MULTICRITERIA DECISION-MAKING IN THE SELECTION OF WARSHIPS: A NEW APPROACH TO THE AHP METHOD

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ABSTRACT

The budgetary constraints for the Brazilian Navy (BN) have caused several negative effects, resulting in an undersized fleet, decreasing the capacity to protect marine oil and natural gas fields, combat marine pollution from ships, and monitor other illegal activities at sea and inland waters. This paper aims to choose a medium-sized warship to be built by the BN, through the application of the Analytic Hierarchy Process (AHP) method. After a bibliometric study on Multiple-Criteria Decision-Making (MCDM), the AHP was chosen as the most appropriate method for the proposed case study. We analyzed three ship projects with regard to nine operational and economic criteria, taking into account the evaluations of BN officers with recognized experience and knowledge in military operations. We also introduced a sensitivity analysis based on the relationship between standard deviation and mean scores in order to verify and increase the reliability of the ranking. As a result, the methodology suggested that the best option is to build a brand-new ship with more significant modernizations to provide for the operational needs of the BN.

Keywords: Analytic Hierarchy Process; multi-criteria; warship

1. Introduction

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

Even in peace times, Brazil must have a modern AF, equipped and trained to guarantee its sovereignty and strategic interests, supporting its foreign policy and positions in international forums. The Brazilian Navy (BN) must have 18 escort ships (including frigates, corvettes and destroyers) to allow the formation of two task groups including one escort close to the main body, and another for the surface action groups' remote defense. Escort ships must have anti-submarine, anti-surface and anti-aircraft (missile availability) defense capabilities. They must be capable of transporting, supplying, operating and maintaining helicopters being prepared to attack surface and submarine targets, as well as carrying out enlightenment operations.

However, since the last decade of the twentieth century, the budget provided by the Federal Government has fallen short of the amount needed to meet the BN needs, making it impossible to allocate the necessary and sufficient funds for operation, maintenance and re-equipment. According to Tenório et al. (2020), due to successive budget restrictions, the BN currently has an undersized fleet of only eleven escort ships, many of which are nearing the end of their useful lives, resulting in non-compliance with the minimum requirements of the naval force, decreasing the operational capacity and the accumulation of demands of various orders.

The budgetary context has caused several negative effects including maintenance reduction, spare parts stocks reduction, and training and labor loss. The natural consequence is the degradation of the naval assets' preparation. Thus, the BN's capacity to protect marine oil and natural gas fields, combat marine pollution by ships, support the prevention of irregular fishing and the monitoring of other illegal activities at sea and inland waters is reduced. Thus, according to Tenório et al. (2020), it is expected that the BN will make "opportunity purchases" or build new vessels, in order to maintain the readiness of the fleet, as well as the training of its entire operating structure.

This paper aims to choose a new vessel to be built for the BN by applying the Analytic Hierarchy Process (AHP) technique. The AHP was chosen because it is a compensatory and hierarchic method that is indicated mainly for problems with a medium number of alternatives and criteria, considering the discrimination of results and cognitive effort in the pairwise comparisons. The concepts of hierarchy and compensatory decision rules are in accord with military culture, which facilitates the analysis by the experts.

The paper is structured into six sections. The introduction describes the objectives of the research. Section 2 presents the literature review. Section 3 provides the theoretical background, while section 4 presents the methodology applied in the study. Section 5 describes the problem, analyzes the results and introduces the sensitivity analysis through the mean scores and standard deviation. Section 6 concludes the research.

2. Literature review

The academic literature contains many examples of the application of multi-criteria decision-making (MCDM) methods in the military field (Hamurcu & Eren, 2020). Bisdikian et al. (2013) proposed a framework for scoring and classification of network sensors, which are relevant for military applications, based on their attributes, using the AHP method. Gigović et al. (2016) presented a new MCDM technique, MAIRCA (Multi-tax Ideal-Real Comparative Analysis), based on the combined use of Geographic Information Systems (GIS) and multicriteria techniques. The authors applied the model DEMATEL-ANP for the selection of suitable locations for the installation of ammunition deposits. Sánchez-Lozano et al. (2015) conducted a study for the selection of military training aircraft for the Spanish Air Force through hybrid modeling composed of AHP, TOPSIS and Fuzzy Logic. According to the authors, this hybrid modeling, MCDM and Fuzzy Logic, can be applied efficiently to solve decision problems with criteria of a different nature. Di Bona et al. (2016) proposed an approach based on the Integrated Factors Method (IFM), whose values are adjusted using the AHP method, depending on the importance of each factor and each unit of the system. The reasons that led to the development of IFM-based AHP are the result of careful analysis of current military and commercial approaches. According to the authors, the result is a dynamic model, which combines the advantages of the allocation method and the multicriteria decision-making technique.

