Supplier Selection of Combat Vessels under Geopolitical Uncertainty: The Case of the Hellenic Navy

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Abstract

This paper tackles the issue of supplier selection as regards combat vessels, in an uncertainty environment. The methodology employed is developed in two stages: The first is the deterministic one which applies the Analytic Hierarchy Process (AHP) aiming at a quantifying assessment of the characteristics of each of the designs and leading to a hierarchy ordering as regards the features of each vessel. At a second step, we introduce stochastic analysis in our model to consider the impact of geopolitical uncertainty, a modification that, to the best of our knowledge, has not been examined before in a military supply selection model. By doing so, we consider the extent to which the initial hierarchy ordering of the vessels obtained after the application of the deterministic methodology is affected. Our method is applied to the case of the procurement of a number of frigates by the Hellenic Navy in 2021. The empirical results underline the role of geopolitical uncertainty as it affects the supplier selection process. Therefore, the paper underlines the importance of considering possible relevant geopolitical benefits to accompany the technical, operational and economic assessment related to the purchase of combat vessels.

Keywords: Uncertainty; Strategic choices; AHP; Defense Procurement; Defense Economics

JEL Classification: D81, H56, H57

1. Introduction

In response to the challenges faced in a volatile geopolitical and geostrategic environment, Greece has recently embarked in a number of decisive moves aiming at upgrading the Hellenic arsenal. One of these moves regarded the purchase of three (with an option of a fourth) frigates for the Hellenic Navy (HN). The decision to purchase the specific type of frigates finally chosen was preceded by a keen competition among leading naval manufacturers both in Europe and the U.S. This paper does not aim to assess the selection procedure which has been followed by the Hellenic government and the General Staff. It aims, however, at highlighting the margins offered in such major weapon systems selection procedures when uncertainty accompanies the operational, economic and financial criteria employed. To do so we shall first present a brief literature review on the subject, followed by a description of the decision - making method used. The empirical section of the paper shows how this method is then applied as the procedure of choosing between the various candidate vessels under purely deterministic criteria. Such choices, however, may be affected by various uncertainty factors outlining the geostrategic and geopolitical environment in the areas of interest. The extent to which uncertainty affects, and even distorts the reasoning of such major choices is then introduced in the paper followed by the concluding remarks.

Our scope is to present an updated methodology of the supplier selection process that considers the technical aspects of the evaluation together with the uncertainty of the international environment. This research comes to fill the relevant gap in the literature by focusing on the case study of the supplier selection of combat vessels of the Hellenic Navy. We make two main contributions to the existing literature. First, we expand the Analytic Hierarchy Process (AHP) to include geopolitical uncertainty and second, we update the extremely limited literature focusing on the supplier selection process in the military sector (combat vessels). The findings of our research show that geopolitical uncertainty may affect the preference ordering of a supplier selection in the case of combat vessels. Specifically, when uncertainty and strategic benefits are introduced in the analysis, we observe that the initial supplier selection order based on the deterministic AHP is affected to a considerable extent. Consequently, when it comes to the policy implications, the paper underlines the necessity to consider not only the technical, operational and economic benefits related to the purchase of defense equipment, naval vessels in our case, but also possible relevant geopolitical benefits during the selection process, following strategic alliances.

The rest of the paper is organized as follows: Section 2 presents a review of previous studies. Section 3 discusses the methodology employed. We present and discuss our results and the data in section 4, while section 5 reports a sensitivity analysis, under two alternative scenarios. Section 6 summarizes the results and presents our conclusions.

2. Literature Review

As early as in the beginning of the nineties, Insua and French (1991), perform a sensitivity analysis within a Bayesian context in a multi-objective decision-making framework. According to the authors this analysis traces the leading inputs in determining equipment selection which can thus be revised most carefully. The paper points to a number of solution - concepts and shows how to identify possible competitors in the case of each such solution. Finally, it concludes by offering examples and suggesting ways of conveying the information to the decision-maker. Later, Hartley (1998) analyzed the demand and supply sides of the defence market with an application to the UK case. Using a non-technical, however, highly descriptive approach, the paper deals with the usefulness or otherwise of retaining a sound domestic industrial base rather than "shopping around".

