ISSN 1980-5411 (On-line version)
Production, 31, e20210011, 2021
DOI: 10.1590/0103-6513.20210011

Thematic Section - Advances in Analytic Hierarchy Process

Multi-criteria analysis applied to aircraft selection by Brazilian Navy

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Abstract

Paper aims: This paper aims to select the best helicopter to be acquired by the Brazilian Navy (BN), enabling greater logistical and combat capacity in marine operations. For this purpose, we applied the AHP-TOPSIS-2N, a hybrid multicriteria method composed by the Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and two normalization procedures (2N).

Originality: In this paper, a real military case study is conducted to support the decision-making process in BN, contributing to the better performance of the Brazilian Armed Forces. The application of the methodology resulted in two lists of ordering and prioritization of helicopters, providing transparency and simplicity to the decision-making process.

Research method: We analyzed six aircraft models, considering attack helicopters used by the Armed Forces of developed countries, in the light of their operational and tactical criteria. The selected helicopter would be employed in the fire support and reconnaissance, required by the Brazilian Marine Corps Amphibious Operations.

Main findings: After the application of the method, the AH-64E APACHE was chosen as the most suitable helicopter to be acquired by the Brazilian Navy.

Implications for theory and practice: This study brings valuable contribution to academia and society, since it represents the application of a Multi-criteria Decision Analysis (MCDA) method in the state of the art to contribute to the solution of a real problem of the BN. The methodology presented in this paper can notably be used to solve real problems of the most varied types – tactical, operational and strategic – thus being a very useful method for decision-making.

Keywords

AHP-TOPSIS-2N. Multicriteria analysis. Decision-making process. Brazilian navy;. Aircraft.

How to cite this article: Maêda, S. M. N., Costa, I. P. A., Castro Junior, M. A. P., Fávero, L. P., Costa, A. P. A., Corriça, J. V. P., Gomes, C. F. S., Santos, M. (2021). Multi-criteria analysis applied to aircraft selection by Brazilian Navy. *Production*, *31*, e20210011. https://doi.org/10.1590/0103-6513.20210011

Received: Mar. 3, 2021; Accepted: June 30, 2021.

1. Introduction

Approved by Decree No. 6,703 of December 18, 2008, the National Defense Strategy (NDS), which was updated in 2012, aims to ensure the security of Brazil both in peacetime and in crises, establishing guidelines for the proper preparation and training of the Armed Forces (AF) (Brasil, 2008).

According to Costa et al. (2020), even in times of peace, Brazilian AF must be equipped and trained to guarantee its sovereignty and strategic interests, supporting its foreign policy and positions in international forums. In 2019, a document entitled Naval Policy (NP) was promulgated by the Brazilian Navy. The NP guides, in accordance with the NDS, the strategic planning of the Brazilian Navy (BN), whose compliance imposes the availability of marine forces able to act in line with the political-strategic and economic magnitude of Brazil in the international scenario (Marinha do Brasil, 2019).

According to the objectives and guidelines established in the National Defense Policy (NDP) and the NDS, high-level documents that condition the preparation and use of the AF, the BN is responsible for the employment of the Naval Power (Marinha do Brasil, 2019).

The Naval Power comprises the ability to use the sea and inland waters, at the disposal of a force with expeditionary property, in a permanent condition of prompt employment, ensuring the projection of power over the land. This force is characterized by an amphibian conjugate, composed of a Naval Force, an Operative Group of embarked Marines and the aeronaval awarded, in a position to fulfill missions related to the basic tasks of the Naval Power (Marinha do Brasil, 2017).

Among the necessary means for carrying out aeronaval missions, we highlight the use of attack helicopters, suitable for reconnaissance and air fire support activities, due to their large amount of armaments and ability to engage air and ground targets. This function is currently performed by helicopters of smaller size and with low firepower, which could be replaced by more modern means, specific for this purpose, thus ensuring better performance in the execution of such activities (Costa et al., 2020).

Therefore, it will be of great value to the Brazilian Marine Corps to acquire new helicopters with the capabilities to provide the necessary fire support to Amphibious Operations, capable of carrying out advanced aerial reconnaissance and offensive air support, especially in the fight against armored vehicles and enemy troops on the ground.

In this sense, the NDS provides, under the leadership of the Ministry of Defense, the acquisition of attack helicopters, acquired with commercial, industrial and technological compensation (Brasil, 2012). Considering this need, due to the quantity, diversity and complexity of existing models today, the task of selecting a more appropriate aircraft to BN's needs, aiming to provide support to the operations performed by the Marines, is not simple at all (Moreira et al., 2021).

In this context, the expression Multiple Criteria Decision Analysis (MCDA) is used as an umbrella term to describe a set of formal approaches which seek to take explicit account of multiple criteria in helping stakeholders and groups explore decisions that matter (Belton & Stewart, 2002).