Zhang et al. (2005) proposed a hybrid model composed of fuzzy trapezoidal AHP and fuzzy integral for ordering and evaluating weapon systems. The performance classifications of the criteria are described by linguistic terms expressed in diffuse trapezoidal numbers, while the weights of the criteria are obtained by fuzzy trapezoidal AHP. Suharyo et al. (2017) selected the best location for the installation of a military naval base by applying a model that compiles an application of the theory and method of the Coverage Technique integrated into the Fuzzy-AHP model. In order to meet the need for military and commercial approaches, Di Bona and Forcina (2017) implemented the reliability allocation method called Analytic Critical Flow Method (ACFM), a reliability allocation model for parallel configurations in series based on the failure analysis of each unit of the system. The new approach is based on the critical flow method, the results of which are combined with the AHP method. Wang et al. (2008) combined the fuzzy AHP and TOPSIS (technique for order performance by similarity to ideal solution) techniques 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 synthesize the classifications of candidate aircraft. TOPSIS was employed to get a crisp overall performance value for each alternative to make a final decision.

Altunok et al. (2010) compared the performance of the AHP, Weighted Product (WP) and TOPSIS methods to select graduate students from the Defense Science Institute of the Turkish Military Academy. According to the study, the AHP presented the best performance in the proposed analysis. Sánchez-Lozano and Rodríguez (2020) applied the Fuzzy Reference Ideal Method (FRIM) and the AHP method to select the best advanced military training aircraft for the Spanish Air Force. Çarman and Şakar (2019) conducted a study on the positioning of the surveillance system within a national security project in Turkey using the AHP method. 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 and Akan (2020) used the Interval Type-2 Fuzzy AHP (IT2FAHP) and Interval Type-2 Fuzzy (IT2FTOPSIS) methods to choose the most suitable aircraft. Şenol (2020) applied the AHP and ANP methods to evaluate airworthiness criteria for military aircraft. Hamurcu and Eren (2020) applied an integrated methodology based on AHP and TOPSIS methods to evaluate unmanned aerial vehicle (UAV) alternatives in the selection process. First, the AHP was used to determine the weights of the criteria, while TOPSIS was applied to classify vehicle alternatives in the decision problem. Starčević et al. (2019)

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selected ground vehicles for the provision of military units intended for multinational operations using the AHP and Data Envelopment Analysis (DEA).

Costa et al. (2021) proposed and applied the ELECTRE-MOR method to select the most suitable hospital aircraft for the Brazilian government to acquire in the fight against the COVID-19 pandemic. Zhang et al. (2012) applied the TOPSIS method in conjunction with Basic Probability Assignment (BPA) to obtain the classification of the threat of military targets. Lu and Wang (2011) provided an alternative, integral fuzzy non-additive approach to dealing with fuzzy MCDA problems, especially when there is dependence on the criteria considered. The main objective of the article was to discuss how the Optimal Compensation Transaction Policy of the Industrial Cooperation Program (ICP), a military trade agreement between Taiwan and the USA works, through the proposed Fuzzy model.

Gazibey et al. (2015) applied the DEMATEL method to understand the cause-and-effect relationships between the criteria for the selection of main battle tanks. The method was applied in the primary and secondary criteria separately. Adetunji et al. (2018) applied the TOPSIS method and Monte Carlo simulations for risk management for obsolescence in the U.S. Armed Forces. Genc (2015) conducted a study to support decision-making in the acquisition of military tanks through the application of the ELECTRE III and PROMETHEE II methods. Costa et al. (2020) applied the THOR 2 method to select the Brazilian navy's most suitable hospital care vessel (NAsH) to support the fight against the COVID-19 pandemic. Tenório et al. (2020) selected a ship for purchase by the BN, from eight ships used by navies around the world through the THOR method. In the study, the authors considered "opportunity purchases" of frigates, while in this paper we analyzed options of corvettes to be built by BN.

2.1 Bibliometric study on “Multicriteria” and “Warship”

The bibliometric research was carried out through the Scopus database using the CAPES (*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* – Brazil) portal during 2020. The terms used were selected by article title, abstract, keywords, document type article, conference paper and article in press, according to Table 1.

