A Novel Extended EDAS in Minkowski Space (EDAS-M) Method for Evaluating Autonomous Vehicles

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Abstract: Multi-Criteria Decision-Making (MCDM) methods have a significant influence on decision making in a variety of strategic fields, including science, business, and real-life studies. These methods also effectively support researchers in solving the emerging issues that may be encountered during their research activity. This work introduces a new Evaluation method based on the Distance from the Average Solution in the Minkowski space (EDAS-M). The main contribution of this study is the EDAS-M based MCDM model for the evaluation of an autonomous vehicle. Besides, the CRITIC (Criteria Importance Through Intercriteria Correlation) was used to determine objective criteria weights. The EDAS-M method provides a modified extension of the conventional Evaluation method based on the Distance from the Average Solution (EDAS) method. Seven different MADM methods are used to compare problem-solving results. Namely, the EDAS, WASPAS (Weighted Aggregated Sum Product ASsessment), SAW (Simple Additive Weighting), ARAS (Additive Ratio ASsessment), TOPSIS (Technique for Order Preference by Similarity Ideal Solution), TOPSIS-M (TOPSIS Minkowski space) and MABAC (Multi-Attributive Border Approximation Area Comparison) techniques validate the stability of the results obtained by using the new method above mentioned. Sensitivity analysis reflects the dynamics of the influence of dynamic matrices. It showed a high correlation of positions with all applied approaches. This correlation has also been maintained in a dynamic environment.

Keywords: EDAS, Minkowski space, EDAS-M, MCDM, Autonomous Vehicle, CRITIC.

1. Introduction

Decision-makers of the modern world need to develop projects, make balanced decisions (Hashemkhani Zolfani et al., 2013), and effectively implement them (Kalibatas & Turskis, 2008). The business ambience is dynamically changing (Turskis et al., 2019), and future decisions should be applied while taking into account available technologies (Štreimikienė et al., 2016). The life-cycle efficiency of relevant choices/alternatives depends on several criteria, whose values are quite often impossible to determine accurately in the early stages of planning (Turskis et al., 2015). Decision-makers must integrate different criteria with different measurements and different optimisation directions (Zavadskas et al., 2013). The modern world proposes different innovative technologies, which have an impact as local as well global business environment (Keshavarz Ghorabaee et al., 2016a). The implementation of decisions depends on multiple persons. Each problem taken separately has its own peculiarities and solving some of them may require the use of new approaches (Ruzgys et al., 2014). The decision-making process, according to Stojić et al., (2018), requires the prior definition and fulfilment of individual factors. The theory of multi-criteria decision-making, according to (Zavadskas et al., 2018a; 2018b) holds a special place in the field of science. MCDM methods represent a handy and applicable tool in various areas. There are many recently developed MCDM methods.

This paper aims to enrich the field of multi-criteria decision-making and to introduce a novel EDAS-M approach that can be useful for all decision-makers in solving their complicated problems.

Keshavarz Ghorabaee et al. (2015) developed the EDAS method for multi-criteria inventory classification. So far, this method has achieved desirable results, as its application in different fields is concerned (Nunić, 2018; Ecer, 2018; Stević et al. 2019). EDAS method has many extensions. Keshavarz Ghorabaee et al. (2016b) developed a fuzzy model for selecting a supplier. Kahraman et al. (2017) extended the model with interval-valued intuitionistic fuzzy sets for selecting a solid waste disposal site. Stanujkić et al. (2017) introduced interval grey numbers to EDAS method. Keshavarz Ghorabaee et al. (2017b) used an extension of EDAS method with Interval type-2 fuzzy sets for supplier evaluation. Stević et al. (2017) have developed a rough EDAS model. Keshavarz Ghorabaee et al. (2017c) created a stochastic EDAS method for

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handling problems where the performance values of alternatives for each criterion follow the normal distribution. EDAS method has certain extensions in the neutrosophic environment: (Peng & Liu, 2017; Karaşan & Kahraman, 2018).

Besides, the integration of EDAS-M with the CRITIC method is also a contribution to the scientific literature that tackles MCDM problems.

