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Selection of a vehicle for Brazilian Navy using the multi-criteria method to support decision-making TOPSIS-M

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Abstract

The vehicle selection problem for the armed forces is a very important problem. In order to make the best decision regarding the selection of the best alternative among the existing options is necessary to use support decision-making tools. The aim of this paper is to demonstrate the functionality of the TOPSIS-M method in a vehicle selection problem for the Brazilian Navy (Marinha do Brasil). Among the vehicles selected as alternatives, the best option, according to the method used, was the vehicle IVECO HI-WAY800S56TZ. According to this work, the method used for vehicle selection proved to be efficient in assisting decision-making for the acquisition of new vehicles for the Brazilian Navy.

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Keywords: Multi-criteria method; TOPSIS-M; Decision Making.

1. Introduction

Decision theory is a strong way to provide support to the decision-maker in choosing the best quality solution, as well as the preference of the results in terms of cost and benefit [1]. The complexity of choosing an alternative is increased in equivalence to the difficulty of the problem, considering the related risks and uncertainties [2]. Distinct steps are involved in decision-making, such as the identification of adversity and criteria, the selection of the method, analysis, evaluation of alternatives, and the verification of the efficiency of the desired solution [3].

Drumond [4] states that the managerial level is evidenced in the decision-making environment and that the proposed solutions can be accepted or not by the decision-makers through the optimization system [5]. The complexity in decision-making is due to risks associated with uncertainties. With this, decision-making proposes different approaches and techniques to be able to make the decision more coherent and assertive [6].

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The transport of heavy loads is of fundamental importance for the armed forces since it is necessary for a vehicle that has the necessary security to ensure the preservation of the cargo [7, 8].

TOPSIS is a widespread decision-making technique used quite frequently to evaluate the performance of alternatives through similarity with the ideal solution [9, 10]. In this scenario, the only way to support the problematic resolution of this complexity in a reasonable time is using multi-criteria models, enabling the implementation of mathematical models for decision-making in complex problems that have been used in several recent problems, such as [11–20].

The work in question will use a variation of the TOPSIS method, the TOPSIS-M, proposed by Costa et al. [21]. The variation is intended to give more importance to satisfying the requests of the decision-maker. At the end of the work, the results of the TOPSIS and TOPSIS-M methods will be presented to verify if there is convergence in the results from the use of the variation of the technique [22].

This study aims to demonstrate the functionality of the TOPSIS-M method with the proposed example, which aims to support decision-makers in obtaining vehicles for the Brazilian Navy. The present work seeks to assist in decision-making for the acquisition of new vehicles for the Brazilian Navy, specifically mechanical horses for the transport of heavy loads.

2. Methodology

The TOPSIS algorithm (English: Technique for Order Preference by Similarity to Ideal Solution) is a well-known technique used to evaluate the performance of alternatives through their similarity with the ideal solution [23]. Being its central and most basic idea very direct [24]. TOPSIS has four advantages [25]:

- A logical sound that represents the foundation of human choice;
- A scalar value that represents the best and worst alternatives simultaneously;
- Simplified computing process that can be easily programmed into a spreadsheet;
- Performance measures of all criteria alternatives can be visualized in a polyhedron, at least for any two dimensions[26].

As this technique proposes, among the alternatives, the best is the one that is closer to the positive ideal solution and further from the non-ideal or negative ideal [27]. Thus, the ideal solution is constituted by taking the best values obtained by the alternatives during the analysis concerning each decision criterion, while the negative ideal solution is formed similarly, taking the worst values [28].

According to Almeida [29], the ideal positive solution is the one that enhances the profitable criteria and decreases the cost criteria, that is, it is the one constituted of the best achievable values of the benefit criteria. On the other hand, the negative ideal solution maximizes the cost criteria and decreases the benefit criteria, that is, it is summarized in the worst achievable values of the cost criteria [30].

For the application of the method, six steps are used: the construction of the decision matrix, the calculation of the normalized matrix, the calculation of the matrix with the weights, the identification of the PIS and the NIS, the calculation of the distances between the positive ideal situation and each alternative (D+) and negative ideal situation and each alternative (D-) and the calculation of the similarity to the positive ideal position [31].