Table 1
Technical and operational characteristics

Headings	Results
"Multicriteria" AND "Warship"	37

Figure 1 shows the journal articles, conference papers and book chapters published by year. The articles began in 1997; however, a temporary gap is observed between 1998 and 2001, 2004, 2006 and 2017. The years with the highest numbers of published papers were 2010, 2011 and 2020.

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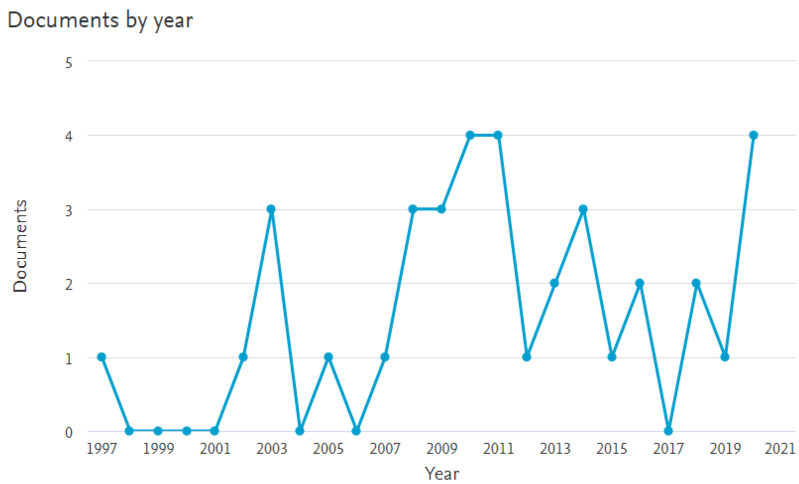

Figure 1 Articles per year
Source: Scopus, 2020

Table 2 shows the institutions that published 2 or more articles. The Harbin Engineering University ranks first with 5 papers. There are 2 institutions that published 3 articles each, 3 institutions with two articles each, and 54 institutions with only one article each, for a total of 60 articles.

Table 2
Most representative institutions

Institutions	Articles
Harbin Engineering University	5
Naval Group	3
Aix Marseille Université	3
University of Michigan, Ann Arbor	2
Syracuse University	2
Naval University of Engineering	2

Table 3 presents the distribution of articles by country or territory. The search found articles from 14 countries. China ranks first with 12 articles, followed by the United States with 8 articles. Europe is represented by 8 countries with 15 published articles (41% of the total). The American continent, with 2 countries, has 9 articles (24% of the total). Asia, with 3 countries, has 15 articles (41% of the total). Oceania, represented by Australia, has 1 article (3% of the total).

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Table 3
Number of articles by country

Countries	Articles
China	12
United States	8
France	3
Italy	3
United Kingdom	3
Netherlands	2
Taiwan	2
Australia	1
Brazil	1
Bulgaria	1
Russia	1
Spain	1
Sweden	1
Turkey	1

Table 4 shows that 3 authors stand out with 3 publications, while 5 authors have 2 articles. The others appear with only one publication each. There is no great preference in the area.

Table 4
Number of articles by author

Authors	Articles published
Li, X.	3
Siegel, P.	3
Toulgoat, I.	3
Chowdhury, S.	2
Lacroix, Y.	2
Li, P.	2
Messac, A.	2
Tong, W.	2

The *Journal of Quality and Reliability Engineering International* stands out with two publications. There are also 35 journals/conferences with 1 article each, for a total of 37 articles. In general, there is no preference for one journal over another, as shown in Table 5.

Table 5
Articles by journals

Journals	Articles
Quality And Reliability Engineering International	2
European Journal Of Operational Research	1
Global Journal Of Flexible Systems Management	1
International Journal Of Applied Decision Sciences	1
Journal Of Global Optimization	1
Journal Of Multi-Criteria Decision Analysis	1
Journal Of Ship Production	1
Marine Technology And SNAME News	1
Naval Research Logistics	1
Smart Innovation Systems And Technologies	1
Software Quality Journal	1
Structural And Multidisciplinary Optimization	1
Systems Engineering And Electronics	1

We emphasize that there have not been any articles on the subject published in the *International Journal on Analytic Hierarchy Process (IJAHP)*. Therefore, this paper represents an opportunity and a real contribution to academia and society, as it represents the employment of the most applied MCDM method to support the decision-making process in a relevant military problem.

Table 6 shows that the area of engineering stands out with 38.5% of the published articles, followed by computer science (23.1%), decision science (12.3%) and mathematics (12.3%). This analysis identifies research for solving warships' problems by methods application, not only for demonstrating mathematical schematization theories.

