Ordinal multicriteria methods applied to the ranking of naval and aerial defense systems: two hierarchical approaches based on the Borda method

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Abstract
The aim of this paper is to enable a wide range of comparisons regarding the relative naval and aerial warfare capabilities of different nations. With this purpose, two ordinal multicriteria methods have been used to rank order the countries comprised in the analysis. The methods applied were the original Borda and its modified version that uses the median to aggregate the criteria. Due to the inherent hierarchy of the criteria structure, it was necessary to develop hierarchical approaches for applying both methods. The results indicate that, although less influenced by irrelevant alternatives, the power of discrimination among alternatives may decrease, when the hierarchical approach builds on the modified Borda method. In the rankings derived from the analysis, the Turkish defense system obtained the first position when the methodology bases on the original Borda method, while Japan is ranked first if the hierarchical approach grounds on the modified version of that method.

Keywords: Multicriteria; Defense System; Borda method; Modified Borda method.

1 Introduction

The concept of power lay at the very basis of political science. Notwithstanding, there seems to be little consensus on it, other than the fact that it is a real and important concept when debating international relations [1].

Since ancient times, strength at the sea has been widely recognized as one of the defining military factors of any world power. Traditionally, nations have used their naval strength to respond to territorial contests, as well as to enforce maritime boundaries and safeguard national interests [2].

Lately, a defense problem that has been receiving a lot of attention is the anti-access/area-denial (A2/AD) one [3]. This is due mainly to the fact that in the international system there are two main categories of nations: the ones with capability to project power and the others. The latter must rely, among others alternatives, on conventional deterrence to obtain some protection against strongest foreign threats. Even though this problem has gained recent attention, as a response to the strategy pursued by nuclear capable countries [4-5], it may be regarded as having more universal application because it is not new. Indeed, the weak has always tried to deny the use of the sea by the strongest.

The answer to this challenge was named AirSea Battle [6]. Although motivated by the Chinese movement to develop their A2/AD capability, it has much broader application as pointed out by [6]: "some of the specific initiatives deriving from a viable concept likely would be applicable elsewhere

against other A2/AD capable adversaries, just as the Army and Air Force employed AirLand Battle principles designed to deter the Soviet Union in Central Europe very successfully in both Gulf Wars". For further discussion on recent crucial issues of military operations (e.g., autonomous robotic vehicles, secure communication systems and image encryption), see, e.g., [7-11].

Taking into regard that naval and aerial power, among many others, still represents an important element of national power [12]; the objective of this paper is to allow for a broad range of comparisons, concerning relative A2/AD capabilities of different nations. In this sense, it seeks to rank order the status of countries in terms of their capacity for naval warfare, which is a more conservative approach [12].

Accordingly, two ordinal multicriteria methods have been applied to derive rankings of the nations comprised in the set of analysis with respect to their conventional (non-nuclear) naval and aerial warfare capabilities that may be used for A2/AD purposes. The strict focus on conventional capabilities is justified by the fact that nuclear weapons and nuclear propulsion belong to a very special military capacity possessed only by very few nations.

Although relatively common in the literature, the use of multicriteria methods in military applications is so far mainly restricted to cardinal methods (for further discussion on cardinal and ordinal scales, see, e.g., [13]). For instance, in the United States, [14] used a multicriteria method to support personnel decisions in the military forces. More recently, [15] applied the Analytic Hierarchy Process (AHP) for allocating areas for military training exercises in Texas. For the selection of a new training aircraft in the Portuguese Air Force, [16] used MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique). For selecting communication technologies in the Brazilian Army, [17] applied AHP and TODIM (an acronym, in Portuguese, for iterative multicriteria decision-making). On the other hand, [18] proposed an ordinal approach for the military staff assignment problem, using ELECTRE TRI.

Therefore, the current study contributes to enlarge the related literature, as it proposes two different ordinal multicriteria hierarchical approaches, herein applied for ranking naval warfare capabilities in the international system. The proposal are based on the method of Borda [19], as well as on its modified version, introduced in [20].

The development of the hierarchical approaches was necessary because of the criteria configuration, as one of the proposed criteria was subdivided, and eventually more than one indicator is used to assess a specific criterion or sub-criterion

The hierarchical approaches proposed and implemented herein differ considerably from the traditional use of the original and the modified Borda methods, inasmuch as these methods are applied sequentially in a bottom-up procedure (i.e., from the lower to the upper hierarchical level). In this sense, the methodologies proposed relate to the complex systems structures connected in different levels addressed by [21], as well as to the decision tree´s concept used by the learning algorithm in [22].

The two different rankings obtained using the proposed methodologies were confronted and their differences analyzed in light of the intrinsic advantages and limitations of each approach.

The next section reviews in brief the ordinal multicriteria methods applied herein. Section 3 describes the problem and define the hierarchy to the decision criteria used in this study. Section 4 introduces the hierarchical approaches, as well as it presents and discusses the results derived. Finally, in the last section, some conclusions are draw and future developments are suggested.

2 Ordinal Multicriteria Methods

The Multicriteria Decision Aid (MCDA) consists of a set of methods and techniques to assist or support the decision-making in the presence of a multiplicity of criteria [23]. Although MCDA formally emerged as a branch of operational research in the 1970s [24], some basic ordinal methods, as those of Borda and Condorcet [19], had already existed since the eighteenth century. In fact, these two methods are, respectively, the precursors of the French and American schools of MCDA [24].

The distinction among different multicriteria methods rely mostly on the way of specifying the preference structure. When a decision-maker faces some difficulty in establishing an accurate cardinal scale of preferences, it is advisable to perform the analysis using ordinal judgments [25]. In this sense, the ordinal methods are quite intuitive and undemanding, both computationally and in terms of the information required from the decision-maker, as they simplify the data considering only the ranks of the observations. In other words, their use requests solely the decision-maker to rank order the alternatives according to his/her preferences in each criterion [19].

Beyond the methods of Borda and Condorcet, other widely referred ordinal multicriteria method is due to Copeland [26(see, e.g., [27]). Some variants may be find in the literature, as the modified Borda

[20] (applied herein) and the Lexicographic-Borda [28], among others.