In the years to follow, the relevant literature assumes the tendency to become more technical, focusing mainly on the supply side, with Sarkis and Talluri (2002) using a model for evaluation and selection of suppliers considering strategic, operational, tangible, and intangible measures. Chan (2003), on the other hand, proposed a method called Chain of Interaction aiming at facing the difficulties linked to the dynamic nature of supply chain management. He suggested an Analytic Hierarchy Process (AHP) which systemizes all initial steps like the formation of selection criteria which lead to the implementation of the AHP. The proposed Interactive Selection Model can be applied to supplier selection through the identification of buyer–supplier interactions and the valid data-collection methods. An interesting paper by Bui et al. (2009), pointed to a risk-based framework for military capability planning, within which evolutionary algorithms are used to tackle problems with two or even more conflicting objectives. The framework allows the addition of a risk-based objective to the problem in order to support risk assessment during the planning process. The paper thus suggests a risk assessment mechanism analyzing the performance of any proposed framework in a risk – pro or risk - averse environment.

Turning to examining selection processes in a fuzzy environment, Lee (2009) applies a fuzzy analytical hierarchy processing model, which incorporates the benefits, opportunities, costs and risks (BOCR). This evaluates suppliers using a variety of factors that formulate the buyer - to - supplier relationship aiming at obtaining a performance ranking of the suppliers. The paper includes a case study of backlight unit supplier selection for a TFT-LCD manufacturer, with the proposed model facilitating the decision process. Being a general form model, it can be applied by a wide variety of firms that are making decisions on supplier selection. Always in the fuzzy logic context, Lin (2012), uses the fuzzy analytic network process (FANP) approach to consider the effects of interdependence among selection criteria and to handle inconsistent and uncertain judgments. At a next phase, the paper resorts to fuzzy multi-objective linear programming (FMOLP) to select the best suppliers for achieving optimal order allocation in a fuzzy environment. In another interesting paper, Li and Zabinski (2011) present Pareto-optimal solutions to demonstrate the contribution of stochastic programming as well as chance-constrained programming models in the case of a robust supplier selection. The authors underline the tradeoff between costs and risks using multi-parametric programming techniques to analyze the alternative Pareto-optimal supplier selection solutions as it concerns the chance-constrained programming models thus providing insights into the robustness of the solutions with respect to the number of suppliers and the costs. By contrast, New et. al (2012) are much more specific, defining the policy for Reliability Centered Maintenance in the Royal Navy and the Royal Fleet Auxiliaries. The paper focuses on how employment of Reliability Centered Maintenance is integrated into the Safety Case regime and evaluates and discusses its potential benefits. A very useful contribution has been made by Pal et al. (2013) who present a critical evaluation of the relevant literature on supplier selection methods. The issue of supplier selection applied to an automobile company in India is also addressed by Luthra et al. (2016). The authors propose a framework to evaluate sustainable supplier selection by using an integrated AHP approach which identifies twenty-two sustainable supplier selection criteria and three dimensions of criteria (economic, environmental, and social) through literature and experts' opinions. The paper aims at contributing to the process of distinguishing the important supplier selection criteria but also at evaluating the most efficient supplier for sustainability in supply chain, while remaining competitive in the market. In the same context, Taherdoost and Brard (2019) provide an assessment of the research on the issues of supply chain management, the supplier selection criteria and an evaluation of the supplier selection methods. The paper concludes that the application of a structured decision-making technique is vital, especially when considering both qualitative and quantitative criteria. In the same context, in a case study on international plastic raw material suppliers for a U.S. based manufacturer, Hosseini and Khaled (2019) distinguish between three categories of resilience capacities (selection absorptive, adaptive and restorative capacity) in a paper that examines the various relevant criteria for the choice of a supplier. The authors use predictive analytics models to describe the resilience value of each supplier, while improving predictive performance by combining binomial logistics regression and neural networks. Alikhani et al. (2019) focus on a simultaneous consideration of factors like sustainability and risk to propose a multi-method approach based on quantitative empirical investigations, and analytical modeling. Their approach incorporates both sustainability and suppliers' risk factors into the supplier selection problem and regards both risk-neutral and risk-averse decision-makers. The AHP approach is again used in an application to healthcare supply chain issues by Bhosale and Umap (2023). The paper evaluates suppliers using fuzzy stochastic data. The authors argue that the method is applicable to cases in which supplier selection must take place in a short time - period. Finally, a useful paper in more ways than one is Ocampo et al. (2018), which presents a revision of different methods of supplier selection from 2006 to 2016. The authors distinguish between various supplier selection approaches as being individual, integrated and emerging approaches, with the latter involving novel methodologies addressing specific supplier selection issues that include uncertain environment, risks, and sustainability.