In addition to primary considerations, the rest of the paper consists of four sections. The second section includes an overview of the CRITIC method and a detailed algorithm of the new extended EDAS-M method. The third section sets a numerical validation of the proposed method. Here, all computations, which are based on the developed methodology, are presented in detail, considering each step separately. In the fourth section is given a sensitivity analysis through comparison with other MCDM methods, and the influence of dynamic matrices on the change in ranks. The fifth section includes the conclusion with guidelines for some possible future studies.

2. Methods

2.1. The CRITIC Method

In decision-making problems, criteria, as a source of information, possess a weight that reflects the amount of the information contained in each of them. This weight is referred to as "objective weight." Diakoulaki et al. (1995) introduced the CRITIC method as a tool for determining the objective weights of criteria in MCDM problems. This method determines the objective weights of the principles by using contrast intensity of each measure, considered as standard deviation and conflict between criteria, regarded as the correlation coefficient between criteria (Yalçın & Ünlü, 2018; Keshavarz Ghorabaee et al., 2017a; Rostamzadeh et al., 2018).

The following steps describe the CRITIC method. It is assumed that there is a set of n feasible alternatives A_i (i = 1, 2, …, n) and m evaluation criteria C_j (j = 1, 2, …, m).

Step 1. Development of the decision matrix (X), expressed as follows.

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} i = 1,2,...,n;\ j = 1,2,...,m \quad (1)$$

The elements x_{ij} of the decision matrix (X) represent the performance value of i^{th} alternative for j^{th} criterion.

Step 2. Normalization of original decision matrix using the following equations:

for benefit criteria:

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \quad (2)$$

and for cost criteria:

$$r_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \quad (3)$$

Step 3: Calculation of symmetric linear correlation matrix m_{ij}:

A linear correlation coefficient between each pair of measures is estimated using the following equation to quantify the conflict occurring among different criteria. It is obvious that the more discordant the scores of the alternatives in two rules i and j, the lower the value m_{ij}.

Step 4: Determination of the objective weight of a criterion using CRITIC method also requires the estimation of both the standard deviation of the test and its correlation with other measures. In this regard, the weight of the j^{th} criterion w_j is obtained using equation (4).

$$W_j = \frac{C_j}{\sum_{j=1}^{n} C_j} \quad (4)$$

where, C_j is the amount of information contained in the criterion j and is determined as follows:

$$C_j = \sigma \sum_{j'=1}^{n} 1 - m_{ij}, \quad (5)$$

where σ is the standard deviation of j^{th} criterion and the correlation coefficient between the two tests. The CRITIC method assigns a higher weight to the criterion with a higher value of σ and provides a low correlation with the other criteria. A higher value of C_j indicates a more considerable amount of information contained in a particular criterion. Therefore, its weighting quotient is higher.

2.2. A Novel Extended EDAS in Minkowski Space: EDAS-M Method

This paper presents an extension of EDAS method in Minkowski (1909) space, called the EDAS-M method. Using Minkowski space, equations 6–11 need to be modified to find the deviation from the average solution in the conventional EDAS method. A novel extended EDAS-M approach consists in the following steps:

Step 1: Development of MCDM model. Make the selection of appropriate criteria *m* that in the best way describe alternatives *n*.

Step 2: Forming the initial decision-making matrix *X*, as follows:

$$X = \left[x_{ij}\right]_{n\times m} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix} \tag{6}$$

where x_{ij} denotes the performance value of i[th] alternative on j[th] criterion.

