EVALUATION OF ELECTRIC VEHICLES USING THE SIMPLIFIED WISP METHOD

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Abstract
Global warming and the reduction of CO_2 emissions have become very actual problems. One way for reducing CO_2 emissions is to replacement of classic with electric vehicles. For this reason, the electric vehicle market is dynamically and constantly developing. Choosing electric vehicles with adequate characteristics without increasing costs is an important and challenging decision-making problem. This problem is especially evident when selecting electric vehicles, where a greater number of evaluation criteria should be considered. Therefore, in this article, a multiple criteria decision-making model for the evaluation of electric vehicles is proposed, based on the use of the Simplified WISP and Simplified PIPRECIA methods. The conducted analyses and comparisons allowed us to identify the most interesting electric vehicle. The proposed framework can be utilized as a basis for more detailed purchasing decisions.

Keywords: Electric vehicles, MCDM, Simplified WISP, Simplified PIPRECIA, Multi-criteria decision aid.

INTRODUCTION

The need for the larger using of electric vehicles, instead of classic vehicles, has resulted in the design of a larger number of electric vehicle models, which, apart from their appearance, differ in numerous other characteristics such as battery power, the radius of movement on a single battery charge, power consumption, and so on.

A large number of characteristics (criteria), which have different importance when choosing an adequate electric vehicle, represent an ideal problem that can be effectively solved by applying multiple criteria decision-making (MCDM) methods.

Pradhan et al. [1] can be mentioned as example where MCDM methods are used for evaluating electric vehicles. In this article, the COPRAS (COmplex PRoportional ASsessment) method was used in the Fuzzy environment. Similar research conducted Biswas and Das [2], where they used AHP (Analytic Hierarchy Process) and MABAC (Multi-Attributive Border Approximation area Comparison) methods, as well as Ecer [3], which used seven MCDM methods: SECA (Simultaneous Evaluation of Criteria and Alternatives), MARCOS (Measurement of Alternatives and Ranking According to Compromise Solution), MAIRCA (Multi Attributive Ideal-Real Comparative Analysis), CoCoSo (Combined Compromise Solution), ARAS (Additive Ratio ASsessment), and COPRAS (COmplex PRoportional ASsessment), also in Fuzzy environment. Ziemba [4] has proposed a framework for selection of electric vehicles in Poland based on Fuzzy extensions of TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), SAW (Simple Additive Weighting) and PROMETHEE (Preference Ranking Organization METHod for Enrichment of Evaluations) methods. In addition to the above research, numerous similar research can also be stated [5]-[7].

However, the selection of electric vehicles based on purely quantitative criteria does not require a Fuzzy environment, which is why this article considers the application of an approach based on the application of the Simplified

WISP (Integrated Simple Weighted Sum Product) method [8].

In the rest of this article, after Preliminaries, the Simplified WISP and Simplified PIPRECIA (PIvot Pairwise RElative Criteria Importance Assessment) methods are presented in detail in order to use them for evaluating electric vehicles. In the next section the usefulness of the proposed approach is demonstrate. Finally, the conclusions are given.

THE SIMPLIFIED WISP METHOD

The simplified WISP method was formed on the basis of the WISP method [9], and its applicability was proven by comparing the ranking results obtained by applying the mentioned method and some prominent and some newly proposed MCDM methods, such as TOPSIS, VIKOR (VIsekriterijumska optimizacija i KOmpromisno Resenje, in Serbian), SAW, ARAS, WASPAS (Weighted Aggregated Sum Product ASsessment) and CoCoSo [8].

The process of evaluating *m* alternatives based on *n* criteria, using this method, can be clearly presented using the following steps:

Step 1. Construct a decision-making matrix.

Step 2. Construct a normalized decision-making matrix as follows:

$$r_{ij} = \frac{x_{ij}}{\max_i x_{ij}}, \quad (1)$$

where: r_{ij} denotes a dimensionless number that represents a normalized rating of alternative *i* in regards to criterion *j*, x_{ij} denotes rating of alternative *i* in regards to criterion *j*.

Step 3. Calculate the values of two utility measures, as follows:

$$u_i^{sd} = \sum_{j\in\Omega_{\max}} r_{ij}w_j - \sum_{j\in\Omega_{\min}} r_{ij}w_j, \quad (2)$$

$$u_i^{pr} = \frac{\prod_{j\in\Omega_{\max}} r_{ij}w_j}{\prod_{j\in\Omega_{\min}} r_{ij}w_j}, \quad (3)$$

where: u_i^{sd} denote differences between the weighted sum of normalized ratings, and u_i^{pr} denote ratios between a weighted product of normalized ratings of alternative *i*, respectively, and w_j denotes weight of criterion *j*.