Turning again to defense equipment issues, Qin et al. (2019) provide reference for the enhancement of naval equipment capability by studying the structure and main contents of task-oriented naval equipment support system. The study is based on hierarchical thinking, proposing relevant evaluation indices and aggregation methods. Finally, in a recent contribution, Dos Santos et al. (2021) focus on the specific case of choosing a medium-size warship to be built for the Brazilian Navy through the application of the Analytic Hierarchy Process (AHP) method. The paper considers a number of ship projects with regard to several operational and economic criteria. The evaluations of BN officers with recognized experience and knowledge in military operations has been used as an important input to this selection procedure. The evaluation is accompanied by a sensitivity analysis based on the relationship between standard deviation and mean scores to verify and increase the reliability of the ranking.

The literature review analysis revealed the usefulness of the AHP methodology in evaluating different options, among them in the selection process of the military sector. When it comes to military applications, it is evident that the selection process in real life is affected by geopolitical factors and therefore it would be interesting and useful to introduce geopolitical uncertainty in the AHP selection method. Our research comes to fill that gap by focusing on the case study of the supplier selection of combat vessels of the Hellenic Navy .

3. Materials and Methods

The comparison of the various vessels proposed to the Hellenic Navy requires the application of a method which will quantify the characteristics of each of the designs and will determine the standards considered for the selection process.

3.1 Analytic Hierarchy Process (AHP) methodology.

The method applied in this paper belongs to the Multi Criteria Decision Making methods (MCDM) (Caprace and Rigo, 2011) family and is known as the Analytic Hierarchy Process (AHP) (Saaty, 2008). This method is based on the development of matrices by comparing pairs of design choices, in our case vessel types. The score assigned to each vessel choice is produced by setting "how many times more preferred (better)" is one vessel choice over the other for a specific criterion, following Saaty's (2005) scale of relative importance (Table 1).

INSERT TABLE 1 HERE

According to Saaty, (2005, 2008) the scale indicates how many times more important or dominant is one element over another, with respect to the criterion used. The scores assigned vary between 1 and 9, with 1 attributed to vessel choices which are equal between them, for each specific criterion of a system, whereas 9 identifies a vessel choice which the panel of experts considers 9 times more preferred than the other for a specific criterion of a system. The scale described in Table 1 is used to evaluate the relative importance of each pair of vessels, as reported in Table 2.

INSERT TABLE 2 HERE

The last column of Table 2 denotes the formula for calculating the ranking vector of each vessel. This calculation is carried out by taking the average of the scores attributed to one choice over the sum of the scores that the rest of the choices received when compared to that one, as follows:

$$\frac{1}{N}\sum_{j=1}^{N}\left(\frac{v_{1,j}}{\sum_{i=1}^{N} v_{i,j}}\right), for\ vessel\ i = 1 \tag{1}$$

$$\frac{1}{N}\sum_{j=1}^{N}\left(\frac{v_{2,j}}{\sum_{i=1}^{N} v_{i,j}}\right), for\ vessel\ i = 2 \tag{2}$$

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$$\frac{1}{N}\sum_{j=1}^{N}\left(\frac{v_{N,j}}{\sum_{i=1}^{N} v_{i,j}}\right), for\ vessel\ i = N \tag{3}$$

Where $v_{i,j}$ is the relative importance between two alternative designs *i, j* of each design (vessel). We repeat the same process for each criterion of the same system.

