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Evaluation of Agricultural Machinery Using Multi-Criteria Analysis Methods

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Abstract: To achieve the highest possible agricultural production, it is necessary to procure the appropriate agricultural machinery. A tractor is the most useful machine in agriculture that performs various functions. Therefore, the selection of a tractor is one of the key decisions in the agriculture-production process. This study aims to evaluate heavy tractors for agricultural production in Bosnia and Herzegovina. Since this is a selection between different tractors, which are evaluated using several criteria, the methods of multi-criteria analysis (MCDA) were used in this study. Five different methods were used to determine the weight of the criteria, of which a modified standard-deviation method is a new method used in practice, while the tractor ranking was performed using the CRADIS (compromise ranking of alternatives from distance to ideal solution) method. The results showed that the best-ranked tractor is A4, while the most deviations from the ranking occur when the entropy method is used. The contribution of this study is in the systematization of the methods for the objective determination of the criteria weights and the development of new methods to facilitate decision-making in agriculture and other industries.

Keywords: tractor selection; modified standard-deviation method; CRADIS method; ranking

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1. Introduction

Agriculture is a branch of the economy with a high research focus nowadays. As with other industries, the introduction of technological innovation has become imperative for agriculture, so much attention is paid to the modernization of agricultural production [1]. Agricultural mechanization is an important factor in increasing the productivity of agricultural production and the quality development of agriculture [2]. In addition, the low supply of labor in agriculture requires that agricultural activities should be carried out using agricultural machinery [3]. Much attention should be paid to the selection of appropriate machinery in agriculture [4]. The basic requirement in agriculture is to reduce the costs of land cultivation [5], because it is necessary to reduce production costs to achieve higher revenues through the sale of agricultural products [6]. Based on that, productivity is the key economic indicator in achieving the set goals in agriculture. Agricultural production is under the influence of uncertainty, because the annual yield is affected by precipitation, temperature, and other natural conditions. Therefore, in order to reduce the impact of uncertainty on agricultural production, it is necessary to use the economy of scale and plant large quantities of agricultural crops.

Recent emergencies, such as the COVID-19 virus pandemic and local war conflicts, have shown that countries with rich agricultural production are more capable to withstand market fluctuations. To increase agricultural production, it is necessary to select the appropriate agricultural machinery. The purpose of agricultural mechanization is to achieve high income while minimizing costs, which is the basic postulate of agricultural production [7]. Tractors are the basic means of agricultural machinery used in agricultural production. They perform the most important operations in agriculture such as plowing, planting, cultivating, fertilizing, harvesting, and spraying [8]. Today, tractors are the main traction and propulsion tool in agricultural production. The OECD (Organization for Economic Cooperation and Development) defines tractors as self-propelled vehicles with wheels and at least two axles, with a basic use in agriculture, which are designed and constructed to meet the following two operations [9]:

- To tow trailers;
- To carry, tow, or move agricultural and forestry tools and machines, and, where necessary, hand over power for their work while the tractor is moving or stationary.

Buying tractors is a big investment for farmers, so it is necessary to choose from the multitude of the alternatives that exist on the market. When selecting a tractor, the criteria are first determined and then the alternatives are evaluated [10]. The choice of the criteria and alternatives is the basis for the application of multi-criteria analysis methods (MCDA) [11,12]. To cultivate large areas, farmers must choose tractors that fall into the category of heavy tractors [13].

When selecting a tractor using the MCDA method, the criteria for evaluating the alternatives must first be determined, followed by the alternatives. The most important criteria for farmers when buying a tractor are the brand, power, price, and characteristics of the tractor [8]. The selected criteria need to be evaluated, and the weights need to be determined [14]. Two approaches are used in determining the weights, namely the subjective determination of the criteria weights and the objective determination of the criteria weights [15]. When subjectively determining the weight of the criteria, the opinion of decision-makers (DM) is used for the importance of a certain criterion [16]. In the objective determination of the importance of criteria [17], the values of the alternatives are taken and based on these values, and the weights of the criteria are calculated using certain methods [18]. In these methods, there is no effect of DM on the value of the criterion weight [19].

In this study, an objective approach was used for calculating the weight because the values of the alternatives themselves are objectively determined, i.e., they are not determined subjectively. When using objective determination of weighting factors, there are various methods such as CRITIC (CRiteria Importance Through Inter-criteria Correlation), entropy, standard deviation, and MEREC (MEthod based on the Removal Effects of Criteria) [20]. In addition to these methods, the modified standard deviation method was used to determine the weight of the criteria. This method aims to facilitate the calculation of a criterion weight, while obtaining similar weights to the other methods.

Based on the previous, the following goals are set for this study:

- Evaluation of heavy tractors for agricultural production in Bosnia and Herzegovina (BiH) using MCDA methods;
- Determining the influence of criteria weights obtained through methods for the objective determination of criteria weights on tractor evaluation;
- Comparison of the modified standard deviation method with other methods for the objective determination of criteria weights.

In addition to the introduction, the paper is divided into five selections. In Section 2, a review of the literature is performed that focuses on the selection of tractors and on the use of objective methods in agriculture. Section 3 presents the research methodology and research methods. In Section 4, the ranking of different tractors and the selection of the tractor that best meets the set criteria are presented. The results obtained are also discussed. Section 5 presents the most important results and provides guidelines for future research.

2. Literature Review

Within the literature review, a review of the literature on tractor selection is shown first, followed by a review of the literature on the application of objective methods for determining weights in agriculture.