Step 3: Computation of the average solution according to all criteria using equation (7):

$$AV = \left[AV_j\right]_{1\times m} \tag{7}$$

where AV_j is obtained using equation (8):

$$AV_j = \frac{\sum_{i=1}^{n} x_{ij}}{n} \tag{8}$$

Step 4: Calculate the positive distance from average (PDA) and the negative distance from average (NDA) matrix according to the type of criteria (benefit and cost):

$$PDA = \left[PDA_{ij}\right]_{n\times m} \tag{9}$$

$$NDA = \left[NDA_{ij}\right]_{n\times m} \tag{10}$$

if j[th] criterion belongs to benefit group:

$$PDA_{ij} = \frac{\left(x_{ij} - AV_j\right)}{AV_j} \tag{11}$$

$$NDA_{ij} = \frac{\left(AV_j - x_{ij}\right)}{AV_j} \tag{12}$$

and if j[th] criterion pertains to cost group:

$$PDA_{ij} = \frac{\left(AV_j - x_{ij}\right)}{AV_j} \tag{13}$$

$$NDA_{ij} = \frac{\left(x_{ij} - AV_j\right)}{AV_j} \tag{14}$$

where PDA_{ij} and NDA_{ij} denote the positive and negative distance of i[th] alternative from the average solution in terms of j[th] criterion, respectively. These equations are different when compared to the conventional EDAS method because PDA_{ij} and NDA_{ij} could be negative.

Step 5: Determination of the weighted sum of *PDA* and *NDA* in Minkowski space for all alternatives, as follows:

$$SP_i = d_i \left| \sum_{j=1}^{m} k_{ij} \left| w_j PDA_{ij} \right|^m \right|^{1/m} \tag{15}$$

where

$$k_{ij} = 1 \; if \; PDA_{ij} \geq 0 \; and \; k_{ij} = -1 \; if \; PDA_{ij} < 0$$

$$d_j = 1 \quad if \quad \sum_{j=1}^{m} k_{ij} \left| w_j PDA_{ij} \right|^m \geq 0 \quad and$$

$$d_j = -1 \quad if \quad \sum_{j=1}^{m} k_{ij} \left| w_j PDA_{ij} \right|^m < 0$$

$$SN_i = d_i \left| \sum_{j=1}^{m} k_{ij} \left| w_j NDA_{ij} \right|^m \right|^{1/m} \tag{16}$$

$$k_{ij} = 1 \; if \; NDA_{ij} \geq 0 \; and \; k_{ij} = -1 \; if \; NDA_{ij} < 0$$

$$d_j = 1 \quad if \quad \sum_{j=1}^{m} k_{ij} \left| w_j NDA_{ij} \right|^m \geq 0 \quad and$$

$$d_j = -1 \quad if \quad \sum_{j=1}^{m} k_{ij} \left| w_j NDA_{ij} \right|^m < 0$$

$$\sum_{j=1}^{m} k_{ij} \left| w_j NDA_{ij} \right|^m \quad and \quad \sum_{j=1}^{m} k_{ij} \left| w_j NDA_{ij} \right|^m$$

could be negative, also.

w_j is the weight of j^{th} criterion.

Step 6: Normalize the values of *SP* and *SN* for all alternatives, shown as follows:

$$NSP_i = \frac{SP_i}{\max SP_i} \tag{17}$$

$$NSN_i = 1 - \frac{SN_i}{\max SN_i} \tag{18}$$

Step 7: Calculate the appraisal score *AS* for all other options using equation (19):

$$AS_i = \frac{NSP_i + NSN_i}{2} \quad (19)$$

In conventional EDAS method appraisal score AS can be 0≤1, while in this EDAS-M method can be lower than zero and higher than one.

Step 8: Rank the alternatives according to the decreasing values of appraisal score *AS*. The choice with the highest AS is the best among the potential options.

3. A Numerical Example

3.1 The Forming of the Multi-criteria Model

The verification of the novel extended EDAS-M method was carried out through an evaluation of autonomous vehicles (Zavadskas et al., 2018). The CRITIC method determines the weights of the criteria involved. This MCDM model includes seven measures: C_1 – dimensions, C_2 – minimum lift height, C_3 – price, C_4 – capacity of an autonomous vehicle, C_5 – battery capacity of an autonomous vehicle, C_6 – maximum lift height, and C_7 – the speed of an autonomous vehicle and nine alternatives. The first three criteria are associated with costing group criteria, while the other four measures are related to the benefiting group criteria.

