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

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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, nonlinear 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 exhaustible, 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 weightings 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 weightings 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:

$$W=\{W\_i: i=1,2,3 \dots,n\} \tag{2}$$

and a set of criteria:

$$K = \{K_i: j = 1,2,3 \dots, m\} \tag{3}$$

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:

$$Xij = \{x_{ij}: i = 1,2,3 \dots, n;\ j = 1,2,3 \dots, m\} \tag{4}$$

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]:

$$X = \begin{bmatrix} x_{11} & \dots & x_{11} & \dots & x_{1m} \\ \vdots & \ddots & \dots & \dots & \vdots \\ x_{i1} & \dots & x_{11} & \dots & x_{im} \\ \vdots & \dots & \dots & \ddots & \vdots \\ x_{n1} & \dots & x_{nj} & \dots & x_{nm} \end{bmatrix} \quad (5)$$

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]:

$$U = U(f) = U(f_1, f_3, f_3, \quad \dots\dots, \ f_{n,}) \quad (6)$$

where: f_1, f_2, f_3,, $\dots f_n$ 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, i.e. a is preferred over b,
bPa, i.e. b is preferred over a,
aIb, i.e. a and b are equivalent (7)

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

$$aPb \Leftrightarrow U(z_a) > U(z_b)$$
$$aIb \Leftrightarrow U(z_a) = U(z_b) \quad (8)$$

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, i.e. P is asymmetric,⇒
aIa, i.e. I is callback,
aIbbIa, i.e. I is symmetrical,⇒
aPb and bPc aPc, i.e. P is transitive,⇒
aIb and bIc aIc, i.e. I is transitive.⇒ (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.: $S=P\,I\cup$. On the basis of the *S* relation, it is possible to determine the decision-maker's preferences in accordance with [36]:

$$aPb \Leftrightarrow aSb \text{ and } -bSa$$
$$aIb \Leftrightarrow aSb \text{ and } bSa$$
$$aRb \Leftrightarrow -aSb \text{ and } -bSa \quad (10)$$

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⇒ –bPa, i.e. P is asymmetric,
aIa, i.e. I is callback,
aIb ⇒ bIa, i.e. I is symmetrical. (11)

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

aSa, i.e. S is callback,
aSb and bDc ⇒ aSc,
aDb and bSc ⇒ aSc, (12)
$aI_jb \ \forall_{j\neq q} \square aSb \Leftrightarrow aS_qb$

where: *D* – relationship of dominance, I_j – equivalence relationship 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 ELECTE 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 fj are determined. With the equivalence *qj*, preferences *pj* and veto *vj* thresholds and coefficients of importance *wj*, for each criterion j, the adjudicator's preference model is defined. This is subject to the condition,

$$q_j<p_j<v_j \quad (13)$$

II. design of the preference relation – for each pair of variants (*a, b*) the following shall be determined:

a. conformity factors *cj* (*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:

$$c_j(a,b)=\begin{cases}1 \text{ if } f_j(a)+q_j(f_j(a))\geq f_j(b),\\ 0 \text{ if } f_j(a)+p_j(f_j(a))\geq f_j(b)\\ \text{linear function of 0 and 1 value}\end{cases} \quad (14)$$

b. conformity index:

$$C(a,b)=\frac{1}{W}\sum_{j=1}^{n} w_j c_j(a,b) \text{ gdzie } W=\sum_{j=1}^{n} w_j \quad (15)$$

c. non-conformity factors *D*(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:

$$D_j(a,b)=\begin{cases}C(a,b) \text{ jeżeli } D_j(a,b)\leq C_j(a,b),\\ C(a,b)\prod_{j\in(a,b)}\frac{1-D_j(a,b)}{1-C_j(a,b)}\end{cases} \quad (16)$$

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:

$$\lambda=\max S(a,b) \quad (17)$$

Only those pairs of variants *(a, b)* for which *S(a, b)* is located in close proximity to λ undergo the analysis. Position is determined by the difference λ – *s*(λ), where *s*(λ) 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 variants in respect of which case *(a) is* classified below, is calculated on the basis of the λ value.

On the basis of the descending and ascending preorder, a final ranking of solutions is prepared, based on the following 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 (aIb)* if both variants 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: equivalence − *I*, preference − *P* and incomparability *R* [99]. In the ranking matrix, the relations are shown between pairs of variants and written in the form of symbols: equivalence – *I*, preference – *P*, inverse of preferences – (*P*) andincomparability – *R*.

The AHP algorithm assumes that actions are carried out involving:

a. constructing a hierarchical structure of the decision-making process, by setting levels: the objective of the decision-making process, which may be, for example, to organize decision-making variants from best to worst and to choose the preferred variant (level 0) – criteria and evaluation sub-criteria (level 1), decision-making variants (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-criteria (specified for each criterion) and variants (specified for criteria and sub-criteria). The direction in which preference information is written in matrices is always the same, i.e. the relation of the element in the row to the element 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 I of this variant U_i(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_i(t- *2*) is an aggregated assessment, the value of which should be determined from dependencies:

$$U_{i(t-2)} = \sum_{j=1}^{nt}\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{l} w_{i(t-2)}^{k(t-1),(j,t)} \cdot w_{k(t-1)}^{j(t))} \cdot w_{j(t)}^{0} \tag{18}$$

where:

$w_{i(t-2)}^{k(t-1),(j,t)}$ – 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 leve*l t*,

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

$w_{j(t)}^{0}$ – a standardised assessment of the importance (weight) of the 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 *I* and preferred *P*. The scheme of multi-criteria analysis in the PROMETHEE method is carried out in accordance with the procedure:

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

$$D_j(a,b) = \begin{cases} H(x) \text{ if } f_k(a) > f_k(b), \\ 0 \text{ if } f_k(a) \le f_k(b) \end{cases} \tag{19}$$

where: $x = f(a) - f(b), .0 \le H(x) \le 1$

– preference aggregation in the form of preference *π(a, b)* is expressed by a dependency:

$$\pi = \sum w_k \cdot P_k(a,b) \tag{20}$$

– ordering variants based on preference flows φ^+ and φ^- :

$$\varphi^+(a) = \sum_{x \in A} \pi(a,x)$$
$$\varphi^-(a) = \sum_{x \in A} \pi(a,x) \tag{21}$$

The $\varphi^+(a)$ is an indicator of a variant preferences and compared to other variants. The $\varphi^-(a)$ is an indicator of the lack of acceptance (lower rating) of *a* in relation to the other variants. The PROMETHEE I method allows for organizing a set of decision variants by using a preference relation. In the case where variant *a* is not preferred by variant *b,* shall be written according to:

$$a \succcurlyeq_s b \text{ if } \varphi^+(a) \ge \varphi^+(b) \wedge \varphi^-(a) \le \varphi^-(b) \tag{22}$$

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:

$$a \succcurlyeq_s b \wedge b \succcurlyeq_s a \Rightarrow a \approx b \tag{23}$$

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 :

$$a \succcurlyeq_{sII} b \text{ if } \varphi(a) \ge \varphi(ab) \tag{24}$$

dependencies must be resolved:

$$\begin{aligned} \min_{w \in W}(\varphi(a)) - \varphi(b) \ge 0 \\ \min_{w \in W}(\varphi(b)) - \varphi(b) \ge 0 \end{aligned} \tag{25}$$

Procedure for determining resistant relationships of dominance in PROMETHEE I. method:

For all *i* = 1, ... , *m*, *j* = 1, ... , *m*

designate $min_1(i,j)$ according to

$$\min_1(i,j) = \text{argmin}(\varphi^+(a_j) - \varphi^+(a_i)) \text{ for } w \in W \quad (26$$

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$$\varphi^-(a_i) \leq \varphi^-(a_j)$$

For all $i = 1, \ldots, m, \quad j = 1, \ldots, m$

designate $min_2(i,j)$ according to

$$\min_2(i,j) = \operatorname{argmin}(\varphi^+(a_i) - \varphi^+(a_i) \text{ for } w \in W \quad (27$$

$$\varphi^-(a_i) \geq \varphi^-(a_i) \quad)$$

For all $i = 1, \ldots, m, \quad j = 1, \ldots, m$

check if there is a relation $a_i \succcurlyeq w_{wI} a_j$ with

$$a_i \succcurlyeq w_{wI} a_j$$

$$if\ min_1(i,j) \geq 0, \quad \text{and} \qquad (28)$$

$$min_{12}(i,j) > 0\ or\ there\ is\ no\ i\ min_2(i,j) \leq 0$$

Utilits Additives type (UTA) methods are based on minimizing utility error using a linear programming model. The UTASTAR method [105] assumes the objective to minimize the distribution (dispersion) of errors, the UTADIS method determines two error values: ρ_k^+ and ρ_k^- 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* – *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:

$$U(a) = \sum u_i(f_i(a)) \qquad (29)$$

where: $w_{(j)},$ 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):

$$U_j(z_j) = U_j(u_j') + \frac{z_j - u_j^l}{u_j^{l+1} - u_j^l}\left[U_j(u_j^{l+1}) - U_j(u_j^l)\right] \qquad (30)$$

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

$$U(a) = \sum U_i(x_i^a + \delta(a) \qquad (31)$$

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 – *τ* determined by the following formula:

$$\tau = 1 - 4 \cdot \frac{d_k(R,R^*)}{m(m-1)} \qquad (32)$$

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,
$d_k(R,R^*)$ – Kendal's distance, which determines the differences between the different elements R and R^*.

4. Disscusion 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 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 [106].

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:

$$K(d(i),t(i)) = \frac{C^z(i)-RV^b(d^b(i),t^b(s))\cdot RVC(d(i),t(i))}{m^b(i)} \qquad (33)$$

where:

$K(d(s),t(i))$ – the cost of depreciation *i-th* means of transport taking into account the annual mileage and duration of the service in Eur/km,

$C^z(s)$ – the cost of purchase *i* – this means of transport,

$RV^b(d^b(i),t^b(i))\cdot RVC(d(i),t(i))$ – the resale value of the means of transport after the transport task has been carried out,

$m^b(i)$ – the total mileage of *i-th* means of transport.

The cost of tyres $K_{o\ in}$ Eur/km of the *i-th* means of transport during the life of the vehicle is recorded by a dependency:

$$K_o(m(s),t(s)) = \frac{(2s_c\cdot k_w(a) + l_o(b)\cdot(o_l(a)+o_z(a)) + k_{po}(b,i)\cdot n_s)}{2m(i)} \qquad (34)$$

where:

$o_l(a)$ – the cost of purchasing a summer tyre in size *a*,

$o_z(a)$ – the cost of purchasing a summer tyre in size *a*,

$k_w(a)$ – the cost of replacing one tyre in size *a*,

$l_o(b)$ – number of tyres,

$k_{po}(b,i)$ – 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.

$$L(i) = \frac{t_g(s)}{d_p(s)} \qquad (35)$$

where:

$t_g(i)$ – working time in hours of *i-th* means of transport,

$d_p(i)$ – 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:

$$L_{max}(s) = \frac{d_p(i)}{30\ t(i)} \qquad (36)$$

where:

$d_p(i)$ – 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:

$$K = \sum K_{i,k} \cdot d_k \tag{37}$$

where:

K – total cost of local distribution,
$K_{i,d}$ – 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.

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