The ordinal methods present two major advantages: they are, in general, user-friendly and easily understood [28-33]. These features motivate their high acceptance by the users [19], especially in the context of social choice and sports (see, e.g., [24-33]).

Nonetheless, most ordinal methods present a great disadvantage: they cannot produce just choices, as they do not satisfy all Arrow´s axioms [34]: namely, universality, unanimity, independence of irrelevant alternatives, transitivity and totality. In fact, except for dictatorial methods, no choice or decision aid method meet all these five axioms simultaneously.

In the current study, as in [20, 24, 28], the axioms of independence of irrelevant alternatives, transitivity and universality are of special concern. The first axiom affirms that the order of preference between two alternatives must not rely on their preferences regarding a third alternative. The transitivity axiom states that if one alternative is preferable to a second, and this one to a third, then the first must be preferable to the third. The universality axiom, meanwhile, requires the method to function, respecting all the other axioms, for any group of preferences of the decision-makers. Therefore, a method that meets the axioms just in certain cases does not satisfy universality [24, 28].

As any non-dictatorial ordinal method still fails in satisfying all the three above-mentioned axioms, the most suitable method must be chosen by taking into account the problem under analysis. In the current study, the option was to use the method of Borda and its modified version [20], mainly due to their simplicity.

2.1 The Borda Method

Chevalier de Borda (1733-1799) proposed a method, known as the Borda method, which denotes essentially a sum of points. In this method, each decision-maker (herein, each criterion) must order the alternatives according to his/her preferences. The alternative of highest preference scores one point; the second scores two points; and so forth. In case of tie, the analyst must assign an average of points to each alternative. Then, for each alternative, the analyst sum all the points attributed by all the decision-makers (or by all criteria, as in this study), as in (1).

$$P_A = \sum_{i=1}^{n} r_{Ai}, \quad (1)$$

where P_A is the total number of points obtained by alternative A and r_{Ai} is the rank of alternative A in criterion i [28, 35].

The method ranks the alternatives in increasing order according to this sum, i.e., the fewer the points the better the rank [18]. Some variations of the Borda method are widely used in sports, with each competition regarded as a decision-maker [24].

The Borda method does not satisfy Arrow's axiom of independence of irrelevant alternatives. This fact may bring some inconveniences, such as a vote in which the last voter perceives the preferences of the previous ones and changes his/her preferences to provide greater chances to his/her preferred alternative [19]. Additionally, in sports applications, it may incite the unsporting inversion of positions in a competition to favor a particular competitor [19, 24].

2.2 The Modified Borda Method

In [20], the authors introduce a variation of the Borda method. The proposal consists of using the median of the points assigned by all decision-makers (or by all criteria) instead of the sum, to rank order the alternatives. The aim of this modification is to reduce the influence of irrelevant alternatives in the ranking.

The method consists of establishing a ranking of the alternatives according to each one of the criteria. After ordering each criterion separately, the analyst should verify the rank position of each alternative, placing them in ascending order. The value used for the final ranking of the alternatives is the median value of each alternative in the individual rankings.

Due to the use of the median, this variation is more robust than the original method (i.e., it suffers minor influence of extreme values). Besides, this modified version presents the advantage of being less dependent on irrelevant alternatives than the original Borda method.

3 Problem Description

The attempt of assessing the power of a nation vis-à-vis others requires measuring power. The literature suggests many ways for doing so (see, e.g., [12, 36-54]).

In [55], the author divide the theoretical studies on national power in two main streams: the first interprets national power as the nation´s control over resources, while the second understands it as an actual or potential relationship between two or more actors (not necessarily nations). Most studies adopt the former interpretation, assuming that national power derive from the combination of several factors (economic, social and military), which indirectly represent the nation´s ability to wage war [56]. These

works regard the strictly defined military power (weapons, military personnel and expenditure) as a component of national power. As the nature of what makes a nation powerful constantly changes subject to the world dynamics [1], factors such as a technology base, educational level, and economic growth (see, e.g., [57-58]) have become increasingly important to evaluate national power [12]. In fact, the current thinking about national power regards the overemphasis on military power alone as a weakness. The main arguments against these approaches rely on the fact that they focus on nations as a "container for power" and, thus, result in simply gross indices [12].

However, in this study, as the aim is restricted to the assessment of A2/AD capability rather than national power, the methodology applied builds on such conservative approaches that emphasize on military capability. The fact that they often enable solely the rank ordering of countries, as stated in [12], properly fits the objective of ranking the status of countries in terms of their naval and aerial defense system, taking into account the detection and engagement capabilities.

Nevertheless, we acknowledge that the ability to rank order nations according to this specific characteristic does not necessarily allow for investigating the naval defense capability of those nations that may not stand out at the present, but that, given the knowledge revolution and its related technologies as potential equalizers, may emerge as powerful naval nations [1]. In this sense, the approach does not permit any prospective analysis.

3.1 Data and Decision Criteria

To evaluate the relative importance of each nation in terms of A2/AD capabilities (limited to the set of analysis), exclusively data on military conventional assets have been used. Spatial assets (satellites) and countries with nuclear powered submarines were excluded from the analysis.

The dataset comes from the annual publication of the International Institute for Strategic Studies (IISS), entitled "The Military Balance", deemed as the more complete and reliable database on global military capability, and refer to year 2011 [59].

The data analyzed are equipment-related and refer to detection and engagement capabilities. Only assets belonging to the navies and air forces have been taken into account, although some armies may also have assets that may be used for A2/AD operations. These two aspects broadly denote the decision criteria taken into account by the ordinal multicriteria methods applied herein to rank order the alternatives (countries) in terms of naval and aerial defense system.