Table 6
Highlighted knowledge areas

Knowledge Area	Percentage
Engineering	38.5%
Computer Science	23.1%
Decision Science	12.3%
Mathematics	12.3%
Business, Management	4.6%
Materials Science	3.1%
Physics and Astronomics	3.1%
Economics	1.5%
Environmental Sciences	1.5%

Table 7 shows the applications according to the methods used in decision processes. The AHP is the most used method.

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Table 7
Methods and theories applied in the database

Method	Documents	Percentage	Accumulated sum
Analytic Hierarchy Process (AHP)	2.034	20.00%	20.00%
Fuzzy Logic	1.361	13.38%	33.38%
ELECTRE family	1.304	12.82%	46.20%
GIS	1.137	11.18%	57.37%
PROMETHEE family	1.090	10.72%	68.09%
Multi-objective Optimization	928	9.12%	77.21%
TOPSIS	862	8.47%	85.69%
Simple Multi-Attribute Rating Technique (SMART)	405	3.98%	89.67%
Rough set	311	3.06%	92.73%
Macbeth	182	1.79%	94.51%
Regime	153	1.50%	96.02%
Multi-Attribute Utility Theory (MAUT)	104	1.02%	97.04%
Borda	60	0.59%	97.63%
Condorcet	44	0.43%	98.06%
TODIM	43	0.42%	98.49%
Copeland	36	0.35%	98.84%
VIP	35	0.34%	99.18%
Analytic Network Processes (ANP)	32	0.31%	99.50%
ZAPROS	28	0.28%	99.77%
THOR	15	0.15%	99.92%
Tomaso	8	0.08%	100.00%
Total	10.172	100.00%	-

3. Analytic Hierarchy Process (AHP)

A problem can be solved in several ways, even if there is only one solution because it is possible to decide whether to carry out the proposed action or not. Decision-making may involve simple everyday situations or complex issues that require the use of quantitative and qualitative parameters. A good solution implies a multidimensional vision (Gomes et al., 2017; Moreira et al., 2021).

In this context, the MCDM methods are significant tools for public or private organization managers. MCDM consists of a set of techniques to assist a decision-maker (DM). Whether the decision maker is an individual, a group of people, or a technicians' committee or managers, MCDM aids in making decisions about a complex problem by evaluating and choosing alternatives to solve it using different criteria and points of view (Kadziński & Tervonen, 2013). The importance of the criteria is defined by the DM in an interactive process with other technical-political actors (Almeida-Dias et al., 2012).

In multiple criteria decisions, problem alternatives are compared pairwise, and the results express the preferences of the DM with the use of comparative notions. Ranking, choice

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or sorting decisions concerning a finite set of alternatives evaluated on a finite set of criteria are important kinds of problems in many real-world areas of decision-making.

The Multicriteria Decision Analysis (MCDA) methods have been widely used because they are scientific and subjective, and are able to aggregate all the characteristics that are considered important, including non-quantitative ones, with the enabling transparency purpose and process systematization related to decision-making problems (Pinto Junior & Soares de Mello, 2013).

Multicriteria methods are used for decision-making in several areas. For warships, creating a "hierarchy of alternatives" is no simple task. Natalizi (2015) considers this problem because there is a wide variety of technical solutions to carry out the typical features of military ships that cover both platform and combat systems.

MCDA is highly multidisciplinary and based on a set of matrices or models that will aid the decision process (individual or joint) by considering value judgments and not only technical issues to evaluate alternatives in order to solve real problems (Oliveira et al., 2021; Santos et al., 2015). These methodologies operate as a basis for discussion, especially in cases where there are conflicts among the DM, or when the problem perception by the various actors involved is not yet fully consolidated regarding the analysis.

The AHP, proposed by Saaty (1980), is a multicriteria methodology that aims to select or choose the best alternatives through 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. Vaidya and Kumar (2006) state that the method is considered one of the most well-known and widely disseminated decision-making tools, having the greatest number of applications reported in the literature. 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 (1, 3, 5, 7, 9), 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).

According to Ali et al. (2017), the main AHP steps include:

1. Statement of the goal, decision criteria and alternatives.

2. Development of a pairwise comparison matrix. When making criteria and alternative judgments, the expert compares pairwise the elements in the level of hierarchy to each of the elements in the superior level of the hierarchy (Saaty, 2008).