3.2. Determining Criteria Weight Using CRITIC method

Step 1. Development of the decision matrix *X* is included in Table 1.

Table 1. Initial decision matrix

C_1	C_2	C_3	C_4	C_5	C_6	C_7
1	85	90000	1600	240	3000	5
1	85	90000	1600	240	4500	5
1	85	90000	2000	260	2500	5
3	80	75000	1000	210	2500	5.8
1	85	90000	2500	240	2000	5
5	100	65000	1500	240	3900	5.8
7	80	110000	2000	210	3000	5.8
5	80	85000	1600	240	3000	3
7	80	85000	1800	315	3000	3

Step 2. Table 2 shows the normalization of the initial matrix.

Table 2. Normalization of initial decision matrix

C_1	C_2	C_3	C_4	C_5	C_6	C_7
1.000	0.750	0.444	0.400	0.286	0.388	0.714
1.000	0.750	0.444	0.400	0.286	1.000	0.714
1.000	0.750	0.444	0.667	0.476	0.184	0.714
0.667	1.000	0.778	0.000	0.000	0.184	1.000
1.000	0.750	0.444	1.000	0.286	0.000	0.714
0.333	0.000	1.000	0.333	0.286	0.755	1.000
0.000	1.000	0.000	0.667	0.000	0.388	1.000
0.333	1.000	0.556	0.400	0.286	0.388	0.000
0.000	1.000	0.556	0.533	1.000	0.388	0.000

Normalization for cost criteria is performed using equation (2), for example:

$$x_{11} = \frac{1-7}{1-7} = 1.000, \quad x_{41} = \frac{3-7}{1-7} = \frac{-4}{-6} = 0.667,$$

Normalization for benefit criteria is performed using equation (3), for example:

$$x_{14} = \frac{1.6-1}{2.5-1} = 0.400, \quad x_{17} = \frac{5-3}{5.8-3} = 0.714,$$

Step 3. Symmetric linear correlation matrix m_{ij} is shown in Table 3.

Table 3. Symmetric linear correlation matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C1	1.00	-0.13	0.05	0.11	-0.19	-0.10	0.28
C2	-0.13	1.00	-0.59	0.04	0.04	-0.43	-0.41
C3	0.05	-0.59	1.00	-0.55	0.13	0.18	0.01
C4	0.11	0.04	-0.55	1.00	0.24	-0.37	-0.12
C5	-0.19	0.04	0.13	0.24	1.00	0.02	-0.70
C6	-0.10	-0.43	0.18	-0.37	0.02	1.00	0.06
C7	0.28	-0.41	0.01	-0.12	-0.70	0.06	1.00

Step 4. Table 4 shows the determination of the objective criteria weights.

As it can be seen, the seventh criterion with the value of 0.176 is the most important. The second most important one is the first criterion with a value of 0.170. Criteria weights indicate that all the importance of requirements is between 0.120 and 0.176, which means that all seven tests have a significant impact on decision-making in this case study.

Table 4. Results of the CRITIC method application

	1-rij						
C_1	0.000	1.134	0.948	0.892	1.193	1.097	0.716
C_2	1.134	0.000	1.590	0.960	0.965	1.430	1.415
C_3	0.948	1.590	0.000	1.553	0.866	0.815	0.988
C_4	0.892	0.960	1.553	0.000	0.764	1.366	1.117
C_5	1.193	0.965	0.866	0.764	0.000	0.982	1.705
C_6	1.097	1.430	0.815	1.366	0.982	0.000	0.939
C_7	0.716	1.415	0.988	1.117	1.705	0.939	0.000
ST_{DEV}	0.434	0.317	0.272	0.277	0.295	0.304	0.392
SUM	5.980	7.494	6.759	6.652	6.474	6.628	6.879
C_j	2.595	2.378	1.839	1.842	1.911	2.015	2.696
SUM C_j	15.277						
w_j	0.170	0.156	0.120	0.121	0.125	0.132	0.176

3.3 Selection of Autonomous Vehicles Using Extended EDAS-M Method

The first step of EDAS-M approach is the forming of a multi-criteria decision-making model by choosing the essential criteria, which describe potential solutions. Subsection 3.1 explains this procedure. In step 2, the initial decision matrix is formed (Table 1), while in the third step, the average solution according to all criteria is:

$$AV = \begin{bmatrix} 3.4 \\ 84.4 \\ 86.7 \\ 1.73 \\ 243.9 \\ 3.05 \\ 4.8 \end{bmatrix}$$

Step 4: *PDA* is obtained using equation (11) for benefit criteria and applying equation (13) for cost criteria. Table 5 demonstrates it.