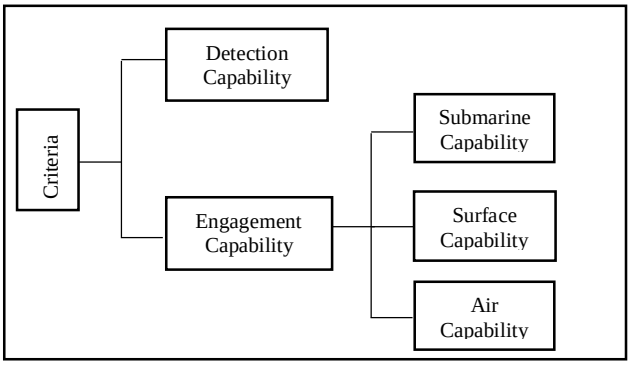

Fig.1. Criteria hierarchy

Notwithstanding, when defining criteria, it is possible to create a hierarchy in tree form, quite similar to that found in the AHP method [60]. In the upper levels, lay the most comprehensive criteria, which can be subdivided in sub-criteria, until there is a family of sufficiently specific criteria for the problem under analysis [20, 23]. Figure 1 depicts the criteria structure adopted herein.

As seen in Figure 1, although the criterion "detection capability" remains undivided, the criterion "engagement capability" was split in three sub-criteria: namely, submarine, surface and air capabilities. Table 1 presents the indicators used to assess each criteria and/or sub-criteria established.

Table 1. Indicators applied for the criteria defined

Criteria		Sub-criteria		Indicators	
C_1	Detection Capability	-		I_{11}	Total number of intelligence, survaillance (including maritime patrol) and reconnaissance aircrafts
				I_{12}	Total number of intelligence, survaillance (including maritime patrol and airborne early warning) and reconnaissance helicopters
				I_{13}	Total number of intelligence, survaillance and reconnaissance unmanned aerial vehicles
C_2	Engagement Capability	S_{21}	Submarine Capability	I_{21}	Total number of conventional (non-nuclear) submarines
		S_{22}	Surface Capability	I_{22}	Total of number of surface combatant vessels (cruiser, destroyers, fighters, corvettes and other patrol crafts) in service and armed with missiles (anti-ship and/or surface-to-air) and/or torpedos (anti-submarine)
		S_{23}	Air Capability	I_{231}	Total number of aircraft/helicopter carriers in service
				I_{232}	Total number of combat-capable aircrafts
				I_{233}	Total number of combat-capable helicopters

The first criterion (C_1, in Table 1) relates to the nation´s detection capability. This criterion is evaluated using three different indicators. The first

(I_{11}, in Table 1) is the total number of fixed-wing aircrafts in service and applied to intelligence, surveillance or reconnaissance activities (including maritime patrol) by the corresponding nation. The second indicator (I_{12}, in Table 1) represents the total number of intelligence, surveillance (including maritime patrol and airborne early warning) and reconnaissance helicopters in service. The third indicator (I_{13}, in Table 1) denotes the total number of intelligence, surveillance and reconnaissance unmanned aerial vehicles (UAVs) in use by the country.

The second criterion (C_2, in Table 1) refer to the nation´s engagement capability for naval warfare in defensive terms. For the better assessment of such capability, this criterion was divided in three sub-criteria, as mentioned above.

Thus, for the evaluation of the first sub-criterion (S_{21}, in Table 1), the total number of conventional (non-nuclear) submarines possessed by the respective navy is computed as an indicator (I_{21}, in Table 1). Beyond attack submarines, this value includes swimmer delivery vehicles, coastal and midget submarines.

To assess the second sub-criterion (S_{22}, in Table 1), the total number of surface fight ships possessed by each national navy is used as an indicator (I_{22}, in Table 1). The corresponding value comprises destroyers, frigates, corvettes and other patrol crafts. The ships took into account must have offensive ship-to-ship capabilities and may include anti-submarine-warfare and/or anti-air capabilities, denoted by the presence of anti-ship missiles (AShM), torpedoes (anti-submarine warfare), and/or surface-to-air missiles (SAM).

Finally, for assessing the third sub-criterion (S_{23}, in Table 1), three indicators were used. The first (I_{231}, in Table 1) is the total number of aircraft and/or helicopter carriers in service. The second indicator (I_{232}, in Table 1) is the total number of combat-capable attack fixed-wing aircrafts, and encloses those aircrafts designed to undertake air-to-surface missions and/or to anti-submarine warfare, with limited or no air-to-air capacity. The third indicator (I_{233}, in Table 1) is the total number of combat-capable attack rotary-wing aircrafts, which includes those helicopters designed to undertake air-to-surface missions and/or to anti-submarine warfare, with limited or no air-to-air capacity.

It is noteworthy that, for those fixed- and/or rotary-wing aircrafts with both detection and attack capabilities (e.g., combat-capable maritime patrol aircrafts), the total number of units is used as a whole in the two criteria and computed in the corresponding indicators entirely.