Despite the diversity of MCDA approaches, methods and techniques, the basic ingredients of MCDA are a finite or infinite set of actions (alternatives, solutions, courses of action, etc.), at least two criteria, and at least one Decision Maker (DM). Given these basic elements, MCDA is an activity which helps in making decisions, mainly in terms of choosing, ranking or sorting the actions (Greco et al., 2016).

According to Hamurcu & Eren (2020), the academic literature contains recent examples of MCDA methods' application in the military field, as presented in (Costa et al., 2021; Almeida et al., 2021; Santos et al., 2021).

The existing helicopter models used in the main AF of the world can be analyzed in the light of various criteria, whether qualitative or quantitative, such as speed, armaments, autonomy, load capacity, and some more complex, like maneuverability, systems and aggregate technologies (Moreira et al., 2021).

We identified that, when analyzing the aircrafts in the light of the established criteria, there was a strong compensatory characteristic in the analysis of the data. Therefore, among the various MCDA methods available, in this paper used the AHP-TOPSIS-2N method, because it is a compensatory model, with the advantage of generating two orders with the same data, providing a sensitivity analysis of the result. According to Oliveira et al. (2021), the method combines a concept of hierarchy with weights associated with the concept of checking how much an alternative is closer and farther from an ideal alternative.

Other reasons to apply AHP and TOPSIS include the fact that the analyzed problem is expected to have more criteria than alternatives (Lombardi Netto et al., 2021) and the criteria are numerically well defined (Oliveira et al., 2021).

This paper aims to support the decision-making process in a real military problem, for choosing the best attack helicopter to be acquired by the BN. This choice fills a gap in the Force's tactical and operational capabilities, as BN does not have helicopters suitable for attack missions. Therefore, the relevance of this paper consists in contributing to increase the country's defense and sovereignty capacity. We analyzed six models of helicopters used by Armed Forces from developed countries (with proven effectiveness in combat). For this, we applied the AHP-TOPSIS-2N method to evaluate the aircrafts in the light of seven criteria. The alternatives and criteria were analyzed considering the opinion of three aviators of the BN, with more than fifteen years of military career and extensive experience and acknowledgement of operations with attack helicopters.

This article is structured into six sections. This introduction describes the objectives of the research. Section 2 presents the literature review. Section 3 provides the methodology, while section 4 presents the case study. Section 5 presents the results and the sensitivity analysis. Finally, Section 6 concludes the research.

2. Literature review

The decision-making process generally involves a choice between several alternatives. The efficiency in decision-making consists of choosing the alternative that, as far as possible, offers the best results. The feasible alternatives of meeting the objective, and selected for evaluation, are compared according to criteria and under the influence of attributes (Cardoso et al., 2009). In this context, the MCDA methods are very useful to support the decision-making process, because they consider value judgments and not only technical issues, to evaluate alternatives in order to solve real problems, presenting a highly multidisciplinary (Santos et al., 2015). Therefore, this methods ensure greater accuracy and reliability in the decision-making process (De Barros et al., 2015; Oliveira et al., 2019).

Among the MCDA methods, the Analytic Hierarchy Process (AHP) is considered one of the most well-known and widely disseminated decision-making tools, having the greatest number of applications reported in the literature (Vaidya & Kumar, 2006).

Regarding the applications of the AHP method in military problems, it stands out: scoring and classification of military network sensors (Bisdikian et al. 2013); ordering and evaluating weapon systems Zhang et al. (2005); selecting the best location for the installation of a military naval base Suharyo et al. (2017); selecting the best advanced military training aircraft for the Spanish Air Force (Sánchez-Lozano & Rodríguez, 2020); positioning of the surveillance system within a national security project in Turkey Çarman & Tuncer Şakar (2019); evaluating airworthiness criteria for military aircraft Şenol (2020); selecting ground vehicles for the provision of military units intended for multinational operations Starčević et al. (2019); and selecting graduate students from the Defense Science Institute of the Turkish Military Academy Altunok et al. (2010).

Regarding the application of TOPSIS, we highlight the studies carried out by Zhang et al. (2012) to obtain the classification of the threat of military targets and Adetunji et al. (2018) for risk management for obsolescence in the U.S. Armed Forces.

According to Pereira et al. (2015), the adoption of a combination of methodologies enables the identification of the variables and a rational analysis of the information. The academic literature contains many applications combining the AHP and TOPSIS methods. Wang et al. (2008) combined the techniques AHP fuzzy and TOPSIS to evaluate the effectiveness of air combat of military aircraft. In the study, the Fuzzy AHP method was used to determine the relative weights of multiple evaluation criteria and to synthesize the classifications of candidate aircraft. TOPSIS was employed to get a crisp overall performance value for each alternative to make a final decision.

Sánchez-Lozano et al. (2015) selected military training aircraft for the Spanish Air Force, through hybrid modeling composed of AHP, TOPSIS and Fuzzy Logic. Sánchez-Lozano et al. (2020) conducted a study to prioritize obsolete military coastal batteries, to transform them into places of tourist interest in Spain, through the application of the GIS, AHP and TOPSIS methods.