Example of *PDA* calculation for cost criteria:

$$PDA_{11} = \frac{3.4 - 1}{3.4} = 0.710,$$

and for benefit criteria:

$$PDA_{41} = \frac{1.6 - 1.73}{1.73} = -0.077,$$

NDA is obtained using equation (12) for benefit criteria and applying equations (14) for cost criteria, as it is shown in Table 6.

Table 5. Positive distance from average (PDA) matrix

PDA	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
C_1	0.710	0.710	0.710	0.129	0.710	-0.452	-1.032	-0.452	-1.032
C_2	-0.007	-0.007	-0.007	0.053	-0.007	-0.184	0.053	0.053	0.053
C_3	-0.038	-0.038	-0.038	0.135	-0.038	0.250	-0.269	0.019	0.019
C_4	-0.077	-0.077	0.154	-0.423	0.442	-0.135	0.154	-0.077	0.038
C_5	-0.016	-0.016	0.066	-0.139	-0.016	-0.016	-0.139	-0.016	0.292
C_6	-0.016	0.475	-0.180	-0.180	-0.328	0.279	-0.016	-0.016	-0.016
C_7	0.037	0.037	0.037	0.203	0.037	0.203	0.203	-0.378	-0.378

Table 6. Positive distance from average (NDA) matrix

NDA	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
C_1	-0.710	-0.710	-0.710	-0.129	-0.710	0.452	1.032	0.452	1.032
C_2	0.007	0.007	0.007	-0.053	0.007	0.184	-0.053	-0.053	-0.053
C_3	0.038	0.038	0.038	-0.135	0.038	-0.250	0.269	-0.019	-0.019
C_4	0.077	0.077	-0.154	0.423	-0.442	0.135	-0.154	0.077	-0.038
C_5	0.016	0.016	-0.066	0.139	0.016	0.016	0.139	0.016	-0.292
C_6	0.016	-0.475	0.180	0.180	0.328	-0.279	0.016	0.016	0.016
C_7	-0.037	-0.037	-0.037	-0.203	-0.037	-0.203	-0.203	0.378	0.378

Example of NDA calculation for cost criteria:

$$NDA_{11} = \frac{1-3.4}{3.4} = -0.710,$$

and for benefit criteria:

$$NDA_{41} = \frac{1.73-1.6}{1.73} = 0.077,$$

Step 5: Tables 7 and 8 show the weighted sum of *PDA* and *NDA,* as it was determined in Minkowski space for all alternatives:

$$k_{ij}(PDA) = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & 1 & -1 & -1 & 1 & 1 & 1 \\ -1 & -1 & -1 & 1 & -1 & 1 & -1 & 1 & 1 \\ -1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 \\ -1 & -1 & 1 & -1 & -1 & -1 & -1 & -1 & 1 \\ -1 & 1 & -1 & -1 & -1 & 1 & -1 & -1 & -1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 \end{bmatrix}$$

The elements of the weighted sum of *PDA* in Minkowski space matrix are obtained in the following way:

The first step is to get the value of $k_{ij}\left|w_j PDA_{ij}\right|^m$. For example:

$$k_{11}\left|w_1 PDA_{11}\right|^m = 1\times\left|0.170\times 0.710\right|^7 = 3.70E-07$$

After that, all $k_{ij}\left|w_j PDA_{ij}\right|^m$ the sum of the respective values is calculated. For instance, for alternative A_1:

$$A_1 = (3.70E-07) + (-1.18E-21) + (-4.57E-17) + (-5.90E-15) + (-1.26E-19) + (-2.21E-19) + (4.94E-16) = 3.70E-07$$

After previously computing and determining d_i values of SP_i are obtained as follows

$$SP_1 = 1\times\left|3.70E-07\right|^{1/7} = 0.121$$

All calculations should be performed in the same way for *SN*.