Thereafter, following the same method, we construct the matrix of the relative importance for the each of the selected criteria (reliability, effectiveness, flexibility, redundancy) and their ranking vector (Table 3), as follows:

$$\frac{1}{4}\sum_{j=1}^{4}\left(\frac{m_{1,j}}{\sum_{i=1}^{4} m_{i,j}}\right), for\ criterion\ reliability \tag{4}$$

$$\frac{1}{4}\sum_{j=1}^{4}\left(\frac{m_{2,j}}{\sum_{i=1}^{4} m_{i,j}}\right), for\ criterion\ effectivenss \tag{5}$$

$$\frac{1}{4}\sum_{j=1}^{4}\left(\frac{m_{3,j}}{\sum_{i=1}^{4} m_{i,j}}\right), for\ criterion\ flexibility \tag{6}$$

$$\frac{1}{4}\sum_{j=1}^{4}\left(\frac{m_{4,j}}{\sum_{i=1}^{4} m_{i,j}}\right), for\ criterion\ redundancy \tag{7}$$

Where $m_{i,j}$ is the relative importance for the selected criteria $(m_{i,j})$

INSERT TABLE 3 HERE

The final evaluation of each of the design-vessels, for each of the systems (propulsion and power generation, armament and electronics) is calculated as the weighted average, where the weight is the relative importance of each criterion, of the all the ranking vectors of the vessels. Therefore, the final evaluation of the w vessel (v_w) for all the criteria, of each system, is calculated as follows:

$$m_1 v_w + m_2 v_w + m_3 v_w + m_4 v_w = \sum_{i=1}^{4} m_i u_w \quad (8)$$

We repeat the above process for each of the three systems (Propulsion and Power Generation, Armament, Electronics). The total assessment of a design choice is calculated by summing the scores over each criterion multiplied by the weight factor of the same criterion.

A fourth group of performance determinants, namely the Main Particulars, is also included using conventional grade scales, depending on the performance of each vessel applying the four criteria (complement, service speed, range and endurance, autonomy). Having evaluated the four systems we get the total weighted evaluation of each vessel (design), which expresses an operational benefit for the buyer, namely the Total Benefit Index (TBI). Thereafter, we calculate the Total Cost Index (TCI) considering the weight of each vessel's price in the average price of the vessels. The Net Benefit Index (NBI) for each vessel is the difference between the TBI and the TCI indices, which shows the ordering of the vessels according to the deterministic methodology.

3.2 Selection methodology under uncertainty

The results obtained under the AHP methodology consider different criteria and systems, thus allowing an in – depth analysis of the possible benefits and costs of each design. However, a supplier selection process that deals with military equipment should also consider factors that aim at diminishing the impact of uncertainty, such as conventional or hybrid threats. Therefore, the candidate suppliers of military equipment are usually in the position, in close cooperation with their governments, to offer to the possible buyer extra benefits, that we call Strategic Benefits (SB), in the form of alliances or technology transfer or even by strengthening the domestic Defence Industrial Base (DIB), to reduce uncertainty. To incorporate uncertainty in our evaluation, we apply Magrabe's (1978) formula. Specifically, we develop the following formula, in line with Wu (2009):

$$NBI_u = TBI\, N(d_1) - TCI\, N(d_2) \tag{9}$$

where, NBI_u is the Net Benefit Index under uncertainty, TBI is the Total Benefit Index and TCI is the Total Cost Index. $N(\cdot)$ denotes the cumulative normal distribution function. It also holds that:

$$d_1 = \frac{ln\left(\frac{TBI}{TCI}\right) + \sigma^2 \frac{T}{2}}{\sigma\sqrt{T}} \tag{10}$$

and

$$d_1 = d_2 - \sigma\sqrt{T} \tag{11}$$

Further, it holds that:

$$\sigma^2 = \sigma_{TBI}^2 + \sigma_{TCI}^2 - 2\rho\sigma_{TBI}\sigma_{TCI} \tag{12}$$

where, σ^2 is the combined volatility, ρ is the correlation between TBI and TCI and T is the duration of the contract.

It should be noted that several researchers use different approaches to determine volatility. For example, Taudes (1998) and Kumar (2002) argued that volatility can be estimated by the experience of the parties included in the process or even by conducting operational research. Bardhan et al. (2004) calculate the volatility by developing alternative scenarios, while Wu (2009) uses numerical simulations, a methodology which is similar to that of Bardhan's et al.

In estimating the volatility of our supplier selection process, we frame our analysis in two steps. In the first step, aiming at comparing the evolution of two indices (NBI, NBI_u) depending on various values of volatility, we conduct numerical simulations (volatility scenarios) with volatility ranging from 0 to 1

$(0.1, 0.2, 0.3, \ldots 0.9)$. At a second step, we introduce in our model the current volatility using as proxy the Geopolitical Risk Index (GPR) by Caldara and Iacoviello (2022) and specifically three different versions of it: (a) Geopolitical Threats Index, (b) Geopolitical Acts Index and (c) Geopolitical Risk index, which is the average of the previous two indices. In doing so, we can compare the NBI, NBI_u indices, assuming an objective measure of the current volatility.