Table 2. Data for each nation in the analysis

Countries	C_1			C_2					Countries	C_1			C_2				
				S_{21}	S_{22}	S_{23}							S_{21}	S_{22}	S_{23}		
	I_{11}	I_{12}	I_{13}	I_{21}	I_{22}	I_{231}	I_{232}	I_{233}		I_{11}	I_{12}	I_{13}	I_{21}	I_{22}	I_{231}	I_{232}	I_{233}
Afghanistan	0	0	0	0	0	0	0	11	Lebanon	1	0	8	0	0	0	7	0
Algeria	8	0	0	4	18	0	125	33	Libya	0	0	0	2	12	0	0	0
Angola	0	0	0	0	5	0	92	44	Macedonia	0	0	0	0	0	0	0	14
Argentina	1	4	0	3	15	0	134	6	Madagascar	0	0	0	0	1	0	0	0
Armenia	0	4	0	0	0	0	16	8	Malawi	3	0	0	0	0	0	0	0
Australia	6	0	8	6	12	0	142	46	Malaysia	8	6	3	2	22	0	67	6
Austria	0	11	0	0	0	0	37	0	Mali	0	0	0	0	0	0	4	4
Azerbaijan	0	0	7	0	0	0	44	26	Mauritania	0	0	0	0	5	0	0	0
Bahamas	0	0	0	0	2	0	0	0	Mexico	20	15	6	0	10	0	83	0
Bahrain	0	2	0	0	7	0	39	28	Montenegro	0	0	0	2	2	0	0	0
Bangladesh	0	0	0	0	18	0	74	0	Morocco	4	0	1	0	20	0	72	3
Belarus	34	20	0	0	0	0	128	50	Mozambique	2	0	0	0	0	0	0	2
Belgium	0	3	13	0	2	0	88	0	Myanmar	0	0	0	0	11	0	136	0
Bolivia	0	0	0	0	0	0	39	0	Namibia	5	0	0	0	1	0	24	2
Bosnia-	2	0	0	0	0	0	19	0	Netherlands	0	0	0	4	6	0	72	34
Botswana	5	0	0	0	0	0	30	0	New Zealand	0	0	0	0	6	0	6	5
Brazil	38	0	1	5	14	1	247	22	Niger	2	0	0	0	0	0	0	0
Brunei	1	0	0	0	4	0	0	0	Nigeria	2	0	0	0	6	0	55	11
Bulgaria	1	0	1	0	10	0	62	24	North Korea	0	0	1	72	55	0	603	20
Burkina Faso	0	0	0	0	0	0	2	2	Norway	0	0	0	6	11	0	63	6
Burundi	0	0	0	0	0	0	1	2	Oman	7	0	0	2	10	0	54	0
Cambodia	5	0	0	0	0	0	24	0	Pakistan	49	6	3	8	16	0	460	54
Cameroon	0	0	0	0	2	0	9	0	Paraguay	0	0	0	0	0	0	6	0
Canada	0	0	6	4	15	0	18	28	Peru	15	0	0	6	15	0	78	23
Cape Verde	0	0	0	0	1	0	0	0	Philippines	14	0	3	0	2	0	24	0
Chad	0	0	0	0	0	0	11	3	Poland	10	2	0	5	8	0	112	42
Chile	14	9	0	4	15	0	81	5	Portugal	7	0	0	2	8	0	43	5
Colombia	22	20	0	4	6	0	82	0	Qatar	0	0	0	0	7	0	18	8
Congo	0	0	0	0	0	0	2	0	Romania	2	0	0	0	10	0	70	0
Côte D´Ivoire	0	0	0	0	0	0	0	1	Rwanda	0	0	0	0	0	0	0	5
Croatia	0	0	0	3	5	0	10	0	Saudi Arabia	18	0	0	0	20	0	296	45
Cuba	1	0	0	0	7	0	45	4	Senegal	0	0	0	0	4	0	1	2
Cyprus	0	0	0	0	0	0	0	11	Serbia	12	0	0	0	0	0	84	2
Czech Republic	0	0	2	0	0	0	47	24	Seychelles	0	0	0	0	2	0	0	0
Democratic Republic of Congo	0	0	0	0	0	0	5	9	Singapore	9	0	46	5	23	0	148	25
Denmark	0	8	0	0	4	0	45	8	Slovakia	0	0	0	0	0	0	22	15
Dominican Republic	0	17	0	0	2	0	8	0	Slovenia	0	0	0	0	0	0	9	0
Ecuador	4	0	6	2	11	0	52	0	South Africa	0	0	4	3	6	0	42	11
Egypt	23	9	52	4	53	0	589	64	South Korea	0	3	103	23	50	0	406	84
El Salvador	13	0	0	0	0	0	16	0	Spain	6	3	4	4	10	1	209	26
Equatorial	0	0	0	0	2	0	4	6	Sri Lanka	0	0	3		3	0	31	11
Eritrea	0	0	0	0	0	0	20	0	Sudan	2	0	0	0	0	0	61	29
Ethiopia	0	0	0	0	0	0	26	18	Suriname	2	0	0	0	0	0	4	0
Finland	0	0	11	0	8	0	109	0	Sweden	4	0	3	6	6	0	115	0
Gabon	0	0	0	0	3	0	14	0	Switzerland	0	0	4	0	0	0	87	0
Georgia	0	0	0	0	0	0	12	0	Syria	0	0	0	0	24	0	365	46
Germany	0	93	15	4	27	0	182	35	Taiwan	13	0	1	4	105	0	501	81
Ghana	0	0	0	0	4	0	13	0	Tajikistan	0	0	0	0	0	0	0	4
Greece	15	0	4	8	31	0	283	48	Tanzania	0	0	0	0	0	0	22	0
Guatemala	0	0	0	0	0	0	9	0	Thailand	53	0	1	0	34	1	208	11
Guinea	0	0	0	0	0	0	0	4	Togo	0	0	0	0	0	0	10	0
Honduras	0	0	0	0	0	0	19	0	Tunisia	0	0	0	0	12	0	24	0
Hungary	0	0	0	0	0	0	14	12	Turkey	36	3	224	14	58	0	375	47
Indonesia	28	4	0	2	46	0	69	6	Turkmenistan	0	0	0	0	0	0	94	10
Iran	9	0	2	23	26	0	339	60	Uganda	0	0	0	0	0	0	14	1
Iraq	0	15	0	0	0	0	3	0	Ukraine	26	0	0	1	10	0	221	211
Ireland	2	0	0	0	0	0	0	0	United Arab Emirates	7	11	0	10	13	0	178	37
Israel	17	12	26	3	59	0	440	91	Uruguay	4	0	1	0	2	0	16	0
Italy	3	4	5	6	16	2	263	85	Uzbekistan	24	0	0	0	0	0	135	29
Japan	43	86	0	18	71	2	466	203	Venezuela	3	0	0	2	9	0	102	15
Jordan	1	0	0	0	0	0	115	25	Vietnam	0	0	0	2	32	0	235	39
Kazakhstan	12	0	0	0	0	0	162	40	Yemen	0	0	0	0	4	0	79	9
Kenya	0	0	0	0	5	0	38	0	Zambia	0	0	0	0	0	0	18	0
Kuwait	0	0	0	0	10	0	66	16	Zimbabwe	2	0	0	0	0	0	46	6
Kyrgyzstan	0	0	0	0	0	0	33	2									

Table 2 displays the dataset related to the foregoing criteria, sub-criteria and indicators for the 129 countries (alternatives) regarded in the analysis. This set represents those nations that possess at least one of the assets regarded as indicators. As previously mentioned (see Section 1), once the aim is to evaluate conventional (non-nuclear) naval capability, in the following analysis, those nations detaining nuclear naval competences are ignored.