2.1. Selection of Tractors in Agriculture

Gürsoy et al. [21] selected the tractor based on its power to optimize mechanization in agriculture. Shorkpor and Asakereh [22] selected the best tractor in the Saral region of the Dyvandara district. According to their results, the best tractor was a medium-range BMI 285. When selecting a tractor, they used the following criteria: driving wheel, gearbox, PTO (RPM), number of cylinders, and power (hp). Zhu et al. [23] evaluated tractor propulsion and introduced a mechanical–electronic–hydraulic powertrain system in tractors to improve tractor performance. Xia et al. [24] investigated how power transmission is performed in tractors and proposed a new power-cycle hydro–mechanical continuously variable transmission to optimize tractor performance. Baek et al. [25] tested gears in a tractor to reduce maintenance costs. Ruiz-Garcia and Sanchez-Guerrero [8] conducted research using a web-based decision-support tool.

Mishra and Satapathy [26] surveyed farms on the maintenance of agricultural machinery with an emphasis on the maintenance of tractor attachments, and they used the SWARA (Step-wise Weight Assessment Ratio Analysis) method. Lalremruata et al. [27] analyzed the impact of the noise of six tractors on the driver's ear during tillage operations. When selecting a tractor, they used the following criteria: engine, power drive, power, rated engine speed, weight, and number of gears. Okoko and Ajav [28] examined how different ways of plowing affect tractor operation and obtained results on how tractor speed and tillage depth affect their operation. Fargnoli and Lombardi [29] reviewed work on examining the safety of tractor use in everyday agricultural activities because of the high rate of injuries to farmers. Hou et al. [30] examined how much the use of tractors in Beijing districts emits harmful particles into the atmosphere. Mutlu [31] researched which tractors are the best-selling on the market.

Russini et al. [32] conducted a study of the traction performance of agricultural tractors and observed a high correlation between the power obtained in the test and the estimated power. Lee et al. [33] tested the engine speed-control system to maximize fuel efficiency in tractors. Lagnelöv et al. [34] investigated the application of autonomous tractors to batteries in agriculture. They pointed out that the biggest costs are related to batteries, but in addition, these tractors have proven to be competitive compared to classic tractors. Malik and Kohli [35] examined the application of electric tractors in agriculture to apply sustainable agricultural production. Lipkovich et al. [36] considered the application of the fifth generation of tractors based on mobile powertrains. Sunusi et al. [37] reviewed the possibility of applying online control over tractors in agriculture.

Perez-Domnguez et al. [38] evaluated tractors using dimensional analysis and aggregated intuitionistic fuzzy dimensional (AIFDA) techniques. Ormond et al. [39] conducted an experiment with soybean sowing using a tractor and found that the density of sowing leads to a higher prevalence of Asian rust. They used the area under the disease progress curve (AACPD) method. Hu et al. [40] used the ANP (analytic network process) and BSC (balanced scorecard) methods in order to develop a network of machinery maintenance for agricultural production. Hoose et al. [41] used the AHP and DEA (data envelopment analysis) methods to select tractor-trailers for grain transportation. Lu et al. [42] used the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method to select suppliers for new agricultural machinery for the development of agricultural production.

Yang et al. [43] applied multi-objective disassembly of harvester production to reduce the carbon footprint of production. For this purpose, they used the MDFOA method (multi-objective disassembly line balancing fruit fly optimization algorithm). Lalghorbani and Jahan [44] evaluated combined harvesters using the MULTIMOORA (multi-objective optimization on the basis of ratio analysis) method in order to optimize agricultural production. Han et al. [45], using the multi-objective mixed integer program (MIP) method, which optimized the use of agricultural mechanization during production in such a way that more work can be accomplished with fewer visits to service centers. Houshyar et al. [46] evaluated the distribution of agricultural machinery for the needs of agricultural production in Iran using fuzzy AHP and weight-restriction DEA methods. Shoaei et al. [47] made a selection of places for the service of agricultural machinery using a GIS system in order to improve agricultural production.

2.2. Application of Objective Methods for Determining the Weight of Criteria in Agriculture

Objective methods for determining the weight of criteria have been used in various fields of agriculture. Table 1 presents some papers in the last five years in which the methods to be used in this paper were applied. Objective methods for determining the weight of criteria have been used in various fields of agriculture.

Table 1. Review of papers on the application of objective methods for determining the weight of criteria in agriculture.

No.	Authors	Year	Method	Application/Development
1	Deepa and Ganesan [48]	2018	Entropy	Selection of agricultural crops
2	de Araujo et al. [49]	2019	Entropy	Price analysis of agricultural products
3	Deepa et al. [50]	2019	CRITIC	Ranking of agricultural data
4	Lu et al. [51]	2019	Entropy	Selection of agricultural machinery
5	Sadeghi Ravesh [52]	2019	Entropy	Desertification and remediation plans for degraded land in agriculture
6	Gomes et al. [53]	2020	CRITIC	Application of sewage sludge in agriculture
7	Sabzevari et al. [54]	2020	Entropy	Choice of vegetable growing
8	Khodaei et al. [55]	2021	Entropy	Strawberry storage
9	Nedeljković et al. [56]	2021	CRITIC	Selection of harvesting machine
10	Wichapa et al. [57]	2021	CRITIC	Agricultural waste management
11	Polcyn [58]	2021	CRITIC	Eco-efficiency and human capital on farms
12	Polcyn et al. [59]	2021	CRITIC	The relationship between education and production on farms
13	Dabkiene et al. [60]	2021	Entropy	Evaluation of farm and orchard efficiency
14	Mitra et al. [61]	2022	CRITIC	Evaluation of crude fiber
15	Lu et al. [42]	2022	CRITIC Entropy	Selection of agricultural machinery
16	Puška et al. [62]	2022b	CRITIC	Selection of pear varieties
17	Kaghazchi et al. [63]	2022	Entropy	Irrigation systems

Based on the above papers, it can be concluded that in the objective determination of the weight of the criteria, the entropy and CRITIC methods were mostly used in agriculture. The MERAC method is new and has not yet been used in the field of agriculture. In determining the weight by standard deviation, it is difficult to find papers because in one part of the CRITIC calculation the standard deviation is used and these two terms overlap.