Later, the value of $k_{ij}(NDA)$ is calculated contrary than previously shown value of $k_{ij}(PDA)$.

Step 6: Normalized values of *SP* and *SN* for all alternatives are obtained using equations (17) and (18), while *AS* is obtained using equation (19).

Table 7. The weighted sum of PDA in Minkowski space

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
C_1	3.70E-07	3.70E-07	3.70E-07	2.43E-12	3.70E-07	-1.56E-08	-5.09E-06	-1.56E-08	-5.09E-06
C_2	-1.18E-21	-1.18E-21	-1.18E-21	2.48E-15	-1.18E-21	-1.59E-11	2.48E-15	2.48E-15	2.48E-15
C_3	-4.57E-17	-4.57E-17	-4.57E-17	2.94E-13	-4.57E-17	2.24E-11	-3.76E-11	3.57E-19	3.57E-19
C_4	-5.90E-15	-5.90E-15	7.55E-13	-8.98E-10	1.23E-09	-2.97E-13	7.55E-13	-5.90E-15	4.61E-17
C_5	-1.26E-19	-1.26E-19	2.63E-15	-4.80E-13	-1.26E-19	-1.26E-19	-4.80E-13	-1.26E-19	8.60E-11
C_6	-2.21E-19	3.82E-09	-4.31E-12	-4.31E-12	-2.83E-10	9.08E-11	-2.21E-19	-2.21E-19	-2.21E-19
C_7	4.94E-16	4.94E-16	4.94E-16	7.52E-11	4.94E-16	7.52E-11	7.52E-11	-5.87E-09	-5.87E-09
SUM	3.70E-07	3.73E-07	3.70E-07	-8.25E-10	3.71E-07	-1.54E-08	-5.09E-06	-2.15E-08	-5.10E-06
Di	1.00	1.00	1.00	-1.00	1.00	-1.00	-1.00	-1.00	-1.00
SPI	0.121	0.121	0.121	-0.050	0.121	-0.077	-0.175	-0.080	-0.175

Table 8. The weighted sum of NDA in Minkowski space

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
C_1	-3.70E-07	-3.70E-07	-3.70E-07	-2.43E-12	-3.70E-07	1.56E-08	5.09E-06	1.56E-08	5.09E-06
C_2	1.18E-21	1.18E-21	1.18E-21	-2.48E-15	1.18E-21	1.59E-11	-2.48E-15	-2.48E-15	-2.48E-15
C_3	4.57E-17	4.57E-17	4.57E-17	-2.94E-13	4.57E-17	-2.24E-11	3.76E-11	-3.57E-19	-3.57E-19
C_4	5.90E-15	5.90E-15	-7.55E-13	8.98E-10	-1.23E-09	2.97E-13	-7.55E-13	5.90E-15	-4.61E-17
C_5	1.26E-19	1.26E-19	-2.63E-15	4.80E-13	1.26E-19	1.26E-19	4.80E-13	1.26E-19	-8.60E-11
C_6	2.21E-19	-3.82E-09	4.31E-12	4.31E-12	2.83E-10	-9.08E-11	2.21E-19	2.21E-19	2.21E-19
C_7	-4.94E-16	-4.94E-16	-4.94E-16	-7.52E-11	-4.94E-16	-7.52E-11	-7.52E-11	5.87E-09	5.87E-09
SUM	-3.70E-07	-3.73E-07	-3.70E-07	8.25E-10	-3.71E-07	1.54E-08	5.09E-06	2.15E-08	5.10E-06
Di	-1.00	-1.00	-1.00	1.00	-1.00	1.00	1.00	1.00	1.00

Table 9 shows the results of the EDAS-M method. They indicate that the second autonomous vehicle represents the best solution, while the first, third and fifth alternatives represent a solution which is very close to the best one.