According to Almeida [30], there are four normalization procedures presented in equations (1) to (4), usually used in the calculation of the normalized matrix. They are:

1st Procedure acts through the maximum value of the scores;

$$P_{ij} = \frac{x_{ij}}{max x_{ij}} \quad (1)$$

2nd Procedure acts through the difference of scores and the maximum and minimum value of the scores;

$$P_{ij} = \frac{x_{ij} - min\, x_{ij}}{max\, x_{ij} - min\, x_{ij}} \quad (2)$$

3rd Procedure operates as a result of the sum of the scores;

$$P_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}}} \tag{3}$$

4th Procedure proceeds from the square root of the sum of squares of the scores;

$$P_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{4}$$

The applicability of this method is detailed in the subsequent steps that are detailed below:

Step 1- Construction of the decision matrix: It occurs with the construction of a decision matrix m x n, being "m" the alternatives and "n" the evaluation criteria [32];

$$M = \begin{array}{c} \\ A_1 \\ \vdots \\ A_i \\ \vdots \\ A_1 \end{array} \begin{array}{c} \begin{array}{cccccc} C_1 & C_2 & \cdots & C_j & \cdots & C_m \end{array} \\ \begin{bmatrix} m_{11} & m_{12} & \cdots & m_{1j} & \cdots & m_{1m} \\ \vdots & \vdots & & \vdots & & \vdots \\ m_{i1} & m_{i2} & \cdots & m_{ij} & & m_{im} \\ \vdots & \vdots & & \vdots & & \vdots \\ m_{n1} & m_{n2} & \cdots & m_{nj} & \cdots & m_{nm} \end{bmatrix} \end{array} \tag{5}$$

Step 2- Calculation of the normalized matrix: According to Drumond [33], the normalization of the decision matrix is carried out in several ways. Usually, the TOPSIS method uses linear normalization, according to the formula (6) below:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{6}$$

The goal of normalization is to make values of the same dimension dimensionless.

Step 3- Calculation of the matrix with the weights: The multiplication of the normalized matrix by the weights of the corresponding criteria is performed. The determination of weights is obtained through the formula (7) by understanding the value of the decision-maker or a group of decision-makers.[34] use the acquisition of weights in the application of linear weights;

$$r_{ij} = w_j n_{ij} \tag{7}$$

Let be the weight of the attribute or criterion (8) and:

$$\sum_{j=1}^{n} w_j = 1 \tag{8}$$

Step 4- Identification of the ideal solution (PIS) and the non-ideal solution (NIS): At this stage, the best levels are designated, which characterize the ideal solution (S^+) (9) for each of the criteria considered. It operates in the same way concerning the worst levels, which correspond to the non-ideal solution (S^-) (10). The equations outlined below are used:

$$S^+ = \{(maxv_{ij} \mid j \in J), (minv_{ij} \mid j \ \in J')\} \tag{9}$$

$$S^- = \{(minv_{ij} \mid j \in J), (maxv_{ij} \mid j \ \in J')\} \tag{10}$$

Step 5- Calculation of the distances between the positive ideal situation and each alternative (D+) and the negative ideal situation and each alternative (D-): The separation measure for each alternative is determined by the ideal and non-ideal solution. Due to the formulas (11) and (12) below, the Euclidean distances between each alternative and its positive ideal solution (and its non-ideal solution () are calculated.

$$D_i^+ = \sqrt{\sum_{j=1}^{n}\left[v_{ij}(x) - v_j^+(x)\right]^2} \tag{11}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left[v_{ij}(x) - v_j^-(x)\right]^2} \tag{12}$$

Step 6- Calculation of the similarity to the positive ideal position: In summary, the coefficient C or response of the approximation of the ideal situation (C) is reached, and the definition of the ordering of the alternatives, using equation (13):

$$c_j = \frac{D_i^-}{D_i^+ + D_i^-} \tag{13}$$

The classification of the alternatives occurs in a decreasing manner by the values of the approximation coefficient established in the interval [0; 1]. The most satisfying options are those that have the overall performance closest to 1.

2.1 TOPSIS-M

The extent of the method in question attaches greater importance to fulfilling user requests [35]. In this extension, the values chosen for each criterion are indicated by the user. The TOPSIS method is performed in a normal way, but the value of the alternative criterion is used at a base value of 70%, proposing to achieve or not the value requested by the user. Consequently, the values that exceed the requested value represent less in the total ranking of the alternatives[36].

TOPSIS-M calculates a matching value for each alternative using the equation (14):

$$M_i = \sum_{j=1}^{n}\left(\frac{0.7}{n}\right) x m_{ij} \tag{14}$$

Where is 1 if the criterion value responds to the requested value and 0 does not respond. Based on such values, the calculation of the relative proximity of the ideal solution undergoes the change presented in the formula (15):

$$c_i 7 = 0.3\left(\frac{s_{i-}}{s_i + s_{i-}}\right) + M_i \tag{15}$$

Therefore, 70% of the final value will be composed of the matching values, and the remaining 30% will be composed of the normal values of TOPSIS.

3. Case Study

Three vehicle models were chosen through expert research for the execution of the method, being them the Mercedes-Benz Actros 2553 6x2 LS, the Iveco HI-WAY 800S56TZ 6x4, and the Volkswagen Meteor 29,520. All three models can be used for the transport of heavy loads, such as inputs, armored vehicles, etc.