3. Research Methodology and Methods

Modern agriculture requires the use of advanced types of tractors, i.e., tractors with a role that is multiple. Therefore, there are different design solutions when it comes to determining the characteristics of the tractors used. When selecting tractors for the needs of agricultural production in BiH, the methodology presented in Figure 1 was used.

According to this methodology, the selection of the alternatives was accomplished first. When selecting the alternatives, a study was conducted to assess which tractors are represented on the BiH market and which belong to the category of heavy tractors. Based on this, the alternatives were formed and marked from A1 to A6. This was accomplished because this paper is primarily conceptual and aims to present a new method of objectively determining weights. In addition, the experiences of the users of these tractors were not taken, only seven of their characteristics were. These tractors, which are agricultural machines of the latest generation, belong to the category of heavy tractors based on the power of the installed engine. Germany and the USA were chosen as the countries of origin of these tractors, given the current presence (availability) in the market of BiH.

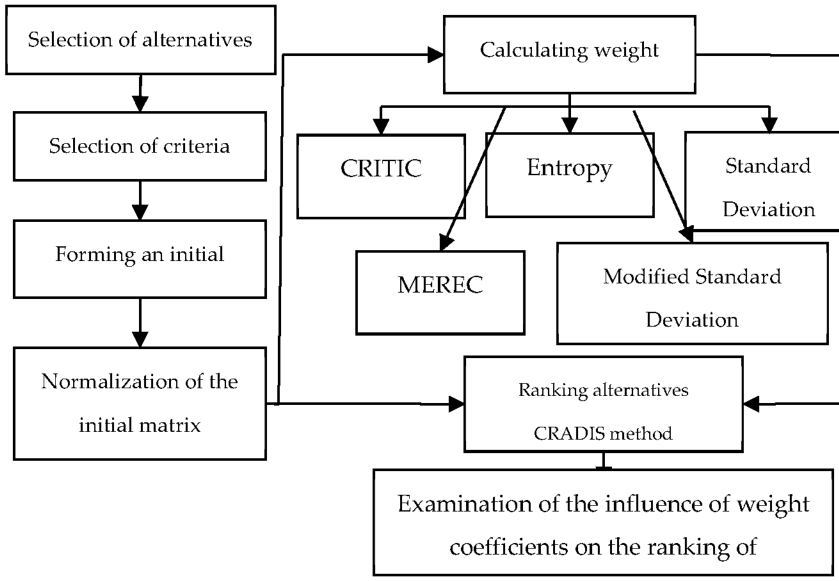

Figure 1. Research methodology.

To evaluate these tractors, it was necessary to select criteria. When choosing the criteria, all relevant criteria necessary for the implementation of agricultural production were taken into account. Based on this, the following criteria were selected: power (C1), torque (C2), tank capacity (C3), tractor weight (C4), cubic capacity (C5), price (C6), and fuel consumption (C7). It should be emphasized that the cubic-capacity criterion does not directly affect the performance of the engine and the tractor, but it can still have an effect, which is why this criterion was taken. The second reason is that this criterion is a numerical criterion and, as such, is suitable for the analysis in this study. In addition to technical criteria, the criteria also included economic criteria (price) and environmental criteria (fuel consumption) to make decision-making more comprehensive.

Once the alternatives and criteria for evaluating the alternatives were determined, an initial-decision matrix was formed. The first step in any method of multi-criteria analysis is to normalize the initial-decision matrix [64]. Normalization is performed, so that all data are uniform [65] to perform the steps from the MCDA method [66]. For all criteria, there is a different unit of measure for determining the value of the alternatives, according to certain criteria, so this is another reason why normalization is performed (Table 1).

Since five different methods were used in this study to determine the criteria, the same normalization was used to reduce the difference in their use. In addition, the same normalization was used with the CRADIS method for ranking the alternatives. However, when normalizing the data, it was necessary to determine which type of criteria was used when evaluating the alternatives. When observing the type of criteria, it was necessary to determine DM preferences. E.g., each DM prefers to have the lowest possible price and fuel consumption, and these criteria fall into the category of "cost" criteria, while cubic capacity and tank capacity should be as high as possible, and these criteria fall into the category of "benefit" criteria. Based on this, it was necessary to assign the type of criterion for each criterion to perform the correct normalization. Table 2 presents the criteria with definitions and the types of criteria used to perform the appropriate normalization.

Table 2. Criteria in tractor selection.