4. Empirical Results

We frame our empirical analysis in two stages. First, we apply the AHP, to quantify the characteristics of each of the designs (Table A.1 of the Appendix) and calculate the NBIs. Second, we apply the selection methodology under geopolitical uncertainty to calculate the NBI_us and compare the results, namely the vessels' ordering under deterministic and stochastic environment, respectively.

4.1. Criteria Selection and their Ranking Vector

The first step to comparing the six (6) frigate designs is the selection of the criteria according to which the optimization will take place. Analyzing the operational requirements prevailing in the Greek maritime environment together with the integrated defence doctrine to which the Hellenic Navy is required to abide, the selected criteria are chosen to be reliability, effectiveness, flexibility and redundancy.

More specifically, reliability measures the extent to which the systems of a vessel perform as designed, something which implies that the higher the reliability the lower the degree of unplanned repairs. Effectiveness measures the degree to which the vessel can execute the mission required by the buyer, while flexibility measures the ability to undertake different types of operations or missions. Finally, redundancy measures the extent to which the vessel's critical systems are backed up and therefore, the ability of the vessel to remain operational following a sustained damage. Table 4 depicts the values of the relative importance assigned to each of the criteria. Table 5 presents the corresponding ranking vector for each of the criteria, in which reliability appears to be the most important one, as it measures the extent to which the systems of a vessel perform as designed. Given the friction prevailing in the Aegean and the Eastern Mediterranean Sea which requires pronounced military power, reliability ensures not only the attainment of the operational targets but also a low degree of unplanned repairs. Concerning effectiveness, this describes the degree to which the vessel can execute the mission required by the buyer, at the lowest possible cost. This is a paramount constraint, given the tight fiscal restrictions imposed on the Greek economy. Turning to redundancy, the high-friction environment under which the vessel is expected to perform entails considerable damage possibilities which should not deprive the vessel from accomplishing its mission. Finally, flexibility measures the ability to undertake different types of operations or missions. This has not been rated as being a top priority for the Hellenic Navy since the environment in which its units are expected to operate require more specialization rather than flexibility.

INSERT TABLE 4 HERE

INSERT TABLE 5 HERE

4.2. Evaluation of the Systems

At the next step we focus on four systems comprising the design of each vessel, namely, Propulsion and Power Generation, Armament, Electronics and Main Particulars. Our study takes for granted that all sellers offer a more or less similar full support logistic package.

4.2.1 Propulsion

The role of the propulsion and power generation systems of each vessel is decisive[1]. Given that the HN has shown preference for Diesel and/or Gas engines (mainly for their "or" propulsion variants like CODOG and COGOG), we need to observe that diesel engines provide a cost efficient and very reliable option while gas turbines will offer greater power density (acceleration and top speed), suffering however by higher consumption and being a more fragile arrangement. Indeed, Diesel engines grant considerable fuel economy, as well as extreme reliability and toughness,

[1] Several design choices are available such as CODAD (Combined Diesel and Diesel), CODOG (Combined Diesel or Gas), CODAG (Combined Diesel and Gas), DAGWARP (Diessel and Gas WARP stands for Water jet And Refined Propeller), CODLAG (Combined Diesel Electric and Gas), IEP (Integrated Electric Propulsion), et c. each of which will result in a different profile in terms of fuel consumption, propulsive power, power density, maneuverability and maintenance requirements.

while their wide commercial use means there are many places/ports where they can be repaired. For a balanced evaluation one must consider the Diesel engine disadvantages too, which sum up to their weight and size, as well as their noise and vibration (Kayadelen and Ust, Y, (2013).

Turning to the alternative engine options, Gas engines are compact with excellent acceleration and power. Electric motors are silent and efficient at low RPMs, while IEP is more damage resistant with more design freedom.