Kiracı & Akan (2020) used the Interval Type-2 Fuzzy AHP (IT2FAHP) and Interval Type-2 Fuzzy (IT2FTOPSIS) methods to choose the most suitable aircraft to be acquired. Hamurcu & Eren (2020) applied an integrated methodology based on AHP and TOPSIS methods to evaluate Unmanned Aerial Vehicles (UAV) alternatives in the selection process. First, the AHP was used to determine the weights of the criteria, while the TOPSIS was applied to classify vehicle alternatives in the decision problem.

Moreira et al. (2021) evaluated attack helicopters through an integration of ordinal evaluation into the cardinal procedure from the PROMETHEE method, enabling to perform qualitative and quantitative data.

Based on the applications of MCDA for aircraft selection, as presented in Moreira et al. (2021) and Sánchez-Lozano et al. (2015), we can define, together with the experts, the important criteria to evaluate attack helicopters:

- C1. Maximum Speed (km/h): Speed developed with the maximum engine regime, essential for reconnaissance, interception and fire support to troops in critical situations;
- C2. Payload (kg): Measure obtained by reducing the aircraft's weight from the maximum take-off weight. Such a measure is relevant because it will directly influence the range, quantity of fuel and ammunition/armament that the helicopter will be able to carry.
- C3. Main Cannon (mm): This weapon is used in close combat, which consists of aerial actions by fixed-wing and rotating aircraft against hostile targets that are close to friendly forces. Such a component can be used against

ground troops, vehicles, buildings, or even hostile aircraft. This study compared the calibers of this weapon, where the greater the caliber, the greater the power of destruction of the projectiles.

C4. The number of Main Cannon Ammunition (units): Due to the importance of effective and durable fire support, the amount of main cannon ammunition that an aircraft can transport is relevant.

C5. Number of Rockets (units): This type of weaponry is used primarily against ground targets and can be guided. Due to the great need for fire support in aeronaval missions, the larger the number of rockets shipped, the better this support will be provided.

C6. Amount of Air-To-Earth Missiles (units): They have great power of destruction and are usually laser-guided. Also, the missiles can be used against armored vehicles, buildings and other types of targets. However, due to their larger size, they are transported in smaller numbers than rockets in combat aircraft.

C7. Reach (Km): Whereas a Theatre of Operations may be large, the greater the scope of an aircraft, the greater the capacity to operate in different missions.

The literature review revealed several applications of the AHP and TOPSIS methods to support the decision-making process in military problems. The modeling presented in this paper includes, in addition to the hybrid modeling composed of the two methods, two normalizations of the results. This feature allows a sensitivity analysis, which provides security, transparency and simplicity to the decision-making process (Gomes et al., 1997).

3. Methodology

According to the classification proposed by Creswell & Creswell (2017), this research can be characterized as a mixed qualitative-quantitative research, combining, combining case study and mathematical modeling (Bertrand & Fransoo, 2002). The Brazilian Navy is the research object, which is previously introduced in Sections 1 and 2, along with the justification for its choice.

Details of the object are presented in Section 4, as alternatives in the proposed MCDA model, which are attack helicopters to be acquired by the BN. Mathematical modeling of MCDA runs through four main steps, summarized as follows (Figure 1): structuring (identification of decision objective, criteria, and alternatives); measurement (designation of weights for the criteria and scores for the alternatives); synthesis of the results obtained by consensus of the three experts; and Sensitivity Analysis, varying the criteria weights according to the individual evaluations of each expert, based on the procedure presented by Oliveira et al. (2021).

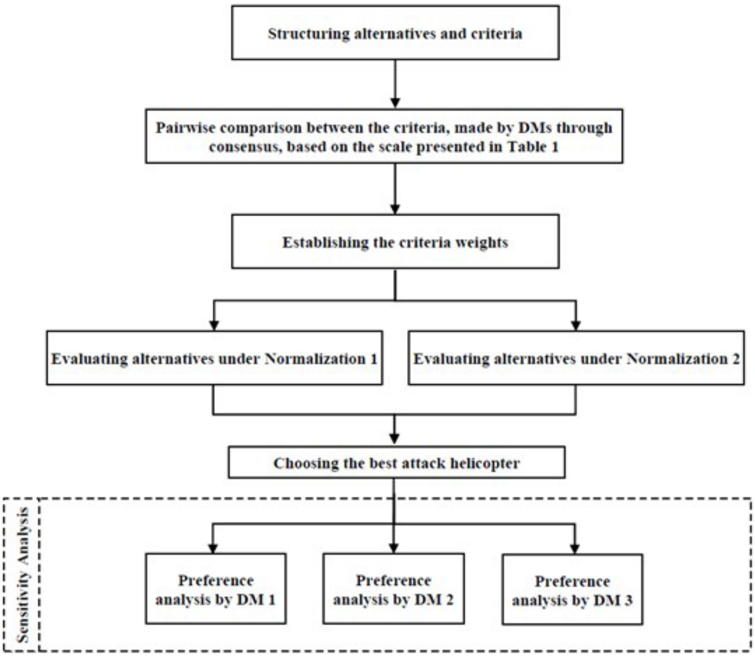

Figure 1. Steps of the methodology.