Id	Criterion	Unit	Definition	Type	References
C1	Power	kW	Torque function, multiplication of the torque and speed of the motor.	Benefit	[22–24,27,33]
C2	Torque	Nm	The product of the force (by generating the action of combustion gases on the piston head) and the arm on which that force acts.	Benefit	[23,24,32]
C3	Reservoir capacity	L	The place of collection (refueling) of motor fuel depends on the power (type) of the tractor.	Benefit	[28,67]
C4	Tractor weight	kg	Tractor weight depends on the type of tractor, engine power, purpose of the tractor, tractor transmission, towing, or mounted implement.	Benefit	[25,27,32]
C5	Cubic	cm^3	Cylinder working space size in motor vehicles (tractors).	Benefit	[28,32]
C6	Price	euro	The market unit of measure is expressed in a certain currency and depends on many technical characteristics of the tractor.	Cost	[8,34,68]
C7	Consumption	g/kWh	Fuel consumption depends on the power and purpose and other technical characteristics of the tractor as a motor vehicle.	Cost	[27,69,70]

Before the alternatives are ranked, it was necessary to calculate the weights of the criteria. This study was performed using five methods: CRITIC, entropy, standard deviation, MEREC, and modified standard deviation. The reason for using these methods was to examine the impact of criteria weights on the ranking of the alternatives. In addition, using additional different methods and weighting criteria provided more information for DMs, which they can use when buying a tractor. Finally, the CRADIS method was used to examine how the weight coefficients have an impact on the ranking of tractors and which tractors should be the first choice for farmers in BiH.

3.1. Objective Methods for Determining Weight Criteria

Five methods for determining the weights of the criteria were applied in the study. The CRITIC, entropy, standard deviation, and MEREC methods are presented only in brief outlines, while the modified standard deviation method is explained in more detail, as it represents a new method.

3.1.1. CRITIC Method

Step 1. Normalization of the initial-decision matrix. The same normalization will be used for all methods:

$$n_{ij} = \frac{x_{ij}}{x_{j\ max}},\ \text{for benefit criteria} \tag{1}$$

$$n_{ij} = \frac{x_{j\ min}}{x_{ij}},\ \text{for cost criteria} \tag{2}$$

Step 2. Calculation of standard deviation and linear correlation matrix by columns.

Step 3. Determining the amount of information.

$$C_j = \sigma \sum_{k=1}^{m} \left(1 - r_{jk}\right) \tag{3}$$

where r represents a correlation coefficient for particular criteria.

Step 4. Calculation of the final weights of the criteria.

$$w_j = \frac{C_j}{\sum_{j=1}^{m} C_j} \tag{4}$$

3.1.2. Entropy Method

The entropy method consists of the following steps:
Step 1. Normalization of the initial-decision matrix.
Step 2. Determining the entropy value (e_j).

$$e_j = -k \sum_{i=1}^{n} r_{ij},\ j = 1, 2, \ldots, m \tag{5}$$

Step 3. Calculation of the degree of diffraction (d_j).

$$d_j = 1 - e_j,\ j = 1, 2, \ldots, m \tag{6}$$

Step 4. Calculation of the final weights of the criteria.

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{7}$$

3.1.3. Standard Deviation Method

The standard deviation method has the following steps:
Step 1. Normalization of the initial-decision matrix.
Step 2. Calculation of standard deviation (σ).
Step 3. Calculation of the final weights of the criteria.

$$w_j = \frac{\sigma_j}{\sum_{j=1}^{m} \sigma_j} \tag{8}$$

3.1.4. MEREC Method

The MEREC method has the following steps:
Step 1. Normalization of the initial-decision matrix.
Step 2. Calculation of the overall performance of the alternatives (S_i).

$$S_i = \ln\left(1 + \left(\frac{1}{m} \sum_j \left|\ln\left(n_{ij}^x\right)\right|\right)\right) \tag{9}$$

Step 3. Calculate the effects of the alternatives for each criterion.

$$S'_{ij} = \ln\left(1 + \left(\frac{1}{m} \sum_{k, k \neq j} |\ln(n_{ik}^x)|\right)\right) \tag{10}$$

Step 4. Calculate the sum of the deviations from the absolute values.

$$E_j = \sum_i \left|S'_{ij} - S_i\right| \tag{11}$$

Step 5. Calculate the final weights of the criteria.

$$w_j = \frac{E_j}{\sum_k E_k} \tag{12}$$

3.1.5. Modified Standard Deviation Method

The modified standard deviation method is an extension of the standard deviation method and, unlike it, uses two additional steps, which are to calculate the sum of the column and correct the value of the standard deviation with this indicator. This method has the following steps:

Step 1. Normalization of the initial-decision matrix.

Step 2. Calculation of the standard deviation (σ).

Step 3. Calculation of the sum of the sum of the columns $\sum_{j}^{m} x_{ij}$.

Step 4. Calculate the corrected value of the standard deviation.

$$\sigma' = \frac{\sigma}{\sum_{j}^{m} x_{ij}} \tag{13}$$

Step 5. Calculation of the final weights of the criteria.

$$w_j = \frac{\sigma'_j}{\sum_{j=1}^{m} \sigma'_j} \tag{14}$$

In this way, the values of the criteria after normalization are compared. If the values of the criteria are approximately the same, the value of the sum of the column will be higher, so the value of the corrected standard deviation (σ') will be lower. If the values of the criteria are different, the value of the sum of the column will be smaller, so the value of the corrected standard deviation (σ') will be higher. Applying the modified standard deviation additionally takes into account the existence of a larger deviation in the data within the criteria. Applying this method, the criteria for which the data have a larger deviation will get a higher value. The logic of this method is that if the values of the alternatives within one criterion are similar, the weight of that criterion will be less, and vice versa. Thus, diversity within one criterion is evaluated.

3.2. CRADIS Method

Once the weights of the criteria have been determined, it is necessary to rank the alternatives. The ranking of the alternatives will be accomplished using the CRADIS method. The CRADIS method was developed by Puška et al. [71] and has the following steps:

Step 1. Formation of a decision matrix.