3. Development of a standardized/normalized matrix.

4. Development of a priority vector.

5. Computation of the consistency ratio. According to Serra Costa (2011), even when judgments are obtained from experts, some inconsistency may occur. One way of measuring the intensity or degree of inconsistency in a matrix of pairwise judgments is to

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evaluate how the highest eigenvalue of this matrix deviates from the order of the matrix (Saaty, 1980). The Consistency Index (C.I.) can be calculated as shown in (1).

$$\boldsymbol{C.I.} = \frac{|\lambda_{max} - n|}{n-1} \tag{1}$$

The gravity of the occurrence of inconsistency can be evaluated by considering its ratio to the average C.I. obtained from a large number of matrices of the same order generated by entering random judgments. This is the Consistency Ratio (C.R.), and it is used as a parameter to evaluate the inconsistency obtained from the judgment matrix order (Saaty, 1980) as shown in (2).

$$\mathbf{C.R.} = \frac{C.I.}{\mathbf{R.I.}} \tag{2}$$

where R.I.= the consistency index obtained from a large number of randomly generated reciprocal matrices with non-negative elements (Brunelli & Fedrizzi, 2011). According to Vargas (1982), if the calculated C.R. is lower than 0.1, the judgment matrix is considered consistent.

6. Development of a priority matrix.

After steps 2 through 5 have been performed for each criterion, the results of step 4 are summarized in a priority matrix by listing the decision alternatives vertically and the criteria horizontally. The column entries are the priority vectors for each criterion.

7. Development of a criteria pairwise development matrix.

8. Development of an overall priority vector.
Multiplying the criteria priority vector (from step 7) by the priority matrix (from step 6), which may then be used to determine the overall ranking of alternatives (step 8).

9. Choosing the alternative with the highest rank.

4. Methodology

For the development of modeling a problem, it should be noted that many possibilities lead to several applicable models according to Saaty and Vargas (2013). In this context, considering the hierarchical organizational culture of the BN, the compensatory nature of the problem and that the study presents well-defined characteristics of the alpha type problem, the AHP method was selected from among numerous other multiple-criteria models presented in the bibliometric study by Bhutia and Phipon (2012).

Based on Vogt (2013), this research followed four steps:

1. Interviews with 10 BN officers, with more than 20 years of experience, to obtain the alternatives of ships and criteria to be considered in the proposed analysis, for the choice of the most suitable vessel to be built by the BN, as well as to establish the weights between criteria;

2. Creating the decision matrix with all cells filled, where each cell corresponds to a ship alternative and its respective criterion;

3. Obtaining the ranking of ships as a result;

4. Sensitivity analysis with standard deviation and mean.

4.1 Selection of alternatives

In 1994, the BN began the construction of the Corvette Barroso at the Navy Arsenal of Rio de Janeiro (NARJ), a medium-sized vessel weighing 2.500 tons, which was finally launched in 2008, 14 years after the start of construction. This long timespan makes it a new ship, but not a modern ship.

Today, with the need to build new ships for the Brazilian fleet, the BN faces a new challenge, the choice of three project ships, which make up the set of alternatives to be analyzed in this research.

Model 1. Replicate the current Corvette Barroso;

Model 2. Build a slightly modernized ship (2.600 ton corvette); or

Model 3. Build a model with more significant modernizations (3.000 ton corvette).

4.2 Selection of criteria

Table 8 summarizes the main technical and operational characteristics of the 3 vessels.

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Table 8
Technical and operational characteristics