3.1 The AHP-TOPSIS-2N method

The AHP-TOPSIS-2N hybrid method, initially proposed by De Souza et al. (2018), consists of two multicriteria decision-making techniques that are usually adopted in complex scenarios, characterized by multiple and conflicting objectives: the AHP and TOPSIS methods. To understand the method, it is necessary a prior understanding of the two techniques that compose it.

The AHP, proposed by Saaty (1980), is a multicriteria methodology that aims to select or choose the best alternatives in a process that considers different evaluation criteria. According to Costa et al. (2016), the AHP method allows the comparison of both quantitative and qualitative criteria.

According to Santos et al. (2021), it is a compensatory and hierarchic method, indicated mainly for problems with a medium number of alternatives and criteria, considering the discrimination of results and cognitive effort in the pairwise comparisons. Also, the concepts of hierarchy and compensatory decision rules are in accord with military culture, which facilitates the analysis by the experts (Santos et al., 2021).

The AHP is a comprehensive tool developed for constructing decision models and establishing decision priorities concerning a finite set of alternatives (Dong & Cooper, 2016). Comparisons are made using a scale of absolute judgments (Table 1), as well as intermediate values between the two judgments that represent the relative measure of one alternative over another with respect to a given criterion (Dožić & Kalić, 2014).

Table 1. Saaty fundamental scale.

Degree of importance	Definition	Explanation
1	Equal importance	The two activities contribute equally to the goal
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	One activity is strongly favored over another; element is very dominant as shown in practice
9	Extremely important	The evidence is in favor of one activity over another, to the greatest extent possible
2, 4, 6, 8	Intermediate values between two judgements	They are used to express preferences that are between the values of the above scale

Source: Adapted from Saaty (1980).

One of the advantages of the AHP method is the possibility to identify the inconsistencies of DM. A Consistency Ratio (CR) less than 0.10 is considered acceptable. CR greater than 0.10 generates the need for the decision-taker to make assessments or judgments again (García et al., 2014).

The TOPSIS method, presented by Hwang & Yoon (1981), orders the alternatives according to the proximity of the Positive Ideal Solution (PIS). The best alternative is the one that is closer to the PIS and the farthest from the Negative Ideal Solution (NIS).

For the application of the AHP-TOPSIS-2N method, De Souza et al. (2018) defined nine steps, described below:

Step 1. Establishment of the Decision Matrix, expressing the score of each alternative in each criterion analyzed;

Step 2. Preparation of the Weighting Matrix, using the Saaty fundamental scale, by evaluating alongside each criterion;

Step 3. By applying the AHP method, the weights of each criterion are obtained. The importance of calculating CR should be less than 0.1 to ensure the consistency of the analysis;

Step 4. Obtaining the standard decision matrix: The four standardization procedures most used in the literature are described by De Souza et al. (2018) as explained below:

Standardization procedure N1: by using the maximum value of the scores (Equation 1).

$$p_{ij} = \frac{x_{ij}}{\max x_{ij}} \quad \text{where i} = 1,\ m\ldots,; and,\ j = 1,\ldots,\ n \tag{1}$$

Standardization procedure N2: by using the ratio between the difference of the scores and the minimum value of the scores, and the difference between the maximum value and the minimum value of the scores (2).

$$p_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \text{, where } i = 1,\ldots, m \text{ ;and, } j = 1,\ldots, n \quad (2)$$

Standardization procedure N3: by using the sum of the scores (Equation 3).

$$p_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \text{, where } i = 1,\ldots, m \text{ ;and, } j = 1,\ldots, n \text{ .} \quad (3)$$

Normalization procedure N4: by using the square root of the sum of the squares of the scores (4).

$$p_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=0}^{m} x_{ij}^{2}}} \text{, where } i = 1,\ldots, m \text{ ;and, } j = 1,\ldots, n \text{ .} \quad (4)$$

It is worth noting that in this study, all four normalization procedures mentioned were tested, but only two of them had consistent results in terms of the order of alternatives. As such, the AHP-TOPSIS-2N method considers the normalization procedures N2 (Equation 2) and N4 (Equation 4). Normalizations N1 and N3 gave many discrepant results, corroborating with the results obtained by De Souza et al. (2018) and Oliveira et al. (2021), who identified the most appropriate normalizations to the hybrid methodology.

Step 5. Construction of the Weighted Standard Decision Matrix: weighted matrices are obtained by multiplying the weights calculated in step III by the normalized matrices:

Step 6. Obtaining the PIS (A^+) and NIS (A^-) (5);

$$A^{+} = \left\{p_1^{+}, p_2^{+}, \ldots, p_m^{+}\right\}; \quad A^{-} = \left\{p_1^{-}, p_2^{-}, \ldots, p_m^{-}\right\} \quad (5)$$

Step 7. Calculation of the Euclidean distances of each of the alternatives to PIS (D_i^+) and NIS (D_i^-) (6, 7):

$$D_i^{+} = \sqrt{\sum_{j=1}^{n} \left(p_{ij} - p_j^{+}\right)^2} \quad (6)$$

$$D_i^{-} = \sqrt{\sum_{j=1}^{n} \left(p_{ij} - p_j^{-}\right)^2} \quad (7)$$

Step 8. Calculation of proximity to the ideal alternative (8):

$$C_i^{+} = \frac{D_i^{-}}{D_i^{+} - D_i^{-}} \quad (8)$$

Step 9. Ordering preferences.