Step 4. Recalculate values of above mentioned utility measures, as follows:

$$\bar{u}_i^{sd} = \frac{1+u_i^{sd}}{1+max_i\, u_i^{sd}}, \quad (4)$$

$$\bar{u}_i^{pr} = \frac{1+u_i^{pr}}{1+max_i\, u_i^{pr}}, \quad (5)$$

where: $\bar{u}_i^{sd}$and $\bar{u}_i^{pr}$ denote recalculated values of u_i^{sd} and u_i^{pr}.

Step 5. Determine the overall utility u_i of each alternative as follows:

$$u_i = \frac{1}{2}(\bar{u}_i^{sd} + \bar{u}_i^{pr}). \quad (6)$$

Step 6. Rank the alternatives and select the most suitable one. The alternatives are ranked in descending order, and the alternative with the highest value of u_i is the most preferred one.

THE SIMPLIFIED PIPRECIA METHOD

The simplified PIPRECIA method [10] is proposed based on PIPRECIA method [11]. In both of these methods, the criteria weights are calculated based on the pairwise comparison of criteria. However, in the PIPRECIA method, the importance of each criterion is compared with the importance of the previous criterion, while in the Simplified PIPRECIA method the importance of each criterion is compared with the importance of the first criterion.

The procedure for determining the relative importance of an alternative using the PIPRECIA method can be presented as follows:

Step 1. Determine the set of evaluation criteria.

Step 2. Set the relative significance s_j of each criterion, except the first, as follows:

$$s_j = \begin{cases} >1 & if\ C_j \succ C_1 \\ 1 & if\ C_j = C_1 \\ <1 & if\ C_j \prec C_1 \end{cases}, \quad (7)$$

where $j \neq 1$. For $j = 1$, s_j has the value 1.

Similar to the PIPRECIA method, the value of s_j belong to the interval (1, 1.9] when $C_j \succ C_1$, that is to the interval [0.1, 1) when $C_j \prec C_1$.

Step 3. Calculate the value of coefficient k_j as follows:

$$k_j = \begin{cases} 1 & if\ j = 1 \\ 2 - s_j & if\ j > 1 \end{cases}. \quad (8)$$

Step 4. Calculate the recalculated weight q_j as follows:

$$q_j = \begin{cases} 1 & if\ j = 1 \\ \frac{1}{k_j} & if\ j > 1 \end{cases}. \quad (9)$$

Step 5. Determine the relative weights w_j of the evaluation criteria as follows:

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k}. \quad (10)$$

A NUMERICAL ILLUSTRATION

In order to present the procedure for evaluating electric vehicles based on quantitative data, using the Simplified WISP method, five electric cars were evaluated based on the following criteria:

- C_1 - Battery power (kWh)
- C_2 - Radius of movement on a single battery charge (km)
- C_3 - Power consumption (kWh/100km)
- C_4 - Engine power (kw)
- C_5 - Acceleration 0 -100 km/h (s)
- C_6 - Price (Eur)

The data used for the evaluation, downloaded from the website https://www.cars-data.com/en/, are shown in Table 1.

Table 1. *Initial decision-making matrix*

		C_1	C_2	C_3	C_4	C_5	C_6
	wi	0.15	0.19	0.15	0.15	0.19	0.19
Model	*Opt*	max	max	min	max	min	min
Volkswagen ID.3	A_1	58.00	424.00	15.50	150.00	7.30	40,380.00
Hyundai IONIQ	A_2	38.30	311.00	13.80	100.00	9.90	40,767.00
Nissan LEAF	A_3	40.00	350.00	14.10	110.00	7.90	34,140.00
Mazda MX-30	A_4	35.50	200.00	19.00	107.00	9.70	33,100.00
Renault ZOE	A_5	52.00	390.00	19.30	100.00	9.50	37,550.00

Table 1 also shows the optimization directions of the criteria, as well as their weights, which in this case were determined using Simplified PIPRECIA. Calculation details obtained using the Simplified PIPRECIA method are summarized in Table 2.