Step 2. Normalization of the decision matrix.

Step 3. Computing the normalized-decision matrix. In this step, the value of the normalized-decision matrix is multiplied by the corresponding weights.

$$v_{ij} = n_{ij} \cdot w_j \tag{15}$$

Step 4. Determination of ideal and anti-ideal solutions. The ideal solution is the greatest value v_{ij} in an aggravated-decision matrix, while the anti-ideal solution is the smallest value v_{ij} in an aggravated-decision matrix.

$$t_i = \max v_{ij} \tag{16}$$

$$t_{ai} = \min v_{ij} \tag{17}$$

Step 5. Calculation of the deviation from the ideal and anti-ideal solutions.

$$d^{+} = t_i - v_{ij} \tag{18}$$

$$d^{-} = v_{ij} - t_{ai} \tag{19}$$

Step 6. Calculation of the deviation of the individual alternatives from the ideal and anti-ideal solutions.

$$s_i^+ = \sum_{j=1}^{n} d^+ \tag{20}$$

$$s_i^- = \sum_{j=1}^{n} d^- \tag{21}$$

Step 7. Calculation of the utility function for each alternative in relation to the deviations from the optimal alternatives.

$$K_i^+ = \frac{s_0^+}{s_i^+} \tag{22}$$

$$K_i^- = \frac{s_0^-}{s_i^-} \tag{23}$$

where s_0^+ is the optimal alternative that has the smallest distance from the ideal solution, s_0^- is the optimal alternative that has the greatest distance from the anti-ideal solution.

Step 8. Ranking the alternatives. The final order is obtained by looking for the average deviation of the alternatives from the degree of utility.

$$Q_i = \frac{K_i^+ + K_i^+}{2} \tag{24}$$

4. Results and Discussion

After the tractors and the evaluation criteria are selected, the initial-decision matrix was formed (Table 3). In this study, six alternatives for heavy tractors and seven evaluation criteria were observed. The next step was to calculate the maximum and minimum values of the criteria, to normalize the data. Depending on the type of criteria, different formulas were applied for normalization, whether expression 1 was used for benefit criteria or expression 2 was used for cost criteria.

Table 3. Initial-decision matrix.

	Power (C1)	Torque (C2)	Reservoir Capacity (C3)	Tractor Weight (C4)	Cubic (C5)	Price (C6)	Consumption (C7)
Alternative A1	166	955	505	9300	6057	182,000	192
Alternative A2	181	934	400	9100	6057	168,385	264
Alternative A3	151	896	455	8299	6728	175,723	248
Alternative A4	194	835	550	10,800	6728	189,371	258
Alternative A5	180	840	310	6640	6600	175,000	265
Alternative A6	165	940	395	8140	6728	169,518	233

By applying the appropriate formula for normalization to the initial-decision matrix, a normalized-decision matrix was formed (Table 4). This decision matrix was used to calculate criterion weights and to rank the alternatives. All methods used the same normalized-decision matrix.

Table 4. Normalized-decision matrix.

	C1	C2	C3	C4	C5	C6	C7
A1	0.9096	0.8743	0.6139	0.8611	1.0000	0.9611	0.7245
A2	0.8343	0.8940	0.7750	0.8426	1.0000	0.8892	0.9962
A3	1.0000	0.9319	0.6813	0.7684	0.9003	0.9279	0.9358
A4	0.7784	1.0000	0.5636	1.0000	0.9003	1.0000	0.9736
A5	0.8389	0.9940	1.0000	0.6148	0.9177	0.9241	1.0000
A6	0.9152	0.8883	0.7848	0.7537	0.9003	0.8952	0.8792

Once the normalized-decision matrix was determined, the weights of the criteria were calculated first using the CRITIC method (Table 5). The first step in calculating the CRITIC method is to calculate the standard deviation value. This standard deviation value was used for both the standard deviation method and the modified standard deviation method. The correlation value for the criteria was calculated. Correlation values for all observed criteria ($1 - r$) were then subtracted from the value of 1. These values were summed for the criteria and the value of the amount of information (C_j) was calculated. The last step was to calculate the weighting criteria (expression 4).

Table 5. Calculation of criterion weight using the CRITIC method.

		C1	C2	C3	C4	C5	C6	C7
	σ	0.0782	0.0547	0.1563	0.1286	0.0496	0.0419	0.1052
Correlation (r)	C1	1.0000	−0.5380	0.0998	0.3986	−0.0716	−0.3591	−0.4145
	C2	−0.5380	1.0000	0.0448	0.0356	−0.5976	0.4808	0.6464
	C3	0.0998	0.0448	1.0000	0.9064	−0.0436	−0.7549	0.3999
	C4	0.3986	0.0356	0.9064	1.0000	−0.1674	−0.6038	0.1726
	C5	−0.0716	−0.5976	−0.0436	−0.1674	1.0000	−0.1656	−0.4396
	C6	−0.3591	0.4808	−0.7549	−0.6038	−0.1656	1.0000	−0.2391
	C7	−0.4145	0.6464	0.3999	0.1726	−0.4396	−0.2391	1.0000
$1 - r$	C1	0.0000	1.5380	0.9002	0,6014	1.0716	1.3591	1.4145
	C2	1.5380	0.0000	0.9552	0,9644	1.5976	0.5192	0.3536
	C3	0.9002	0.9552	0.0000	0,0936	1.0436	1.7549	0.6001
	C4	0.6014	0.9644	0.0936	0.0000	1.1674	1.6038	0.8274
	C5	1.0716	1.5976	1.0436	1,1674	0.0000	1.1656	1.4396
	C6	1.3591	0.5192	1.7549	1,6038	1.1656	0.0000	1.2391
	C7	1.4145	0.3536	0.6001	0,8274	1.4396	1.2391	0.0000
sum ($1 - r$)		6.8848	5.9280	5.3476	5.2580	7.4854	7.6417	5.8742
$C_j = \sigma \sum_{k=1}^{m} \left(1 - r_{jk}\right)$		0.5384	0.3240	0.8361	0.6762	0.3712	0.3201	0.6180
w_j		0.1461	0.0879	0.2269	0.1836	0.1008	0.0869	0.1677