According to De Souza et al. (2018), this methodology has the following advantages:

- Possibility of identifying the normalization of AHP-TOPSIS;
- The possibility of two coherent normalizations allows a sensitivity analysis of the Result;
- The AHP-TOPSIS combination makes the process axiomatically correct; and
- The concept of hierarchy with weights associated with the concept of checking how much an alternative is closer and farther from an ideal alternative.

4. Case study

For the feasibility of the analysis, we consulted three BN aviators (DMs), with extensive experience and acknowledgment in aeronaval operations with attack helicopters. We developed video-conference interviews with the specialists, who evaluated six helicopter models used in AF of developed countries, with proven combat effectiveness. Data were collected in March 2021. To bring greater reliability to the evaluation, the only information available in the manuals of helicopter manufacturers was analyzed.

4.1. Presentation of helicopter alternatives

A1 - AH-1Z VIPER - BELL

The Bell AH-1Z VIPER was built to meet the needs of the United States Marine Corps (USMC), being used by this force since 2009 (Bell, 2020). Due to the USMC operating in various environments, mainly at sea, this aircraft has been specially developed to withstand the maritime weather (Bell, 2020).

BELL has equipper flexibility according to each specific mission, with the carrying capacity of 28 APKWS guided precision rockets; 16 HellFire Air-To-Earth missiles; 76 Mk-66 rockets 70 mm and a 20 mm M-197 main gun with a capacity of 650 rounds. Also, it has two Air-To-Air missiles attached to the side, allowing the use of space destined to the war system for ground attack armament.

A2 - ATAK T129 - Turkish Aerospace

Manufactured by Turkish Aerospace, the T129 ATAK was developed to meet the needs of the Turkish Armed Forces. It is a twin-engine attack helicopter, optimized for carrying out attack missions, armed reconnaissance and precision attacks, under various weather conditions and during day and night periods.

According to the manufacturer's information (Turkish Aerospace, 2020) (Turkish Aerospace, 2020), the aircraft is equipped with a 20mm machine gun with a capacity of 500 ammunition and 76 integrated rockets (70mm); Also, based on the characteristics of the missions can be integrated the aircraft 16 Air-To-Earth Missiles Cirit 70mm guided by laser, 8 umtas long-range anti-tank missiles and 8 Air-To-Air Missiles Stinger (Turkish Aerospace, 2020).

A3 - Mi-35M - *Russian Helicopters*

The Mi-35M helicopter, currently manufactured by Russian Helicopters and originally developed by Mil Moscow Helicopter Plant, is an aircraft with relatively larger weight and dimensions than a common attack helicopter. In addition, it has a transport cabin, with a loading capacity of up to 08 equipped paratroopers, internal loads of up to 1,500 kg and even medical staff to perform aeromedical evacuations.

According to Russian Helicopters (2020), the Mi-35Ma has a 23 mm dual machine gun with a capacity of up to 470 rounds; up to 80 rockets (80 mm); up to 20 122 mm S-13 rockets; and up to 08 9M114/9M120.

A4 - Ka-52K Katran - *Russian Helicopters*

The Ka-52 Aliggator, produced by Russian Helicopters, is a state-of-the-art reconnaissance and combat aircraft, aiming to destroy armored and unarmored ground targets, troops and enemy helicopters on both the front line and tactical reserves. This helicopter also has a small cargo compartment, is capable of operating during night and day time and under severe weather conditions (Russian Helicopters, 2020).

This model is equipped with a 30 mm machine gun with a capacity for up to 460 rounds of ammunition, in addition to the other missiles and rockets operating on the Mi-35M.

A5 - TIGER HAD - *Airbus*

The HAD Tiger is Airbus Helicopters' multifunctional attack helicopter, which aims to conduct armed reconnaissance, air-to-ground escorts, air-to-air combat, air-to-air support and attacks on armored targets on land, day/night and in harsh conditions. They have a special version for operation in marine environments from ships (Helibras, 2020).

The aircraft is equipped with a 30mm main gun with a capacity for 450 rounds, 68 68mm rockets or 52 70mm rockets and up to 16 Hellfire and infrared ER Spike fiber-optic air-to-ground missiles. An advantage of this aircraft is the possibility of having its maintenance carried out in Brazil by Helibras, a subsidiary company of Airbus Helicopters.