An expert was consulted to determine the criteria to be compared in the method, which are the price, power, torque, displacement, maximum speed, fuel tank capacity, total combined gross weight (PBTC), and maximum traction capacity (CMT).

The data on the vehicles were obtained from the technical data sheets available on the websites of the automakers and are presented in Table 1 with the decision matrix together with the value requested by the user, the respective weights of the criteria, and the definition of the criterion is monotonic of cost or profit [37].

Table 1: Decision Matrix with the requested values and the weights of the criteria.

	Amount Requested							
	700000	530	2500	12500	120	1000	25	70
	Min	Max	Max	Max	Max	Max	Max	Max
Weights	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1
	Price (R$)	Power (hp)	Torque (Nm)	Cylinder capacity (cc)	Max Speed (km/h)	Fuel Tank Cap. (L)	PBTC (t)	CMT (t)
Mercedes-Benz Actros 2553	803.500.00	530	2600	12800	120	1015	28.1	60
IVECO HI-WAY 800S56TZ	597.557.00	560	2500	12880	124	900	29.8	80
VW Meteor 29.520	660.400.00	520	2500	12419	120	940	23	80

Table 2 below presents the values already normalized according to formula (5) and weighted with formula (6), together with the respective ideal and non-ideal solutions.

Table 2: Normalized and weighted Decision Matrix.

	Price (R$)	Power (hp)	Torque (Nm)	Cylinder capacity (cc)	Max Speed (km/h)	Fuel Tank Cap. (L)	PBTC (t)	CMT (t)
Mercedes-Benz Actros 2553	0.133	0.056	0.059	0.058	0.0570	0.061	0.119	0.046
IVECO HI-WAY 800S56TZ	0.099	0.060	0.056	0.058	0.0589	0.054	0.126	0.062
VW Meteor 29.520	0.110	0.055	0.056	0.056	0.0570	0.056	0.097	0.062
Ideal Solution	0.099	0.060	0.059	0.058	0.0589	0.061	0.126	0.062
Non-Ideal Solution	0.133	0.055	0.056	0.056	0.0570	0.054	0.097	0.046

Table 3 below shows the values found of the positive and negative distances, calculated with the formulas (7) and (8), followed by the relative proximity obtained with the formula (9).

Table 3: Positive and negative distances and the respective values of the relative proximities.

Alternatives	S_i^+	S_i^-	C
Mercedes-Benz Actros 2553	0.038595	0.023008	0.37349
IVECO HI-WAY 800S56TZ	0.007331	0.04783	0.8671
VW Meteor 29,520	0.031628	0.028619	0.47503

Table 4 shows the ranking of the trucks according to the relative proximity found, with the best vehicle presenting the greatest relative proximity and so on.

Table 4: Relative proximity values considering the *matching* value.

Alternatives	C*	Ranking
Mercedes-Benz Actros 2553	0.37349	2nd place
IVECO HI-WAY 800S56TZ	0.8671	1st place
VW Meteor 29,520	0.47503	3rd place

Table 5 presents the result of the comparison of the TOPSIS method and the TOPSIS-M method.

Table 5: Ranking of the TOPSIS method and the TOPSIS-M method.

Alternatives	TOPSIS		TOPSIS-M	
	C	Ranking	C*	Ranking
Mercedes-Benz Actros 2553	0.37349	3rd Place	0.637048	2nd place
IVECO HI-WAY 800S56TZ	0.8671	1st Place	0.872629	1st place
VW Meteor 29,520	0.47503	2nd Place	0.492509	3rd place

According to Table 5, the result of the TOPSIS method would be the IVECO HI-WAY 800S56TZ in the first place, the VW Meteor 29.520 in second place, and the Mercedes-Benz Actros 2553 in third place, while the result of the TOPSIS-M method would have in third place the VW Meteor 29.520, in second place the Mercedes-Benz Actros 2553 and first place, would keep the IVECO HI-WAY 800S56TZ. The product of the TOPSIS-M method reaffirmed the result of the first place obtained previously by the TOPSIS method.

It can be observed that the TOPSIS-M method presented greater relative proximity to the alternatives, with more grouped results, changing the second place but keeping the first place being the vehicle IVECO HI-WAY 800S56TZ.

4. Conclusion

It is concluded that the present study was effective in aiding decision-making for the purchase of new vehicles for the Brazilian Navy, as it resulted in the TOPSIS-M method being assertive and organized in its alternatives. At a certain point, when presenting the results of the TOPSIS method compared to that of TOPSIS-M, consistency in the use of the TOPSIS-M method is tested.

It is believed that from the above and exemplified, the method when comparing the evaluation criteria: price, power, torque, displacement, maximum speed, fuel tank capacity, total combined gross weight (PBTC), and maximum traction capacity (CMT), determines a favorable and valid result.

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