic Publishers, Dordrecht 1994.

[71] Brans J., Vincke P., A Preference Renking Organization Method, Management Science, Vol. 31, s. 647-656, 1985.

[72] Brans J.P., L’ingenierie de la decision; Development of decision-support instruments. La methode PROMETHEE, [in:] Nadeau R., Landry M. (eds.): L'aide a la decision: Nature, Instruments et Perspectives d'Avenir, Presses de l'Universite Laval, Quebec 1982.

[73] Górecka D., Muszyńska J., Spatial analysis of innovation of Polish regions, Acta Universitatis Lodziensis Folia Geonomica, Publishing House of the University of Lodz, p. 55-70, 2011.

[74] Diakoulaki D., Koumoutsos N., Cardinal ranking of alternative actions: extension of the PROMETHEE method, European Journal of Operational Research, 53, 1991.

[75] Górecka D., Szalucka M., Country market selection in international expansion using multicriteria decision aiding methods, Multiple Criteria Decision Making⁶, p. 31-55, 2013.

[76] Nowak M., Investment project evaluation by simulation and multiple criteria decision aiding procedure, Journal of Civil Engineering and Management, 11, p. 193-202, 2005.

[77] Górecka D., Application of multi-criteria methods based on superiority relationships for the evaluation of European investment projects, Publishing House of the University of Economics in Katowice, Katowice 2010.

[78] Jahanshaloo G. R., Hosseinzadeh Lotfi F., Izadikhah M., Extension of the TOPSIS method for decision-making problems with fuzzy data, Applied Mathematics and Computation 185, p. 1544-1551, 2007.

[79] Opricovic S. Tzeng G. H., Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS, European Journal of Operational Research⑥, 156 (2), p. 445-455, 2004.

[80] Gabus A, Fontela E., Perceptions of the world problematic: Communication procedure, communicating with those bearing collective responsibility, DEMATEL 1. Battelle Geneva Research Centre, Geneva 1973.

[81] Buchanan J., Sheppord P., Ranking Projects Using the ELECTRE Method, Proceedings of the 33rd Annual Conference of Operational Research Society of New Zealand, Auckland, 1998.

[82] Beria P., Maltese I. I Mariotti I., multicriteria versus Cost Benefit Analysis: a comparative perspective in the assessment of sustainable mobility, European Transport Research, Vol. 4, s. 137-152, 2012.

[83] Trzaskalik T., Sitarz S., Dominik C., Unified procedure for Bipolar method, [in:] Zadnik L., Zerovnik J., Poch J., Drobné S., Lisek A. (eds.): SOR’13 Proceedings 2013.

[84] Beder S., Costing the Earth: Equity, sustainable development and environmental economics, New Zealand Journal of Environmental Law, Nr 4, s. 227-243, 2000.

[85] Bonsall P., Borken J., Are We Moving in the Right Direction? Transport's Environmental Impact Assessment with ELECTRE III. W: Jaszkiewicz A. (red.): Advanced OR and AI Methods in Transportation, Poznań, 2005, s. 166-171.

[86] Nowak M., Interactive multi-criteria decision support under risk conditions, Methods and applications, Publishing House of the Academy of Economics in Katowice, Katowice 2008.

[87] Nowak M., Trade-off analysis in discrete decision making problems under risk, [in:] Lecture Notes in Economics and Mathematical Systems 638, [in:] Jones D., Tamiz M., Ries J. (eds.): New Developments in Multiple Objective and Goal Programming, Springer Verlag, p. 103-115, 2010.

[88] Malczewski J., Moreno-Sanchez R., Bojorzquez-Tapia L., On-gay-Dellhumeau E., Multicriteria Group Decision - Making for Environmental Conflict Analysis in the Cape Region, Mexico, Journal of Environmental Planning and Management, Vol. 40, Nr 2-3, s. 175-1891992.