A6 - AH-64E APACHE – *Boeing*

One of the world's best-known attack helicopters, the AH-64E APACHE, produced by Boeing, is widely employed by several AF, such as the United States Army, Egypt, Greece, India, Indonesia, Israel, Japan, Korea, Kuwait, Netherlands, Qatar, Saudi Arabia, Singapore, United Arab Emirates and the United Kingdom (Boeing, 2020).

This model is equipped with a 30 mm main cannon with a capacity of up to 1,200 rounds of ammunition, with the highest capacity among attack helicopters. It can also operate up to 76 70 mm rockets and 16 Hellfire (Boeing, 2020). Besides, this helicopter model is already operated in the Atlantic Helicopter Carrier while it belonged to the Royal Navy, thus proving its ability to operate in marine environments.

4.2 Hierarchical structure of the problem

After defining the main objective of the study, alternatives and criteria, we obtained the hierarchical structure of the analyzed problem (Figure 2).

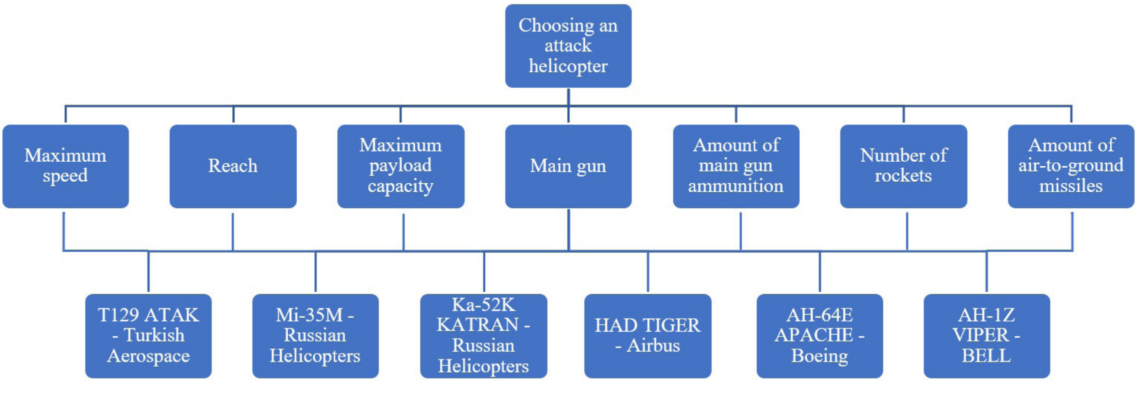

Figure 2. Hierarchical structure of the problem.

We emphasize that the experts stated that there is no need to establish subcriteria, which is why all criteria present the same hierarchical level in the analysis.

5. Application of the AHP-TOPSIS-2N method

In this section, all the steps described for the application of the AHP-TOPSIS-2N method are performed.

5.1. Decision matrix (Step 1)

In order to obtain the weights of the criteria (by applying the AHP method), interviews were conducted through video conference with each of the three DMs involved, which individually evaluated the importance of the criteria. After that, a new interview was conducted with the three specialists together to establish the degrees by consensus. The application of this approach aimed to identify the existence of possible abrupt variations in evaluations by the DMs.

Table 2 illustrates the compiled data of the alternatives in each criterion considered in the study,

Table 3 shows the pairwise comparison between the criteria, based on the Saaty fundamental scale (Table 1). The degrees assigned in the peer evaluation were obtained by consensus of the three DMs.

5.2. Obtaining the weights of the criteria (Steps 2 and 3)

Table 4 presents the weights obtained through pairwise comparison of each DM individually and by consensus. To obtain the weights for each DM, the same procedure of the pairwise comparison (Table 3) was performed.

Table 2. Decision matrix.

	C1 (Km/h)	C2 (Kg)	C3 (mm)	C4 (Un)	C5 (Un)	C6 (Un)	C7 (Km)
A1	281	2,710	20	500	76	16	537
A2	310	2,400	23	470	80	20	460
A3	370	2,615	20	650	76	16	485
A4	300	3,300	30	460	80	12	460
A5	271	2,030	30	450	68	8	740
A6	279	2,835	30	1,200	76	16	476

Table 3. Pairwise comparisons between the criteria.

	C1	C2	C3	C4	C5	C6	C7
C1	1	2	1/2	1/3	1/2	1/3	1/2
C2	1/2	1	1/3	1/3	1/4	1/3	1
C3	2	3	1	1	1/2	1/2	3
C4	3	3	1	1	2	1	1
C5	3	4	2	1/2	1	1/2	4
C6	3	3	2	1	2	1	3
C7	2	1	1/3	1	1/4	1/3	1

Table 4. Weights obtained after analysis along with the criteria.

Criteria		Weight			
		DM 1	DM 2	DM 3	Consensus
C1	Max Speed (Km/h)	0.1	0.09	0.08	0.08
C2	Payload (Kg)	0.06	0.07	0.05	0.06
C3	Main Cannon (mm)	0.18	0.16	0.16	0.16
C4	Amount of Main Cannon Ammunition	0.18	0.2	0.19	0.19
C5	Number of Rockets	0.19	0.21	0.18	0.19
C6	Number of Air-To-Earth Missiles	0.22	0.18	0.24	0.23
C7	Range (Km)	0.07	0.09	0.1	0.09
	λmax = 7.4634;	Consistency Ratio (CR) = 0.058		Consistency Index (IC) = 0.077	

Analyzing the results obtained by consensus, we verified much greater weight assigned to the criterion related to firepower, such as the number of Air-To-Earth missiles, rockets and parameters related to the main cannon.