After the weights were calculated using the CRITIC method, the weights of the criteria were calculated using the entropy method (Table 6). When calculating the weights of the criteria using the entropy method, the values of the natural logarithm (ln) were first calculated for all values of the normalized-decision matrix. This value was multiplied by the value of the normalized-decision matrix. When this value was obtained, its sum was calculated according to the criteria. To carry out the next step, it was necessary to calculate the natural logarithm for the number 6 (ln (6)). The number six was selected because there are so many alternatives in this example. Then, the negative reciprocal of the natural logarithm of number 6 (−0.5581) was calculated. This was needed to calculate the entropy value (e_j), which was obtained by multiplying the sum of the criteria by the previously obtained value. The divergence rate was then calculated ($d_j = 1 - e_j$), and the weight-value criterion is calculated (w_j) (expression 7).

The next method for calculating criteria weights was the standard deviation (SD) method (Table 7). This method is the simplest of all methods and has the fewest steps. First, the value of the standard deviation for the criteria was calculated, and then the obtained value was used to calculate the weights of the criteria (expression 8).

The next method to calculate the weights of the criteria applied in this study was the MEREC method (Table 8). The first step in computing the MEREC method was to compute the absolute number from the natural logarithm for a normalized-decision matrix. The total performance of the alternatives was then found (S_i), by calculating the natural logarithm from the value of the sum of number 1 and by dividing the sum of the absolute values of the natural logarithms by the number of criteria (m). The next step was to calculate the effects of the alternatives for each criterion (S'_{ij}). The procedure is similar in that for each criterion, calculating the effects of the alternatives is not taken into account. The absolute value of the difference between the effects of the alternatives for each criterion and the overall performance of the alternatives was then calculated ($\left|S'_{ij} - S_i\right|$), and the sum of that for the criteria was calculated. The last step was to calculate the weight of the criteria (expression 12).

The last method used to calculate criteria weights was the modified standard deviation (MSD) method (Table 9). Unlike the standard deviation method, this method divides the value of the standard deviation (σ) by the sum of the values of an individual criterion. ($\sum_{j}^{m} x_{ij}$). When the modified value of the standard deviation was obtained, the value of the weight of each criterion was calculated (expression 14).

After calculating the weights using different methods, it can be seen that the largest deviation in the weights of the criteria is in the results obtained by the entropy method (Table 10). Criteria that have low weights with other methods have high weights with the entropy method. The reason for this should be sought in the calculation of weights, because the entropy method utilizes neither the criteria nor the alternatives for calculating the weights of the criteria. The calculation of weights was performed using the values of the elements of the decision matrix, and the values of the columns were added, and based on that, the weights were obtained. If the values of the alternatives are higher for a certain criterion, the greater the weight of that criterion is, and vice versa. Other methods take into account the diversity of values within the criteria.

Table 6. Calculation of criterion weights using the entropy method.

	C1	C2	C3	C4	C5	C6	C7
C1	−0.1559	0.0000	−0.0854	−0.1495	−0.1051	−0.0778	0.0000
C2	−0.0694	−0.0222	−0.3185	−0.1713	−0.1051	0.0000	−0.3185
C3	−0.2506	−0.0638	−0.1896	−0.2634	0.0000	−0.0427	−0.2559
C4	0.0000	−0.1343	0.0000	0.0000	0.0000	−0.1175	−0.2955
C5	−0.0749	−0.1283	−0.5733	−0.4864	−0.0192	−0.0385	−0.3222
C6	−0.1619	−0.0158	−0.3310	−0.2828	0.0000	−0.0067	−0.1935
C1	−0.1334	0.0000	−0.0784	−0.1288	−0.0946	−0.0719	0.0000
C2	−0.0647	−0.0217	−0.2316	−0.1443	−0.0946	0.0000	−0.2316
C3	−0.1950	−0.0598	−0.1569	−0.2024	0.0000	−0.0409	−0.1981
C4	0.0000	−0.1174	0.0000	0.0000	0.0000	−0.1044	−0.2199
C5	−0.0695	−0.1129	−0.3232	−0.2991	−0.0188	−0.0371	−0.2335
C6	−0.1377	−0.0156	−0.2377	−0.2131	0.0000	−0.0067	−0.1595
sum	−0.6003	−0.3274	−1.0277	−0.9877	−0.2080	−0.2610	−1.0426
e_j	0.3351	0.1827	0.5736	0.5512	0.1161	0.1457	0.5819
d_j	0.6649	0.8173	0.4264	0.4488	0.8839	0.8543	0.4181
w_j	0.1473	0.1811	0.0945	0.0994	0.1958	0.1893	0.0926

Table 7. Calculation of criteria weights using the standard deviation method.

	C1	C2	C3	C4	C5	C6	C7
σ	0.0782	0.0547	0.1563	0.1286	0.0496	0.0419	0.1052
w_j	0.1273	0.0889	0.2544	0.2093	0.0807	0.0682	0.1712

Table 8. Calculation of the weight of the criteria using the MEREC method.