Characteristics	Barroso Configuration 1	CV -2600 Configuration 2	CV-3000 Configuration 3
L over-all(m)	103.4	115.00	118.00
L water-line(m)	96.30	105.00	108.00
B water-line(m)	11.40	13.00	13.50
B max(m)	Flare 7.5° :12.70	15.00	15.50
T(m)	4.00	4.00	4.30
D(m)	6.75	8.70	9.00
L/B(wl)	8.45	8.08	8.00
Lwl/D	14.27	12.07	12.00
T/D	0.59	0.49	0.48
Cb	0.53	0.48	0.48
Cp Long.	0.67	0.622	0.622
Lightweight	1710	1.815	2.030
Lightweight + Res.Proj(ton)	1.813	1.924	2.152
DWT(tons)	418	589	728
Maximum Displacement(tons)	2.231	2.513	2.880
Max. Displacement + SLA(tons)	2.388	2.690	3.085
B/D	1.69	1.494	1.500
S water plane(m2)	1.029	1.057	1.133
Master section(m2)	36.12	40.14	44.82
GM(m)	1.70	1.68	1.68
T roll(sec)	6.97	7.99	8.3
T pich(sec)	5.19	5.40	5.48
S wet area(m2)	1.215	1.348	1.463
Propulsion(mode)	Codog/Codad	Codad/Codoe	Codad/Codoe
PB max(MW)	Speed 15Kts: 1.994	22.03	23.79
Action radius(n.m.)/15	4.000	9.330	10.660
Action radius(n.m.)/18	Xxx	7.070	8.011
Fuel endurance(days)/15	11	26	30
Fuel endurance(days)/18	Xxx	16	19
Autonomy(days)	30	25	35
Crew(people)	150	100+20	100+20
Maximum speed(knot)	27	28	28
SLRVnax	1.415	1.405	1.386
Froude Number	0.452	0.449	0.442
Propeller(day/rmp/28kts)	Xxx	3.50 m/5 blades/285 RPM	3.50 m/ 5 blades/ 292 RPM
Electrical generation(KW)	2.600	3.240KW + 408 KW	3.240 KW + 408 KW
Primary cannon	BA e 114 mm MK	Oto Melara76mmSp	Oto Melara76mmSp
Secondary cannon	Bofors40mm MK-3	2x Bofors40mm MK-4	2x Bofors40mm MK-4

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Characteristics	Barroso Configuration 1	CV -2600 Configuration 2	CV-3000 Configuration 3
Machine guns			
ASuW Missiles	8x Exocet SSM40 BI 3	8x Exocet SSM40 BI 3	8x Exocet SSM40 BI 3
AAW Missiles			
ASW Torpedoes	2x III Raytheon MK-46	2x III Raytheon MK-46	2x III Raytheon MK-46
Helicopter	1x lynx / AW 159	1x lynx / AW 159	1x lynx / AW 159
Initial cost to obtain	US$ 290 million	US$ 310 million	US$ 310 million
Life cycle 35 years	US$ 592 million	US$ 633 million	US$ 633 million
First class Commissioning time	6 years	8 years	8 years

Source: Vogt, 2013

From the interviews with the experts (BN officers) and analysis of the operational and technical data of the vessels (Table 8), the following criteria were chosen for the choice of a vessel:

• Action radius (C_1): greatest distance (in nautical miles) the ship can travel from its base and return without refueling.

• Fuel endurance (C_2): time interval (in days) that a ship can navigate without refueling with speed at 15 knots.

• Autonomy (C_3): maximum interval of time (in days) that a ship can operate without any type of supplies (fuel, drinking water, foodstuff, etc.).

• Primary cannon (C_4): a weapon with a high rate of fire that functions to warn or neutralize possible threats, such as ships, aircraft or missiles. It is called "primary" when the ship has other alternative guns, usually of smaller caliber.

• Secondary cannon (C_5): an alternative cannon to the "primary cannon", usually of smaller caliber.

• AAW missiles (C_6): anti-aircraft warfare missiles.

• Initial Cost (C_7): cost of obtaining or building a ship.

• Life Cycle Cost (C_8): life cycle cost of a ship, includes the purchase (or construction), operation and modernization. The purchase price represents about 25%, the expenses for crew and operations account for 67%, and the possible modernization corresponds to 5% to 8%.

• Construction Time (C_9): criterion is self-explanatory, considering from the start of the project to the actual delivery of the ship to the operating sector.

5. Application of the AHP method

5.1 Decision matrix

Table 9 presents the decision matrix.

Table 9
Decision matrix

	Model 1	Model 2	Model 3
Action Radius (C1)	4000	9330	10660
Fuel Endurance (C2)	11	26	30
Autonomy (C3)	30	25	35
Primary Cannon (C4)	25	25	120
Secondary Cannon (C5)	1	2	2
AAW Missiles (C6)	0	1	1
Initial Cost (C7)	R$ 290,000,000	R$ 310,000,000	R$ 310,000,000
Life Cycle Cost (C8)	R$ 592,000,000	R$ 633,000,000	R$ 633,000,000
Construction Time (C9)	6 years	8 years	8 years

For the criteria to be compared in parity, all the values in the decision matrix were normalized within each criterion. In this paper, we used a weighted average to normalize the values (Table 10).