After obtaining the weights, we consulted the DMs, who validated the results. According to the experts, the values are coherent because the greater the firepower, the greater the combat capacity of military helicopters. Besides, there were no major discrepancies between individual evaluations.

In order to obtain greater reliability and precision in the evaluation process, the values of the weights of the criteria obtained by consensus were used in the next steps. Considering the Theorem 1 (Saaty, 1980) given that the number of alternatives is greater than four, the CR must be less than or equal to 0.1. In this case, CR = 0.0585, lower than the acceptable. Therefore, the values of the weights obtained after the analysis of the DMs can be considered consistent.

5.3. Obtaining standard decision matrices (Steps 4 and 5)

Using the Normalization N2 (2), we obtained Table 5.

Table 5. Normalized matrix – Normalization N2.

	C1	C2	C3	C4	C5	C6	C7
A1	0.3788	0.4133	0.3151	0.3016	0.4077	0.4313	0.4093
A2	0.4168	0.366	0.3624	0.2835	0.4291	0.5392	0.3506
A3	0.4974	0.3988	0.3151	0.3921	0.4077	0.4313	0.3697
A4	0.4033	0.5033	0.4726	0.2775	0.4291	0.3235	0.3506
A5	0.3643	0.3096	0.4726	0.2715	0.3648	0.2157	0.5641
A6	0.3751	0.4324	0.4726	0.724	0.4077	0.4313	0.3628

Table 6 shows the weighted normalized values, after multiplication by the weights of the criteria previously obtained. Normalized values range from 0 < V < 1.

Table 6. Weighted matrix – Normalization N2.

	C1	C2	C3	C4	C5	C6	C7
A1	0.0286	0.0242	0.0493	0.0576	0.0766	0.1064	0.0342
A2	0.0316	0.0214	0.0568	0.0541	0.0806	0.133	0.0293
A3	0.0377	0.0234	0.0493	0.0749	0.0766	0.1064	0.0309
A4	0.0305	0.0295	0.074	0.053	0.0806	0.0798	0.0293
A5	0.0276	0.0181	0.074	0.0519	0.0685	0.0532	0.0472
A6	0.0284	0.0253	0.074	0.1383	0.0766	0.1064	0.0303

By applying the Normalization N4 (4), we obtained table 7. It is noteworthy that, in this normalization, unlike the first, the values range from $0 \leq V \leq 1$. The alternatives T129 ATAK and BELL AH-12 VIPER obtained a value of 0 in the light of the Main Cannon criterion, because they present the worst performance in this criterion.

Table 7. Normalized matrix – Normalization N4.

	C1	C2	C3	C4	C5	C6	C7
A1	0.101	0.5354	0	0.0667	0.6667	0.6667	0.275
A2	0.3939	0.2913	0.3	0.0267	1	1	0
A3	1	0.4606	0	0.2667	0.6667	0.6667	0.0893
A4	0.2929	1	1	0.0133	1	0.3333	0
A5	0	0	1	0	0	0	1
A6	0.008	0.6339	1	1	0.6667	0.6667	0.0571

On the other hand, the MI-35M alternative stands out, which obtained a score of 1 in the criteria Number of rockets and air-to-ground missiles, because it presents the best performance in the two parameters between the evaluated alternatives.

Table 8 presents the weighted normalized values, after multiplication of the values in Table 7 by the weights of the criteria previously obtained by consensus.

Table 8. Weighted normalized matrix – Normalization N4.

	C1	C2	C3	C4	C5	C6	C7
A1	0.0076	0.0314	0	0.0127	0.1252	0.1645	0.023
A2	0.0298	0.0171	0.047	0.0051	0.1878	0.2467	0
A3	0.0757	0.027	0	0.0509	0.1252	0.1645	0.0075
A4	0.0222	0.0586	0.1566	0.0025	0.1878	0.0822	0
A5	0	0	0.1566	0	0	0	0.0836
A6	0.0061	0.0371	0.1566	0.191	0.1252	0.1645	0.0048

5.4. Obtaining the orders for the two normalizations (Steps 6 to 9)

Table 9 presents the ordering of the alternatives after the two normalization processes. To obtain D^+, D^- and score (C^+) values, we applied Equation 6, 7 and 8 respectively.

After applying the AHP-TOPSIS-2N method, we verified three clusters:

(1) Cluster 1: Includes alternatives with scores between 0.4791 and 0.7587 in N2 and between 0.5684 and 0.6852 in N4 procedure: A6 - AH-64E APACHE and A3 - MI-35M helicopters. We emphasize that APACHE presented the best ordering in both scenarios, and can be considered the most suitable helicopter to be purchased by the Brazilian Navy;

Table 9. Ordering of alternatives in both normalization processes.