	C1	C2	C3	C4	C5	C6	C7	sum
A1	0.1559	0.0000	0.0854	0.1495	0.1051	0.0778	0.0000	0.0788
A2	0.0694	0.0222	0.3185	0.1713	0.1051	0.0000	0.3185	0.1341
A3	0.2506	0.0638	0.1896	0.2634	0.0000	0.0427	0.2559	0.1417
A4	0.0000	0.1343	0.0000	0.0000	0.0000	0.1175	0.2955	0.0753
A5	0.0749	0.1283	0.5733	0.4864	0.0192	0.0385	0.3222	0.2108
A6	0.1619	0.0158	0.3310	0.2828	0.0000	0.0067	0.1935	0.1325
C1	0.0580	0.0788	0.0674	0.0588	0.0648	0.0684	0.0788	
C2	0.1254	0.1314	0.0935	0.1125	0.1209	0.1341	0.0935	
C3	0.1102	0.1338	0.1180	0.1085	0.1417	0.1364	0.1095	S'_{ij}
C4	0.0753	0.0573	0.0753	0.0753	0.0753	0.0596	0.0353	
C5	0.2021	0.1959	0.1422	0.1529	0.2086	0.2064	0.1728	
C6	0.1120	0.1305	0.0902	0.0965	0.1325	0.1317	0.1080	
C1	0.0208	0.0000	0.0113	0.0199	0.0140	0.0103	0.0000	
C2	0.0087	0.0028	0.0406	0.0216	0.0132	0.0000	0.0406	
C3	0.0316	0.0079	0.0238	0.0332	0.0000	0.0053	0.0322	$\left\|S'_{ij} - S_i\right\|$
C4	0.0000	0.0180	0.0000	0.0000	0.0000	0.0157	0.0399	
C5	0.0087	0.0150	0.0686	0.0579	0.0022	0.0045	0.0380	
C6	0.0205	0.0020	0.0423	0.0360	0.0000	0.0008	0.0245	
E_j	0.0902	0.0456	0.1867	0.1687	0.0294	0.0366	0.1753	
w_j	0.1232	0.0623	0.2548	0.2303	0.0401	0.0500	0.2393	

Table 9. Calculation of the weight of the criteria using the method of modified standard deviation.

	C1	C2	C3	C4	C5	C6	C7
σ	0.0782	0.0547	0.1563	0.1268	0.0496	0.0419	0.1052
$\sum_{j}^{m} x_{ij}$	5.3454	5.6545	4.7545	4.8406	5.7815	5.7281	4.7942
σ′	0.0146	0.0097	0.0329	0.0266	0.0086	0.0073	0.0219
w_j	0.1203	0.0795	0.2705	0.2185	0.0706	0.0602	0.1805

Table 10. Criteria weight values.

	C1	C2	C3	C4	C5	C6	C7
CRITIC	0.1461	0.0879	0.2269	0.1836	0.1008	0.0869	0.1677
Entropy	0.1473	0.1811	0.0945	0.0994	0.1958	0.1893	0.0926
SD	0.1273	0.0889	0.2544	0.2093	0.0807	0.0682	0.1712
MEREC	0.1232	0.0623	0.2548	0.2303	0.0401	0.0500	0.2393
MSD	0.1203	0.0795	0.2705	0.2185	0.0706	0.0602	0.1805

Based on the application of these methods, the weights of the criteria used to rank the alternatives were obtained. A complete calculation of the ranking order of the alternatives was performed for the weights obtained by the CRITIC method, while for the other weights only the value of the CRADIS method and the ranking order of the alternatives were given.

The first step in the CRADIS method was the normalization of the decision matrix (Table 3), then these normalized values were multiplied by the weight of the criteria and an aggravated-normalized-decision matrix was obtained (Table 11). To calculate the ideal and anti-ideal solutions, it was necessary to calculate the minimum and maximum values of the aggravated-normalized-decision matrix.

Table 11. Aggravated-normalized-decision matrix.

	C1	C2	C3	C4	C5	C6	C7	
A1	0.1030	0.0795	0.2483	0.1882	0.0635	0.0557	0.1805	
A2	0.1123	0.0778	0.1967	0.1841	0.0635	0.0602	0.1313	
A3	0.0937	0.0746	0.2237	0.1679	0.0706	0.0576	0.1397	
A4	0.1203	0.0695	0.2705	0.2185	0.0706	0.0535	0.1343	
A5	0.1116	0.0699	0.1524	0.1344	0.0692	0.0579	0.1308	
A6	0.1023	0.0783	0.1942	0.1647	0.0706	0.0598	0.1487	
max	0.1203	0.0795	0.2705	0.2185	0.0706	0.0602	0.1805	0.2705
min	0.0937	0.0695	0.1524	0.1344	0.0635	0.0535	0.1308	0.0535

The next step was to calculate the deviation between the ideal and anti-ideal solutions. For each element of the aggravated matrix, the deviation from the ideal and anti-ideal solutions was calculated. This was followed by the calculation of the assessment of the deviation of the individual alternatives from the ideal and anti-ideal solutions, which was accomplished by calculating the sum of the deviations for the individual alternatives. Before ranking the alternatives, it was necessary to calculate the utility function for the optimal alternative. The alternatives should be as close as possible to the optimal alternative, to be better ranked. The last step was to calculate the ranking of the alternatives, which was accomplished by calculating the average deviation of the alternatives from the degree of utility (Table 12).