Table 9. Results of EDAS-M method

NSPI	NSNI	ASI	RANK
0.999	1.687	1.343	**3**
1.000	1.688	1.344	**1**
0.999	1.687	1.343	**4**
-0.417	0.713	0.148	**5**
0.999	1.688	1.343	**2**
-0.634	0.563	-0.036	**6**
-1.452	0.000	-0.726	**8**
-0.665	0.542	-0.061	**7**
-1.453	0.000	-0.726	**9**

4. Sensitivity Analysis Based on a Comparison of EDAS-M with Other Methods

The results determined by means of a sensitivity analysis, which consists in comparing the EDAS-M with seven different MCDM approaches and the influence of dynamic matrices on the change in ranks.

4.1 Sensitivity Analysis Based on a Comparison with Other Methods

A sensitivity analysis validates the proposed EDAS-M method. Figure 1 shows the sensitivity analysis based on a comparison of the results of seven different MCDM approaches: EDAS (Keshavarz Ghorabaee et al., 2015), TOPSIS-M (Hwang & Yoon, 1981; Zavadskas et al., 2016c), SAW (MacCrimmon, 1968), MABAC (Pamučar & Ćirović, 2015), ARAS (Zavadskas & Turskis, 2010), WASPAS (Zavadskas et al., 2012), and TOPSIS (Hwang & Yoon, 1981).

Figure 1 shows that the second alternative is in the first position for all approaches. Comparing the EDAS-M method presented in this paper with conventional EDAS, one can notice a difference in ranking for the first and third alternative. Alternative ranks changed positions. Alternative A_1 moved from third place in the EDAS-M method to the fourth position according to the EDAS method. When comparing EDAS-M with TOPSIS-M ranks are very close, and the difference is in one position, except for alternative A_5, which ranking differ in two places. Figure 1 shows similar ranks, obtained using SAW, MABAC, ARAS, WASPAS and TOPSIS methods. Based on all possible comparisons, it can be concluded that EDAS-M has a high correlation with other approaches as alternative ranking is concerned.

4.2 The Influence of Dynamic Matrices on Rank Change

Changing specific parameters of the decision matrix, such as introducing a new choice or

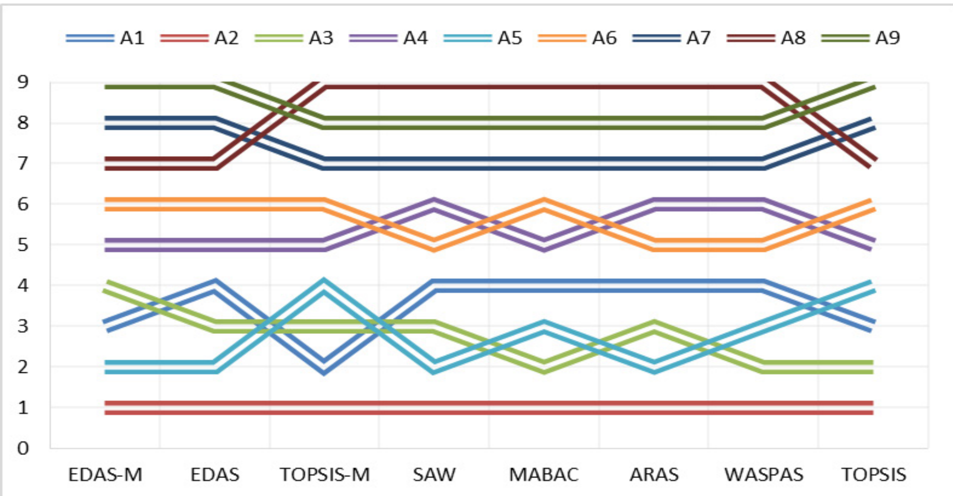

Figure 1. Ranking alternatives trough different MCDM methods (developed by the paper authors)

eliminating the existing one, can lead to changes in preferences. Therefore, in the next part, seven scenarios (Figure 2) were created where the shift in decision matrix elements is simulated. The scenarios were created so that the worst alternative is eliminated from subsequent considerations in each situation. At the same time, the remaining options are ranked for each scenario according to the new initial decision-making matrix.