Normalization N2					Normalization N4				
Alternative	D^+	D^-	Score	Rank	Alternative	D^+	D^-	Score	Rank
A6	0.0329	0.1048	0.7587	1	A6	0.0329	0.1048	0.6852	1
A3	0.076	0.0573	0.4791	2	A3	0.2542	0.2213	0.5684	2
A1	0.0909	0.0522	0.4421	3	A4	0.2673	0.2696	0.4965	3
A2	0.0896	0.0755	0.3778	4	A1	0.28	0.2057	0.4785	4
A4	0.102	0.0398	0.2809	5	A2	0.1487	0.3254	0.4333	5
A5	0.1173	0.0322	0.2037	6	A5	0.3699	0.1868	0.3204	6

(2) Cluster 2 – It includes alternatives with scores between 0.2809 and 0.4421 in the normalization N2 and between 0.4333 and 0.4965 in the N4: A1 - BELL AH-1Z VIPER, A2 - T129 ATAK and A4 - KA-52K Katran helicopters;

(3) Cluster 3 – The A5 - Tiger HAD helicopter, which achieved the worst performance in both normalization processes.

5.5. Sensitivity Analysis

In the sensitivity analysis, we applied the AHP-TOPSIS 2N method, considering the three DM individually to verify if the best alternative is stable in a long term. Table 10 illustrates the orderings obtained taking into account the weights of the criteria for each DM individually, according to Table 3.

Table 10. Sensitivity analysis.

DM 1				DM 2				DM 3			
Normalization N2		Normalization N4		Normalization N2		Normalization N4		Normalization N2		Normalization N4	
A6	0.7394	A6	0.693	A6	0.802	A6	0.8147	A6	0.7753	A6	0.798
A2	0.4746	A4	0.5477	A2	0.482	A4	0.6601	A2	0.5474	A4	0.6555
A3	0.4166	A1	0.5323	A4	0.4489	A1	0.5728	A4	0.4479	A2	0.5286
A1	0.3646	A2	0.5203	A1	0.3863	A2	0.4631	A3	0.4279	A1	0.5247
A4	0.3504	A4	0.5011	A3	0.3831	A3	0.3003	A1	0.3971	A3	0.3475
A5	0.3066	A5	0.4502	A5	0.3421	A5	0.276	A5	0.363	A5	0.3362

Analyzing the results obtained, the A6 - APACHE helicopter presented the best classifications in both normalization processes, in the assessment of all DMs. It is noteworthy that this helicopter was the only one that did not present a score equal to zero in any of the criteria analyzed in the normalization N4. It illustrates well the regularity of this alternative in all criteria.

On the other hand, the A5 - TIGER, alternative with the worst ordering in all the evaluations, presented a minimum score in five of the seven criteria evaluated. This poor performance justifies its ranking in both scenarios.

Besides, we can note that the alternatives A1 - BELL AH-1Z, A2 - T129 ATAK, A3 - MI-35M and A4 - KA-52K presented significant changes in both normalizations. The Ka-52K Katran helicopter presented the highest number of maximum scores, with the best performance in three of the seven criteria, but in the other ones, it did not perform well. This alternative was the one that presented the largest difference in the classifications in both scenarios (5th place in the normalization N2 and 3rd in the N4 procedure). Probably this disparity resulted from the excellent performance in some criteria and the poor performance in the others.

After the sensitivity analysis, we verified that the alternative MI-35M, initially a component of cluster 1, was relocated to cluster 2. This change corroborates with the choice of APACHE as the most suitable helicopter to be purchased by BN.

6. Conclusion

This research planned to solve a real military problem, within a case study. The results obtained in this paper can support the High Naval Ministry in the decision-making process of a complex problem involving sovereignty and defense of the country.

The proposed analysis indicated the AH-64E APACHE as the most appropriate helicopter to be acquired by BN, which achieved the best result in both scenarios. This proposed algorithm presented robust and reliable findings, with a sensitivity analysis of the results in various scenarios.

The possibility of evaluating two forms of normalization, combined with sensitivity analysis, allow us to observe the behavior of alternatives in both scenarios, providing additional information to the DM.

The AHP-TOPSIS-2N method proved to be efficient for the proposed analysis, enabling the achievement of the criteria weights, taking into account the opinion of multiple DMs, in addition to the concept of checking how much an alternative is closer and farther from an ideal alternative. The method can be used to solve the most diverse real problems of daily life, being an especially useful method to support high-level decision making in operational, tactical and strategic problems.

Another important criterion to make up the model would be the cost of acquiring each helicopter. However, because they are military aircrafts, it was not possible to obtain direct data or reliable estimates of such values, since these parameters are confidential.

Finally, we suggest that this model of ordering and distribution in clusters of alternatives using the AHP-TOPSIS-2N can be expanded in other applications, serving as a basis for decision making in the most diverse areas of the public and private sectors.

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