Table 12. Results of the CRADIS method.

	s_i^+	K_i^+	s_i^-	K_i^-	Q_i	Rank
A1	0.9746	0.9165	0.5442	0.8699	0.8932	2
A2	1.0674	0.8368	0.4514	0.7215	0.7791	4
A3	1.0654	0.8384	0.4534	0.7248	0.7816	3
A4	0.9560	0.9343	0.5628	0.8996	0.9169	1
A5	1.1670	0.7654	0.3518	0.5624	0.6639	6
A6	1.0746	0.8312	0.4441	0.7100	0.7706	5
A_0	0.8932		0.6256			

Based on the results obtained using the weights calculated by the CRITIC method, the best alternative is A4, and the second-ranked alternative is A1, while the worst-ranked alternative is A5.

To determine the impact of the criteria weights obtained by the different methods, the alternatives were ranked with the weights obtained using these methods. The procedure is the same, the only difference is in the weights of the criteria. The obtained results (Table 13) show that for all obtained criteria weights, the best alternative is A1, while the worst-ranked alternatives are A2 and A5 for the weights obtained by the entropy method.

Table 13. Results when applying different criteria weights.

	CRITIC		Entropy		SD		MEREC		MSD	
	Q_i	Rank	Q_i	Rank	Q_i	Rank	Q_i	Rank	Q_i	Rank
A1	0.8844	2	0.8475	2	0.8819	2	0.9025	2	0.8932	2
A2	0.7775	3	0.8008	4	0.7661	3	0.7885	3	0.7791	4
A3	0.7762	4	0.7829	5	0.7658	4	0.7857	4	0.7816	3
A4	0.9206	1	0.8602	1	0.9087	1	0.9141	1	0.9169	1
A5	0.6609	6	0.7241	6	0.6455	6	0.6802	6	0.6639	6
A6	0.7661	5	0.8133	3	0.7571	5	0.7786	5	0.7706	5

To perform the analysis of the obtained results, a correlation analysis was used for the values of the CRADIS method using individual weights and the value of the ranking rank (Table 14). This analysis shows that there is the greatest correlation between SD and

MSD methods (r = 0.9999) for ranking the alternatives. The reason for this is that the MSD method is only a slightly modified SD method. However, what is characteristic of the MSD method is that the values of the CRADIS method are more related to the values obtained by the CRITIC methods yet are less related to the values obtained by the MEREC method compared to the SD method. This analysis shows that the value of the CRADIS method of the obtained weight of the entropy method is the least related to the other methods. The same is the case in the ranking of the alternatives, where the alternative has the same ranking in terms of the weight that was obtained by the CRITIC, SD, and MEREC methods. The ranking order of the obtained weight of the MDS method deviates from these (r = 0.9429), due to the different ranks of the alternatives, A2 and A3. The reason for this should be sought in the values of these alternatives, which are approximate, and there is very little difference between them. It is noticeable that the results obtained using the calculated weights of the entropy method deviated the most from the other results. However, in addition to the different ranking order, A4 is the best.

Table 14. Value of correlation analysis.

	Value of Methods				
	CRITIC	Entropy	SD	MEREC	MSD
CRITIC	1.0000	0.9600	0.9993	0.9966	0.9990
Entropy		1.0000	0.9632	0.9599	0.9609
SD			1.0000	0.9987	0.9999
MEREC				1.0000	0.9989
MSD					1.0000
	Value of Rank				
	CRITIC	Entropy	SD	MEREC	MSD
CRITIC	1.0000	0.8286	1.0000	1.0000	0.9429
Entropy		1.0000	0.8286	0.8286	0.7714
SD			1.0000	1.0000	0.9429
MEREC				1.0000	0.9429
MSD					1.0000

5. Conclusions

This study was conducted to select the tractor that best meets the set criteria. Six types of tractors were used in this study, which were evaluated using seven criteria. The evaluation of the tractors was accomplished using MCDA methods. Objective methods for determining the weights of the criteria and the CRADIS method for tractor ranking were used.

The obtained results showed that the best tractor is A4 because this tractor best meets the objectives of this study. The worst-ranked tractor of the used tractors is A5. These results were confirmed using the different weights obtained by the different methods. The results showed that the weights obtained by the entropy method were the highest.

The new modified standard deviation method does not deviate significantly from other methods and can be used in further research. In addition, this method is one of the simpler methods for determining the weight coefficients. In the standard deviation method, only the standard deviation is calculated, while in the modified standard deviation method, the sum of the criteria elements is used.

In addition to the presented modified standard deviation method and the standard deviation method, the new modified standard deviation method does not differ significantly from other methods and is the easiest to calculate, thus, it is recommended for use in similar studies. It should be emphasized that the entropy method differs from most of the other methods, and it is not recommended to be used primarily in similar decision-making problems, only as a method for weight comparison.

The limitations of this study are that more tractors with similar characteristics were not taken into account. However, the tractors that were evaluated can be found on the BiH market, thus, only these tractors were used. Furthermore, another limitation can be considered, which is that more criteria have not been used (according to which the alternatives could be evaluated). However, taking more criteria would only complicate the decision-making process. The aim here was to show the influence of objective methods for determining the weights of criteria on the ranking of the alternatives, thus, the focus of the study was on that aim.

In future research, this new method needs to be compared with other methods for objectively calculating the weights of criteria that were not used in this research. It is necessary to use this method in other examples where decision-making is represented, because it has shown great flexibility and simplicity in work. Furthermore, in future research, it is necessary to use a combination of subjective and objective methods, for the example of multi-criteria decision-making in agriculture.

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