4 Application, Results and Discussion

This section applies the original method of Borda and its modified version [20], presented in Section 2, which uses the median instead of the sum to aggregate the ranks of the alternatives (countries) by all criteria.

Table 3. Borda points assigned to each nation, according to each indicator

Countries	C_1			C_2					Countries	C_1			C_2				
				S_1	S_2	S_3							S_1	S_2	S_3		
	I_{11}	I_{12}	I_{13}	I_{21}	I_{22}	I_{231}	I_{232}	I_{233}		I_{11}	I_{12}	I_{13}	I_{21}	I_{22}	I_{231}	I_{232}	I_{233}
Afghanistan	93.5	77.5	81.5	84.5	103.5	67.5	111	45.5	Lebanon	54.5	77.5	9.5	84.5	103.5	67.5	99	107
Algeria	26.5	77.5	81.5	21	19.5	67.5	28	23	Libya	93.5	77.5	81.5	34	30	67.5	119	108
Angola	93.5	77.5	81.5	84.5	56.5	67.5	35	16	Macedonia	93.5	77.5	81.5	84.5	103.5	67.5	120	41
Argentina	54.5	17.5	81.5	27.5	24.5	67.5	26	55	Madagascar	93.5	77.5	81.5	84.5	76	67.5	121	109
Armenia	93.5	17.5	81.5	84.5	103.5	67.5	84	53	Malawi	41	77.5	81.5	84.5	103.5	67.5	122	110
Australia	31.5	77.5	9.5	11	30	67.5	23	13.5	Malaysia	26.5	14.5	22	34	16	67.5	49	58
Austria	93.5	9.5	81.5	84.5	103.5	67.5	67	80	Mali	93.5	77.5	81.5	84.5	103.5	67.5	104	67
Azerbaijan	93.5	77.5	11	84.5	103.5	67.5	61	28.5	Mauritania	93.5	77.5	81.5	84.5	56.5	67.5	123	111
Bahamas	93.5	77.5	81.5	84.5	70	67.5	112	81	Mexico	12	6.5	13	84.5	38	67.5	39	112
Bahrain	93.5	24.5	81.5	84.5	47	67.5	64	26.5	Montenegro	93.5	77.5	81.5	34	70	67.5	124	113
Bangladesh	93.5	77.5	81.5	84.5	19.5	67.5	44	82	Morocco	37.5	77.5	30	84.5	17.5	67.5	45	70
Belarus	6	3.5	81.5	84.5	103.5	67.5	27	10	Mozambique	47	77.5	81.5	84.5	103.5	67.5	125	74
Belgium	93.5	21.5	7	84.5	70	67.5	36	83	Myanmar	93.5	77.5	81.5	84.5	33	67.5	24	114
Bolivia	93.5	77.5	81.5	84.5	103.5	67.5	65	84	Namibia	34	77.5	81.5	84.5	76	67.5	73	75
Bosnia-Herzegovina	47	77.5	81.5	84.5	103.5	67.5	79	85	Netherlands	93.5	77.5	81.5	21	51.5	67.5	46	22
Botswana	34	77.5	81.5	84.5	103.5	67.5	70	86	New Zealand	93.5	77.5	81.5	84.5	51.5	67.5	100	62
Brazil	4	77.5	30	15	27	4	14	35	Niger	47	77.5	81.5	84.5	103.5	67.5	126	115
Brunei	54.5	77.5	81.5	84.5	61	67.5	113	87	Nigeria	47	77.5	81.5	84.5	51.5	67.5	54	45.5
Bulgaria	54.5	77.5	30	84.5	38	67.5	52	32.5	North Korea	93.5	77.5	30	1	5	67.5	1	36
Burkina Faso	93.5	77.5	81.5	84.5	103.5	67.5	107	71	Norway	93.5	77.5	81.5	11	33	67.5	51	59
Burundi	93.5	77.5	81.5	84.5	103.5	67.5	109	72	Oman	29	77.5	81.5	34	38	67.5	55	116
Cambodia	34	77.5	81.5	84.5	103.5	67.5	72	88	Pakistan	2	14.5	22	7.5	21.5	67.5	5	9
Cameroon	93.5	77.5	81.5	84.5	70	67.5	95	89	Paraguay	93.5	77.5	81.5	84.5	103.5	67.5	101	117
Canada	93.5	77.5	13	21	24.5	67.5	81	26.5	Peru	15.5	77.5	81.5	11	24.5	67.5	43	34
Cape Verde	93.5	77.5	81.5	84.5	76	67.5	114	90	Philippines	17.5	77.5	22	84.5	70	67.5	74	118
Chad	93.5	77.5	81.5	84.5	103.5	67.5	92	69	Poland	23	24.5	81.5	15	44	67.5	31	17
Chile	17.5	11.5	81.5	21	24.5	67.5	41	61	Portugal	29	77.5	81.5	34	44	67.5	62	63
Colombia	11	3.5	81.5	21	51.5	67.5	40	91	Qatar	93.5	77.5	81.5	84.5	47	67.5	82	53
Congo	93.5	77.5	81.5	84.5	103.5	67.5	108	92	Romania	47	77.5	81.5	84.5	38	67.5	47	119