Table 2*. Calculation details obtained using the Simplified PIPRECIA method*

	s_j	k_j	q_j	w_j
C_1	1	1	1	0.15
C_2	1.2	0.80	1.25	0.19
C_3	1	1.00	1.00	0.15
C_4	1	1.00	1.00	0.15
C_5	1.2	0.80	1.25	0.19
C_6	1.2	0.80	1.25	0.19
			6.75	1.00

The normalized, calculated using Eq. (1), is shown in Table 3.

Table 3. *Normalized decision-making matrix*

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	1.00	1.00	0.80	1.00	0.74	0.99
A_2	0.66	0.73	0.72	0.67	1.00	1.00
A_3	0.69	0.83	0.73	0.73	0.80	0.84
A_4	0.61	0.47	0.98	0.71	0.98	0.81
A_5	0.90	0.92	1.00	0.67	0.96	0.92

Two utility measures, their recalculated values, as well as, overall utility of each alternative and ranking order of alternatives, that is, evaluated electric vehicles, are presented in Table 4.

Table 4. *Calculation details obtained using the Simplified WISP method*

	u_i^{sd}	u_i^{pr}	$\bar{u}_i^{sd}$	$\bar{u}_i^{pr}$	u_i	Rank
A_1	0.04	1.364	1.000	1.000	1.000	1
A_2	-0.14	0.361	0.821	0.576	0.699	4
A_3	-0.05	0.684	0.914	0.712	0.813	2
A_4	-0.19	0.210	0.773	0.512	0.643	5
A_5	-0.09	0.498	0.869	0.634	0.751	3

From Table 4, it can be seen that in this case of evaluation, the alternative marked as A_1, i.e. the Volkswagen ID.3 model was chosen as the most acceptable, based on the selected set of criteria and their weights.

Table 5. *Ranking orders obtained using several MCDM methods*

	Simplified WISP	TOPSIS	VIKOR	SAW	ARAS	WASPAS
A_1	1	1	2	1	1	1
A_2	4	4	4	4	4	4
A_3	2	2	1	2	2	2
A_4	5	5	5	5	5	5
A_5	3	3	3	3	3	3

In order to verify the obtained results, an evaluation was carried out with several selected methods of multi-criteria decision-making, i.e. TOPSIS, VIKOR, SAW, ARAS, WASPAS methods. The ranking results achieved by applying the Simple WISP method and the mentioned MCDM methods are shown in Table 5 and graphically represented in Figure 1.

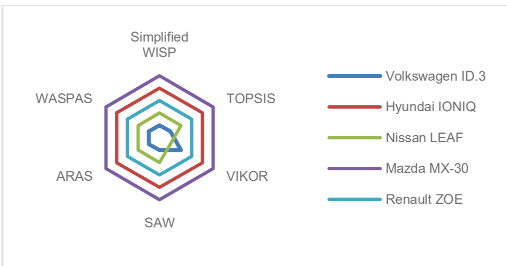

Fig. 1. *Ranking orders obtained using several MCDM methods*

From Table 5, as well as Figure 1, it can be clearly observed that almost all used MCDM methods, except the VIKOR method, provide the same results, which confirms the usability of the proposed electricity evaluation on the basis of quantitative data.

In the aforementioned comparison, the results obtained using the simplified WISP method were compared with the results obtained using three prominent MCDM methods (TOPSIS, VIKOR and SAW) and two more recently proposed but frequently used MCDM methods (ARAS and WASPAS). Those methods were chosen for the following reasons:

The SAW method uses a very simple aggregation procedure, based on the weighted sum approach, as follows:

$$S_i = \sum_{j=1}^{n} r_{ij}\, w_j, \tag{11}$$

where: S_i denotes overall utility of alternative i and r_{ij} denotes normalized rating of alternative i in relation to criterion j.

The SAW method uses a very simple aggregation procedure and can be used with several normalization procedures, such as the normalization procedure used in the WISP method. However, it should be noted here that this method uses different equations for normalizing cost and beneficial criteria.

This method was often used earlier, but over time it was replaced by TOPSIS, VIKOR, and numerous other recently proposed MCDM methods.