Table 10
Normalized decision matrix

	Model 1	Model 2	Model 3	SUM
Action Radius (C_1)	0.1667	0.3889	0.4443	1
Fuel Endurance (C_2)	0.1641	0.388	0.4477	1
Autonomy (C_3)	0.3333	0.2777	0.3888	1
Primary Cannon (C_4)	0.147	0.147	0.7058	1
Secondary Cannon (C_5)	0.2	0.4	0.4	1
AAW Missiles (C_6)	0	0.5	0.5	1
Initial Cost (C_7)	0.3483	0.3258	0.3258	1
Life Cycle Cost (C_8)	0.3483	0.3258	0.3258	1
Construction Time (C_9)	0.4	0.3	0.3	1

5.2 Parity comparison between criteria and weighting matrix

The nine criteria were compared two by two, through an interview with the specialists. The purpose of the interview was to list the pertinent criteria for the choice of the most appropriate vessel for the Brazilian navy's needs, as well as to establish the inter-criteria weights considering Saaty's fundamental scale (Saaty, 1980). From the weights listed above, the following matrix was created (Table 11).

Table 11
Weight matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	1	1	0.33	5	1	0.33	0.33	0.25
C_2	1	1	1	0.33	5	1	0.33	0.33	0.25
C_3	1	1	1	0.33	5	1	0.33	0.33	0.25
C_4	3	3	3	1	3	1	0.33	0.33	0.33
C_5	0.20	0.2	0.2	0.33	1	0.2	0.2	0.2	0.14
C_6	1	1	1	1	5	1	0.33	0.33	0.33
C_7	3	3	3	3	5	3	1	1	1
C_8	3	3	3	3	5	3	1	1	1
C_9	4	4	4	3	7	3	1	1	1

By applying the same normalization procedure in Table 10, the normalized weight matrix is obtained (Table 12).

Table 12
Normalized weight matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	0.06	0.06	0.06	0.03	0.12	0.07	0.07	0.07	0.05
C_2	0.06	0.06	0.06	0.03	0.12	0.07	0.07	0.07	0.05
C_3	0.06	0.06	0.06	0.03	0.12	0.07	0.07	0.07	0.05
C_4	0.17	0.17	0.17	0.08	0.07	0.07	0.07	0.07	0.07
C_5	0.01	0.01	0.01	0.03	0.02	0.01	0.04	0.04	0.03
C_6	0.06	0.06	0.06	0.08	0.12	0.07	0.07	0.07	0.07
C_7	0.17	0.17	0.17	0.24	0.12	0.21	0.20	0.20	0.22
C_8	0.17	0.17	0.17	0.24	0.12	0.21	0.20	0.20	0.22
C_9	0.23	0.23	0.23	0.24	0.17	0.21	0.20	0.20	0.22
SUM	1	1	1	1	1	1	1	1	1

Table 13 shows the priority vector of the criteria. The construction time had greater weight, followed by the initial cost and the life cycle cost. Initial cost and life cycle cost had the same values.

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Table 13
Priority vector of criteria

1º	Construction time	0.217021892
2º	Initial Cost	0.192221993
3º	Life Cycle Cost	0.192221993
4º	Primary Cannon	0.106447057
5º	AAW Missiles	0.073107421
6º	Action Radius	0.065070664
7º	Fuel Endurance	0.065070664
8º	Autonomy	0.065070664
9º	Secondary Cannon	0.023767652

5.3 Results

The multiplication of the normalized decision matrix by the respective priority vector of the criteria gives the following ranking (Table 14).

Table 14
Ranking of alternatives

Classification	Model	Priorities
1st option	Model 3 (totally new model)	0.3949
2nd option	Model 2	0.3207
3rd option	Model 1 (actual model)	0.2843

The application of the AHP method indicates that the best alternative is the construction of a totally new vessel (Model 3), even considering the risks involved. The worst alternative (Model 1) would be to replicate the current Corvette Barroso. This is corroborated by the "score" of the distance of model 3 from model 2 being greater than the distance of model 2 from model 1.

5.4 Sensitivity analysis

The traditional AHP method did generate a small discrimination in the ranking of alternatives, which may indicate the need for a more careful sensitivity analysis. To increase the discriminatory power, we applied the framework presented in Figure 2.