Côte D´Ivoire	93.5	77.5	81.5	84.5	103.5	67.5	115	78	Rwanda	93.5	77.5	81.5	84.5	103.5	67.5	127	64
Croatia	93.5	77.5	81.5	27.5	56.5	67.5	93	93	Saudi Arabia	13	77.5	81.5	84.5	17.5	67.5	11	15
Cuba	54.5	77.5	81.5	84.5	47	67.5	59	65	Senegal	93.5	77.5	81.5	84.5	61	67.5	110	76
Cyprus	93.5	77.5	81.5	84.5	103.5	67.5	116	45.5	Serbia	21.5	77.5	81.5	84.5	103.5	67.5	38	77
Czech Republic	93.5	77.5	25.5	84.5	103.5	67.5	57	32.5	Seychelles	93.5	77.5	81.5	84.5	70	67.5	128	120
Democratic Republic of Congo	93.5	77.5	81.5	84.5	103.5	67.5	102	50	Singapore	24.5	77.5	4	84.5	15	67.5	22	30.5
Denmark	93.5	13	81.5	84.5	61	67.5	60	53	Slovakia	93.5	77.5	81.5	84.5	103.5	67.5	76	39.5
Dominican Republic	93.5	5	81.5	84.5	70	67.5	98	94	Slovenia	93.5	77.5	81.5	15	103.5	67.5	97	121
Ecuador	37.5	77.5	13	34	33	67.5	56	95	South Africa	93.5	77.5	17.5	27.5	51.5	67.5	63	45.5
Egypt	10	11.5	3	21	6	67.5	2	7	South Korea	93.5	21.5	2	2.5	7	67.5	7	5
El Salvador	19.5	77.5	81.5	84.5	103.5	67.5	85	96	Spain	31.5	21.5	17.5	21	38	4	17	28.5
Equatorial	93.5	77.5	81.5	84.5	70	67.5	103	56	Sri Lanka	93.5	77.5	22	84.5	64.5	67.5	69	45.5
Eritrea	93.5	77.5	81.5	84.5	103.5	67.5	78	97	Sudan	47	77.5	81.5	84.5	103.5	67.5	53	24.5
Ethiopia	93.5	77.5	81.5	84.5	103.5	67.5	71	37	Suriname	47	77.5	81.5	84.5	103.5	67.5	105	122
Finland	93.5	77.5	8	84.5	44	67.5	32	98	Sweden	37.5	77.5	22	11	51.5	67.5	29.5	123
Gabon	93.5	77.5	81.5	84.5	64.5	67.5	87	99	Switzerland	93.5	77.5	17.5	84.5	103.5	67.5	37	124
Georgia	93.5	77.5	81.5	84.5	103.5	67.5	91	100	Syria	93.5	77.5	81.5	84.5	14	67.5	9	13.5
Germany	93.5	1	6	21	12	67.5	19	21	Taiwan	19.5	77.5	30	21	1	67.5	3	6
Ghana	93.5	77.5	81.5	84.5	61	67.5	90	101	Tajikistan	93.5	77.5	81.5	84.5	103.5	67.5	129	68
Greece	15.5	77.5	17.5	7.5	11	67.5	12	11	Tanzania	93.5	77.5	81.5	84.5	103.5	67.5	77	125
Guatemala	93.5	77.5	81.5	84.5	103.5	67.5	96	102	Thailand	1	77.5	30	84.5	9	4	18	45.5
Guinea	93.5	77.5	81.5	84.5	103.5	67.5	117	66	Togo	93.5	77.5	81.5	84.5	103.5	67.5	94	126
Honduras	93.5	77.5	81.5	84.5	103.5	67.5	80	103	Tunisia	93.5	77.5	81.5	84.5	30	67.5	75	127
Hungary	93.5	77.5	81.5	84.5	103.5	67.5	88	42	Turkey	5	21.5	1	5	4	67.5	8	12
Indonesia	7	17.5	81.5	34	8	67.5	48	57	Turkmenistan	93.5	77.5	81.5	84.5	103.5	67.5	34	49
Iran	24.5	77.5	25.5	2.5	13	67.5	10	8	Uganda	93.5	77.5	81.5	84.5	103.5	67.5	89	79
Iraq	93.5	6.5	81.5	84.5	103.5	67.5	106	104	Ukraine	8	77.5	81.5	39	38	67.5	16	1
Ireland	47	77.5	81.5	84.5	103.5	67.5	118	105	United Arab Emirates	29	9.5	81.5	84.5	28	67.5	20	20
Israel	14	8	5	27.5	3	67.5	6	3	Uruguay	37.5	77.5	30	6	70	67.5	86	128
Italy	41	17.5	15	11	21.5	1.5	13	4	Uzbekistan	9	77.5	81.5	84.5	103.5	67.5	25	24.5
Japan	3	2	81.5	4	2	1.5	4	2	Venezuela	41	77.5	81.5	34	42	67.5	33	39.5
Jordan	54.5	77.5	81.5	84.5	103.5	67.5	29.5	30.5	Vietnam	93.5	77.5	81.5	34	10	67.5	15	19
Kazakhstan	21.5	77.5	81.5	84.5	103.5	67.5	21	18	Yemen	93.5	77.5	81.5	84.5	61	67.5	42	51
Kenya	93.5	77.5	81.5	84.5	56.5	67.5	66	106	Zambia	93.5	77.5	81.5	84.5	103.5	67.5	83	129
Kuwait	93.5	77.5	81.5	84.5	38	67.5	50	38	Zimbabwe	47	77.5	81.5	84.5	103.5	67.5	58	60
Kyrgyzstan	93.5	77.5	81.5	84.5	103.5	67.5	68	73									