The TOPSIS method is based on the idea that the best alternative should have the shortest distance from the ideal point and the farthest distance from the anti-ideal point in Euclidean space. The relative distance of each alternative from the ideal point d_i^+ and d_i^- anti-ideal point are determined as follows:

$$d_i^+ = \left\{\sum_{j=1}^{n}\left[w_j\left(r_{ij}-r_j^+\right)^2\right]\right\}^{1/2}, \text{ and} \tag{12}$$

$$d_i^- = \left\{\sum_{j=1}^{n}\left[w_j\left(r_{ij}-r_j^-\right)^2\right]\right\}^{1/2}, \tag{13}$$

where: r_j^+ d and r_j^- denotes j-th coordinate of the ideal point and j-th coordinate of the ant-ideal point, respectively.

After that, in the next step, the relative distance C_i of the alternative i to the ideal solution is determined as follows:

$$C_i = \frac{d_i^-}{d_i^- + d_i^+}. \tag{14}$$

According to the TOPSIS method, the alternative with the highest value of C_i is at the same time the best alternative. Finally, it should be noted that TOPSIS method uses vector normalization procedure, without "transforming" the value of cost criteria into the value of beneficial criteria.

The VIKOR method is based on the idea of ideal and compromise solution. The best alternative in this method is determined on the basis of the overall ranking index Q_i, which is determined as follows:

$$Q_i = v\frac{(S_i - S^*)}{(S^- - S^*)} + (1-v)\frac{(R_i - R^*)}{(R^- - R^*)}, \tag{15}$$

where: S_j and R_j denote the average and the worst group score of alternative i, respectively, $S^* = \min_i S_i$, $S^- = \max_i S_i$, $R^* = \min_i R_i$, $R^- = \max_i R_i$, and v represents a significance of the strategy, which value is usually set to be 0.5.

The average and group score for each alternative are determined as follows:

$$S_i = \sum_{j=1}^{n} w_j \frac{x_j^* - x_{ij}}{x_j^* - x_j^-}; \text{ for } p = 1 \text{ and} \tag{16}$$

$$R_i = max_j\left[w_j \frac{x_j^* - x_{ij}}{x_j^* - x_j^-}\right]; \text{ for } p \to \infty, \tag{17}$$

where Ω_{max} and Ω_{min} denote set of the benefit and cost criteria, respectively, and x_j^* is determined as follows:

$$x_j^* = \begin{cases} max_j\, x_{ij} & j \in \Omega_{max} \\ min_j\, x_{ij} & j \in \Omega_{min} \end{cases} \tag{18}$$

The WASPAS method combines two approaches for determining the performance score of alternatives, as follows:

$$Q_i^{(1)} = \sum_{j=1}^{n} r_{ij}\, w_j, \tag{19}$$

$$Q_i^{(2)} = \prod_{j=1}^{n}\left(r_{ij}\right)^{w_j}, \tag{20}$$

where: $Q_i^{(1)}$ and $Q_i^{(2)}$ denote relative importance of alternative i based on WS and exponentially EWP method, respectively.

The performance score of alternatives Q_i are determined as follows:

$$Q_i = 0.5Q_i^{(1)} + 0.5Q_i^{(2)} \tag{21}$$

The WASPAS method uses max normalization procedure, where beneficial and non-beneficial criteria are treated differently.

The calculation procedure of the ARAS method is similar to the calculation procedure of the SAW method, with the difference that the ARAS method also introduces an optimal alternative. The overall performance ratings of the alternative are calculated as in the SAW method, with the difference that the ARAS method uses the SUM normalization procedure.

The final ranking of the alternative is based on the degree of utility Q_i which is calculated as follows

$$Q_i = \frac{S_i}{S_0}, \quad (22)$$

where: S_i denote overall utility of alternative i, and S_0 is the overall utility optimal alternative.

Finally, the discrepancy in the ranking orders of alternatives between the VIKOR method and the other MCDM methods arose as a result of the differences in the calculation procedures of the applied MCDM methods, the normalization procedures, and the weight of the criteria. By slightly changing the weights of the criteria, the VIKOR method would give the same results as the other MCDM methods.

CONCLUSION

This article discusses the application of a simple approach for the evaluation of electric vehicles, which is based on the application of quantitative data and the easy-to-use Simplified WISP method. The Simplified WISP method was deliberately chosen because of its simplicity, in order to enable the use of this approach by decision-makers who are not familiar with MCDM methods.

In addition, the proposed model can be easily extended by adding new criteria, and the Simplified WISP method can be replaced by the WISP method or its extensions that support the application of fuzzy, intuitionistic, or neutrosophic sets.

Finally, the use of a larger number of evaluation criteria and the use of data obtained during real testing of electric vehicles can be mentioned as directions for further development of the presented model.

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