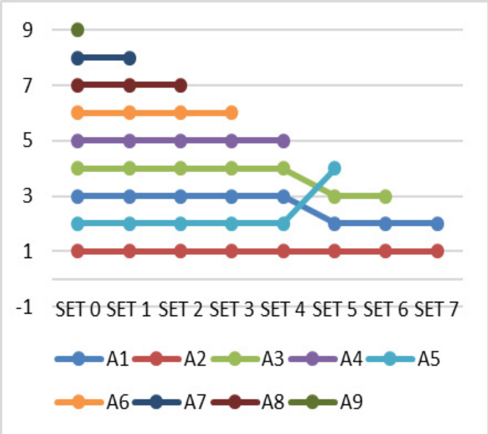

Figure 2. Ranking alternatives trough influence of dynamic matrices on rank change

The set 0 is the initial one representing the initial solution obtained using EDAS-M method: $A_2>A_5>A_1>A_3>A_4>A_6>A_8>A_7>A_9$. The alternative A_9 was identified as the worst, so in the first scenario, it was eliminated from the set. Thus, a new decision matrix was obtained with eight alternatives. A new solution was generated, and the following preferences $A_2>A_5>A_1>A_3>A_4>A_6>A_8>A_7$ were obtained. The preferred options from the initial scenario show that results are the same. Also, sets 2, 3, and 4 show the same ranks while excluding the worst alternative in each situation. The first change is in the fifth scenario where only four choices that are A_1, A_2, A_3 and A_5 were considered. The first alternative takes the second place, while in the previous four situations was on the third place. The ranking in this scenario is $A_2>A_1>A_3>A_5$. In the last two scenarios, the ranking is as follows: $A_2>A_1>A_3$ and $A_2>A_1$ respectively. Based on the results presented, one can conclude that the A_2 alternative remains the best ranked across all the scenarios, and, therefore, it confirms the robustness of the obtained ranks in a dynamic environment.

5. Conclusion

The proposed extended EDAS-M method presented in this paper refers to the modification of the conventional EDAS method in the Minkowski space. Based on the unfolding of such an extended plan, it is possible to tackle problems with multiple criteria in a more precise way, considering the uncertainties and ambiguities. The model has been verified throughout the process of evaluating and selecting autonomous vehicles. The algorithm of EDAS-M method has eight steps, and for each of them, the computation has been explained in detail through a numerical example.

In order to define the stability of the obtained results, a sensitivity analysis has been carried out in which seven other MCDM approaches have been applied namely the EDAS, TOPSIS-M, SAW, MABAC, ARAS, WASPAS, and TOPSIS methods. This comparison showed that the proposed extended EDAS-M method provides good and valid results. The sensitivity analysis showed that the obtained alternatives` ranks for the EDAS-M method highly correlate with the positions of the chosen alternatives for the other approaches. Subsequently, the test of the influence of dynamic matrices on the attitudes of alternatives identified that there were no significant changes in ranks. The analysis mentioned above has two goals: to consider the robustness of the obtained solution under uncertain conditions and to analyse the performance of the EDAS-M method under the terms of a dynamic initial decision matrix.

When decision-makers use the EDAS-M method, the essential influence on problem-solving results is based on criteria, whose values are significantly different from the average values. At the same time, the criteria values that are less different from the average solution values have a weak impact on final solution results.

The EDAS-M approach and the Minkowski space better reflect the vital decision-making practices of experienced executives and are better suited to developing multi-criteria problem models that address real-world strategic challenges by choosing effective alternatives from available alternatives. The presented model will also be used in future decision-making systems. Future studies can be related to developing other methods in Minkowski space and to the integration of EDAS-M practice with different approaches such as fuzzy logic, rough set theory, neutrosophic, etc.

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