As mentioned in Section 1, once a hierarchy is used to structure the criteria (described in the previous section), it was necessary to develop corresponding hierarchical approaches for the application of the chosen methods. Therefore, the methodology applied in the following diverges notably from the traditional utilization of such methods. This occur because one of the criteria was split in three sub-criteria, and eventually more than one indicator is used to assess a specific criterion (namely, C_1) or sub-criterion (namely S_3).

Table 3 exhibits the Borda points assigned to rank the alternatives in descending order, according to each indicator.

4.1 Proposed Hierarchical Borda Approaches

Due to the hierarchical structure of the criteria, the methods must be applied in sequential steps.

The process starts by the more disaggregated level, taking into regard the three indicators (I_{231}, I_{232} and I_{233}) related to sub-criterion S_3. As the original and the modified Borda method [20] are used, these indicators are aggregated in two ways, by the sum and by the median of the corresponding points, respectively, relying upon the method taken into account.

Then, in a second step, as the other two sub-criteria of criterion C_2 individually relate to a single indicator (I_{21} and I_{22}), they may be directly aggregated accordingly (i.e., by the sum or the median) with the aggregated results of the previous step. The same procedure suits to aggregate the indicators (I_{11}, I_{12} and I_{13}) of criterion C_1.

Finally, in the last step, the points individually assigned to criteria C_1 and C_2 shall be aggregated using both methods, and converted into ranks.

4.2 Results and Discussion

Table 4 shows the final ranks derived from the proposed hierarchical approaches, by using the original and the modified Borda methods, as well as the discrepancies between them.

From the results displayed in Table 4, it may be noted that, when it comes to conventional naval and aerial defense systems, Turkey obtains the first position when the original Borda method is used, while Japan gets the first position in the rank derived using the modified version of such method.

The Japanese naval and aerial defense system dominate the Turkish in all the evaluated indicators, but the one related to the availability of UAVs (I_{13}). This situation pushed the former down to the third position in the rank derived from the original Borda method, as there is no record of the above-mentioned assets in the Japanese military forces in year 2011.

On the other hand, the fact that Turkey dominates every country in the analysis with respect to the availability of UAVs and presents consistently good and homogeneous evaluations in both criteria, led it to the top position in the rank derived using the modified version of the Borda method.

Besides Turkey, the European countries best positioned in the rankings herein derived are Italy, Spain, Greece and Germany, whose positions vary from 5th to 11th, depending upon the method applied.

Concerning the Middle East and North Africa, Egypt and Israel alternate between the 2nd and 4th position, subject to the method used.

Table 4. Ranks based on the original (O) Borda method and on its modified (M) version, and differences between them

Countries	Final Ranks			Countries	Final Ranks			Countries	Final Ranks		
	O	M	Diff		O	M	Diff		O	M	Diff
Turkey	1	3	-2	Kazakhstan	44	59	-15	Montenegro	87	91	-4
Egypt	2	4	-2	Bahrain	45	67	-22	Ethiopia	88	91	-3
Japan	3	1	2	Denmark	46	70	-24	Slovenia	89	123	-34
Israel	4	2	2	Philippines	47	36	11	Slovakia	90	91	-1
Pakistan	5	8	-3	Azerbaijan	48	59	-11	Senegal	91	91	0
Italy	6	11	-5	Sri Lanka	49	46	3	Ghana	92	70	22
South Korea	7	7	0	Nigeria	50	44	6	Gabon	93	91	2
Spain	8	9	-1	Vietnam	51	48	3	Cameroon	94	91	3
Greece	9	6	3	Serbia	52	59	-7	Hungary	95	91	4
Germany	10	5	5	Cuba	53	42	11	Mozambique	95	82	13
Brazil	11	16	-5	Romania	54	49	5	Kyrgyzstan	97	91	6
Iran	11	12	-1	Namibia	55	59	-4	Malawi	98	86	12
Taiwan	11	10	1	Czech Republic	56	59	-3	Bolivia	99	91	8
Malaysia	14	21	-7	Norway	56	55	1	Bahamas	100	91	9
Indonesia	15	17	-2	Dominican Republic	58	91	-33	Ireland	100	86	14
Australia	16	18	-2	Netherlands	59	68	-9	Democratic Republic of Congo	102	91	11
Chile	17	19	-2	Sudan	60	59	1	Suriname	102	86	16
Thailand	18	13	5	Syria	60	47	13	Afghanistan	104	113	-9
Colombia	19	20	-1	Austria	62	75	-13	Niger	104	86	18
Poland	20	23	-3	Jordan	63	30	33	Chad	106	114	-8
Singapore	21	14	7	Armenia	64	75	-11	Macedonia	106	75	31
Argentina	22	26	-4	Kuwait	65	58	7	Mauritania	106	91	15
Peru	23	32	-9	Bangladesh	66	75	-9	Cyprus	109	91	18
Ukraine	24	33	-9	El Salvador	67	86	-19	Uganda	110	120	-10
Mexico	25	28	-3	Angola	68	54	14	Cape Verde	111	85	26
United Arab Emirates	25	15	10	Zimbabwe	68	59	9	Mali	112	75	37
Algeria	27	29	-2	Botswana	70	73	-3	Eritrea	113	118	-5
Ecuador	27	38	-11	Croatia	71	91	-20	Burkina Faso	114	115	-1
Sweden	27	38	-11	Switzerland	71	49	22	Burundi	115	116	-1
North Korea	30	31	-1	Lebanon	73	72	1	Guinea	116	91	25
Saudi Arabia	31	24	7	Myanmar	73	75	-2	Honduras	116	121	-5
Belarus	32	40	-8	Cambodia	75	74	1	Seychelles	118	91	27
Canada	32	49	-17	Libya	76	91	-15	Madagascar	119	91	28
Morocco	34	22	12	Yemen	76	57	19	Georgia	120	123	-3
Bulgaria	35	25	10	Qatar	78	66	12	Rwanda	120	91	29
South Africa	36	43	-7	Brunei	79	45	34	Côte D´Ivoire	122	118	4
Belgium	37	35	2	Iraq	80	123	-43	Tajikistan	123	91	32
Uruguay	38	53	-15	New Zealand	81	68	13	Guatemala	124	123	1
Portugal	39	40	-1	Bosnia-Herzegovina	82	83	-1	Congo	125	123	2
Oman	40	33	7	Turkmenistan	82	55	27	Tanzania	126	117	9
Venezuela	40	37	3	Tunisia	84	91	-7	Zambia	127	122	5
Finland	42	49	-7	Kenya	85	75	10	Paraguay	128	123	5
Uzbekistan	43	27	16	Equatorial Guinea	86	84	2	Togo	129	123	6

When it comes to Southeast Asia, after Japan, the best-ranked nations are Pakistan and South Korea. Curiously, South Korea present the same rank position (7th), despite of the method used as basis for the hierarchical approach. This also happens to Senegal (91th position).

Within the Latin-American continent, Brazil is the country best positioned, regardless of the rank derived, followed by Chile and Colombia. (respectively, 13th and 14th positions, in the original Borda-based ranking).