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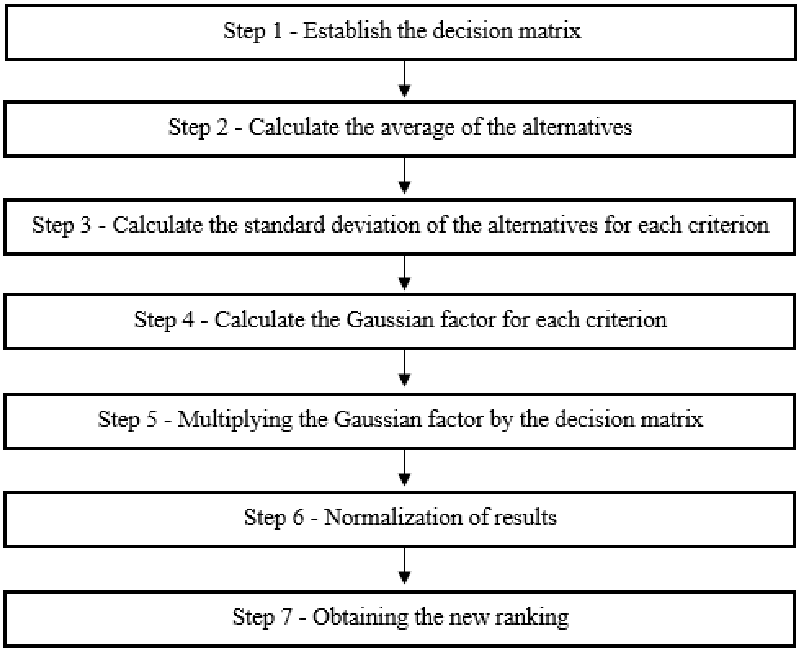

Figure 2 Steps for sensitivity analysis

Step 1 has been fulfilled because the decision matrix has already been established (Table 8).

Table 15 shows the values of the mean scores (Step 2), standard deviations (Step 3) and the Gaussian factor (Step 4), given by standard deviation/mean ratio.

Table 15
Mean score and standard deviation of each criterion

Criterion	Mean Scores	Standard deviation	Gaussian factor
Action Radius	0.3333	0.1469	0.441
Fuel Endurance	0.3333	0.1495	0.448
Autonomy	0.3333	0.0555	0.167
Primary Cannon	0.3333	0.3226	0.968
Secondary Cannon	0.3333	0.1154	0.346
AAW Missiles	0.3333	0.2886	0.866
Initial Cost	0.3333	0.0129	0.039
Life Cycle Cost	0.3333	0.013	0.038
Construction Time	0.3333	0.0577	0.173

The higher the Gaussian factor value, the harder it is to obtain a high score on the criterion. After this calculation, Table 16 provides the new weights (Gaussian factor values) already normalized from each criterion (Steps 5 and 6).

Table 16
New normalized weights of each criterion

Criterion	New weights
Action Radius	0.126
Fuel Endurance	0.129
Autonomy	0.048
Primary Cannon	0.278
Secondary Cannon	0.099
AAW Missiles	0.248
Initial Cost	0.011
Life Cycle Cost	0.011
Construction Time	0.050

Finally, we arrive at the same ranking (Step 7); however, with a more marked trade-off between the alternatives, corroborating that model 3 (totally new) is the most appropriate decision for the BN (Table 17). In this approach, Model 2 was in an intermediate position between Model 3 and Model 1.

Table 17
Sensitivity analysis of the ranking of alternatives

Classification	Model	Priorities
1st option	Model 3 (totally new)	0.5144
2nd option	Model 2	0.3390
3rd option	Model 1 (actual model)	0.1465

6. Conclusion

This paper aimed to choose the best choice for a new vessel to be built for the BN through the application of the AHP method. The definition of the method was made through a bibliometric survey of publications on the multiple-criteria and decision theme, in which we verified that the AHP method is the most used in all areas of knowledge based on Scopus database.

The method proved to be efficient in the proposed analysis, both in obtaining the weights of the criteria, as well as in the ordering of the models evaluated. It was concluded that the best alternative would be the construction of a new vessel, and this option was endorsed through the sensitivity analysis that followed. The use of weights to classify the variables considered all the possibilities involved, providing more reliability to the decision-making process. In summary, the sensitivity analysis increased the accuracy of the decision.

Evaluating the reasons that led to the final ranking of the alternatives, we note that Model 3, although it did not exhibit the best performances on the criteria with higher weights assigned by the specialists, obtained the best results due to its highest performance in the other six criteria, of operational nature, which makes this ship the most suitable to be built by the BN.

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Moreover, we emphasize the ease, flexibility, reliability and speed of application of the sensitivity analysis, which allows the weights to be obtained and alternatives to be ordered through the Gaussian factor, without the need to apply pairwise comparisons of alternatives and criteria.

Finally, we suggest this model of ordering alternatives using the AHP and Gaussian factor to be further applied in tactical, operational and strategic applications in the military area, given that this type of problem greatly affects the sovereignty and public safety of nations around the world.

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