[89] Ngai E., Selection of Web Sites for Online Advertising Using AHP, Information of Management, Vol40(4), p.233-242,2003.

[90] Haefee K., Zhang Y. i Malak N., Determining Key Capabilities of a Firm Using Analytic Hierarchy Process, International Journal of Production Economics, Vol. 76, Nr 1, s. 39-51, 2002.

[91] Olson D. L., Comparison of three multicriteria methods to predict known outcomes, European Journal of Operational Research, Vol. 130, Nr 3, s. 576-587, 2001.

[92] Hababou M., Martel J., A multicriteria approach for selecting a portfolio manager, INFOR, Vol. 36, Nr 3, s. 161-176, 1998.

[93] Spyridakos A., Multicriteria job evaluation for large organisations, European Journal of Operational Research, Vol. 130, Nr 2, s. 375-387, 2000.

[94] Geldermann J., Spengler T., Rentz O., Fuzzy outranking for environmental assessment, Case study: iron and steel making industry. Fuzzy Sets and Systems, Vol. 115, Nr 1, s. 45-65, 2001.

[95] Korpela J., An analytic approach to production capacity allocation and supply chain designing, International Journal of Production Economics, Vol. 78, Nr 2, s. 187-195, 2002.

[96] Žak J., Fiersek S., Zmda-Trzebiatowski P., Kruszyński M.: Multiple Level, Multiple Criteria Ranking Transportation Project, Proceedings of the 13th World Conference on Transport Research, Rio de Janeiro, 2013.

[97] Žak J., Thiel T., Multiple Criteria Evaluation of the Development Scenarios of the Mass Transit System, W: Park C-H., Oh J., Hayashi Y., Viegas J. (red.); CD Selected, Proceedings of the 9th World Conference on Transport Research, Seoul, 2001.

[98] Žak J., Fiersek S., Kruszyński M., Evaluation of different transportation solutions with the application of Macro Simulation tools and Multiple Criteria Group Decision Making/Aiding methodology, Proceedings of the 16th Meeting of the EURO Working Group of Transportation, Porto, 2013.

[99] Žak J., The MCDA Methodology Applied to Solve Complex Transportation Decision Problems, Proceedings of the 9th Meeting of the EURO Working Group on Transportation: Intermodality, Sustainability and Intelligent Transportation Systems, s. 685-693, Bari 2002.

[100] Dulmino R., Minmno V., Supplier Selection Using a Multi-Criteria Decision Aid Method, Journal of Purchasing & Supply Management, Vol. 9, Nr 4, s. 177-187, 2003.
[101] Radojevic D., Petrovic S., A Fuzzy Approach to Preference Structure in Multicriteria Ranking, International Transaction in Operations Research, Vol. 4, Nr 5-6, s. 419-430, 1997.

[102] Jacquet-Lagreze E., Meziani R., Slowiński R., MOLP with an Interactive Assessment of Piecewise-Linear Utility Function, European Journal of Operational Research, Vol. 31, Nr 3, s. 350-357, 1987.

[103] Żak J., Modeling and optimization of decision-making problems in transport and forwarding companies. Use of multi-secretarial decision support methodology for modeling and optimization of decision-making problems in transport and forwarding companies, Institute of Logistics and Warehousing, Poznań, 1999-2001.

[104] Sawicka H., Method of reorganization of the goods distribution system, Doctoral dissertation, Warsaw University of Technology, Faculty of Transport, Warsaw, 2012.

[105] Bradley S., Hax A., Magnanti T., Applied Mathematical Programming, Addison-Wesley Publishing, San Francisco, 1977.

[106] Jacyna M., Turkowski D., Selected aspects of the multi-criteria assessment of the selection of means of transport in vehicle distribution systems, Logistics4/2014.

[107] Milewski D., Optimization problems in the transport of small shipments, Scientific Notebooks of Szczecin University, No. 644, Transport and Logistics Problems No. 14/2011.