Fifty-seven countries ranked worse within the modified Borda-based hierarchical approach. In particular, Iraq is the country that lost absolute positions the most, falling from 80th to 123th, because of its null values in most indicators (six out of eight).

It is noteworthy that, when using the modified Borda method, the number of ties increases (66 against 37). As reported in [20], this is an expected behavior, since such variation undergoes less influence of extreme values than the original method. However, building on the modified version, the ties occur after the 33th position, while in the approach based upon the original Borda method they begin to appear in the 11th position.

To observe if the A2/AD capabilities ranks (which can be regarded as the output of a national effort to create a defense capability) are related directly to the rank of the effort itself (represented by the size of the defense budget), the defense budgets for year 2011, in non-increasing order, are shown in Table 5.

Table 5. Defense budgets in US$ millions

Countries	Defense Budget (US$ million)	Countries	Defense Budget (US$ million)	Countries	Defense Budget (US$ million)
Japan	58400	Romania	2670	Bosnia-Herzegovina	248
Saudi Arabia	46200	Vietnam	2660	Paraguay	248
Germany	44200	Czech Republic	2520	Dominican Republic	229
Brazil	36600	Venezuela	2380	Tanzania	226
South Korea	28500	Philippines	2340	Democratic Republic of Congo	214
Australia	27700	Nigeria	2230	Guatemala	196
Canada	21500	New Zealand	2140	Zimbabwe	195
Italy	21000	Syria	2060	Uganda	189
Israel	15300	Myanmar	2040	Honduras	140
Spain	15300	Yemen	2040	El Salvador	138
Iran	12000	Sri Lanka	1970	Macedonia	137
Netherlands	11700	Peru	1820	Ghana	128
Turkey	10300	Kazakhstan	1740	Rwanda	73
Taiwan	9900	Azerbaijan	1680	Tajikistan	72
Singapore	9660	Ecuador	1510	Madagascar	71
Poland	9430	Hungary	1410	Burundi	64
United Arab Emirates	9320	Jordan	1360	Togo	58
Algeria	8610	Ireland	1310	Montenegro	54
Greece	6830	Bangladesh	1250	Bahamas	51
Norway	6430	Sudan	1150	Malawi	43
Sweden	6210	Lebanon	1110	Kyrgyzstan	33
Colombia	5570	Ukraine	1100	Seychelles	22
Thailand	5520	Slovakia	1070	Cape Verde	9
Switzerland	5480	Serbia	975	Armenia	3.5
Indonesia	5420	Croatia	935	Bolivia	...
Pakistan	5160	Bahrain	873	Burkina Faso	...
Mexico	5150	Bulgaria	725	Chad	...
Denmark	4910	Afghanistan	635	Congo	...
Iraq	4790	Kenya	622	Cuba	...
Malaysia	4540	Slovenia	578	Equatorial Guinea	...
South Africa	4290	Botswana	539	Eritrea	...
Oman	4270	Cyprus	512	Guinea	...
Chile	4240	Uruguay	478	Libya	...
Egypt	4230	Belarus	470	Mali	...
Kuwait	4050	Namibia	421	Mauritania	...
Belgium	3880	Brunei	406	Mozambique	...
Angola	3630	Georgia	395	Niger	...
Qatar	3450	Cameroon	344	North Korea	...
Finland	3430	Côte D´Ivoire	318	Senegal	...
Morocco	3340	Cambodia	298	Suriname	...
Argentina	3100	Zambia	291	Tunisia	...
Austria	2880	Gabon	263	Turkmenistan	...
Portugal	2830	Ethiopia	257	Uzbekistan	...

It may be seen that, out of the top ten countries with the highest defense budgets, eight are ranked in the first twelve positions in terms of naval and aerial defense systems, no matter the method used as a basis: namely, Japan, Germany, South Korea, Italy,

Israel, Spain and Iran. Thus, the nations´ capabilities seem closely associated to their national effort.

5 Conclusion

This paper presented an analysis of the relative warfare capabilities of a set of nations, with respect to their naval and aerial defense systems. For that, two different hierarchical approaches were proposed.

Such proposals comprise the adaptation of two ordinal multicriteria methods, namely the original Borda method, as well as its modified version [20], and were applied herein to rank order the countries under analysis.Since the scope of analysis was restricted to the evaluation of conventional warfare capability, those nations detaining nuclear powered submarines were discarded.

Additionally, once the decision criteria are organized in a hierarchical structure, the development of the hierarchical approaches was necessary. The proposals differ reasonably from the traditional use of the methods in which they are based, in the sense that their implementation is done sequentially in a bottom-up procedure. Simplicity is the major advantage of such proposals, as they do not require any advanced mathematical tools.In the ranks derived, the Turkish defense system got the first position when the hierarchical ordinal approach bases on the original Borda method, whereas Japan is set on the first place if the methodology grounds on the modified version of that method. The difference is due chiefly to the null value of the indicator that denotes the availability of UAVs by the Japanese military system. Furthermore, in general terms, the results suggests that final rank achieved by a country is closely related to its effort to create a defense capability.

Due to the use of the median instead of the sum to aggregate the criteria, the power of discrimination among alternatives decays, when the approach builds on the modified Borda method. However, in this study, as the ties appears only after the 33^{th} position, such limitation does not affect the most representative nations. Moreover, the modified version presents the advantage of being less dependent on irrelevant alternatives than the original method.

Notwithstanding, it is important to remark that choosing between the original Borda method or its modified version, so as to base the hierarchical approach, implies either allowing situations in which results might be more influenced by irrelevant alternatives or possibly experiencing difficulties in the discrimination of the alternatives.

A possible extension of this work consists of incorporating the use of the Copeland method [26] into the proposed hierarchical methodology, to enhance its relative independence of irrelevant alternatives, without compromising its discriminatory power.

Future research may consider the use of other decision aid approaches, such as Data Envelopment Analysis [61], e.g., extending the preliminary study performed by [62], which compares the relative efficiencies of a set of nations in terms of their capacity to convert latent military power into effective. Nonetheless, depending on the set of analysis, the differences among the nations might be significant, and, thus, the use of clustering techniques is recommended, as done, e.g., in [63-65].

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