Each frigate proposed to the HN may be equipped with several propulsion and power generation choices, however our paper will focus on the arrangements considered during the evaluation by the HN. The attribution of the scores in this case has required the consultation of a panel of experts whose extensive experience and knowledge in naval warship design and/or naval operations satisfies the requirement described in AHP literature. The final evaluation depicted in Table 6, after considering the ranking vector of the criteria themselves (weight factors) shows that MMSC scores highest due to its redundant and effective arrangement followed closely by the MEKO class vessel, whereas FREMM and SIGMA frigates obtain similar scores for their propulsion and power generation design choices.

INSERT TABLE 6 HERE

4.2.2 Armament

Armament choices are crucial, by definition, for the operational ability of each naval unit. Again, every class may be equipped with a wide variety of different systems, thus the evaluation must be based on the relevant arrangements proposed during the selection process. The defence equipment arrangement borne by the vessel will determine, to a large extent, the missions and roles that the ships will be able to undertake. The results (Table A.2 of the Appendix) show that MEKO, FREMM and FDI are in rather equal terms. The vessels are equipped with anti-air (e.g., Aster – 30, ESSM) missiles, anti – surface (e.g., Exocet, Harpoon) missiles and anti – submarine (e.g., CAPTAS – 4) systems that ensure hit – to - kill capabilities and a high possibility to defeat suturing attacks. When it comes to MMSC, it performs poorly in this case, mainly because of two reasons; First, due to the lack of hull mounted sonar and second, due to the fact that its initial design referred to a littoral combat vessel, meaning that the addition of extra armament may come at a cost concerning its stability, during open - sea operations in Eastern Mediterranean.

Most types of vessels are well-equipped in terms of point- and area-defence systems. In terms of anti-submarine systems, the MMSC and possibly the Type 31 seem to be lagging behind. In the case of the former, even if a towed sonar is installed, this may present compatibility problems due to the waterjets noise.

Regarding aircraft carried, all types are equipped with a reliable helicopter (Seahawk, NH90 or Wildcat) and while the MMSC and the FDI use, in addition, UAVs (Firescouts for the former and Schiebel Camcopters for the latter).

4.2.3 Electronics

In all cases, the sensors and processing systems of all types of vessels are up to the standards of the state of the art in terms of technology. An exception may be the Lockheed Martin COMBATSS-21 combat management system, a modified version of Aegis, the technology of which dates to the decade of the eighties.

The electronics on board, in several cases coordinated with the armament of the vessel, cover a wide range of systems, such as target identification, navigational equipment, electronic countermeasures and integrated communication systems. However, unlike the armaments case, we assume that all vessels are equipped with cutting edge technology tailored to fulfill the requirements of modern sea warfare and therefore we rate them as being of equivalent performance (Table A.3 of the Appendix).

4.2.4 Main Particulars

Finally, we evaluate a fourth group of performance determinants, namely Main Particulars, which is composed of four criteria (complement, service speed, range and endurance/autonomy) that may be crucial for the performance of the vessels but have not been included in the evaluation thus far. To rate each of the main particulars we develop grade scales, depending on the performance of all vessel types regarding each of the four criteria as this is considered by the HN. In fact, the HN requirements call for a high number of endurance days and a range as long as possible, compatible with the Integrated Defence Doctrine demands. There is also a preference for a rather low complement figure given the country's declining birth rates. Table 7 shows the grade scales and Table 8 the corresponding evaluation for each vessel. The weight of each of the criteria in the final average of the Main Particulars system is 25%. We observe that

FDI scores highest mainly due to its autonomy (45 days), a performance which, however, is close to that of almost all competitors, with the exception of the MMSC, which is a littoral combat vessel. On the issue of the limited range of MMSC we should add that the shallow draft of the vessel, despite its advantage in the Aegean Sea, may become a serious disadvantage for operations in the Eastern Mediterranean Sea as it affects the ship's stability, especially in bad weather conditions. On the other hand, one cannot overlook the MMSC's speed performance along with the limited complement needs.

INSERT TABLE 7 HERE

INSERT TABLE 8 HERE

4.3 Total Benefit, Total Cost and Net Benefit Indices

Having evaluated the four systems of each vessel, we thereafter get the total weighted evaluation of each vessel. Each of the vessel's four systems offers an operational benefit and therefore the total weighted evaluation shows the total benefits for each vessel (Table 9). Note that Propulsion and Power Generation and Armament bear equal weights (25% each), while electronics bear a slightly lower weight (20%) contrary to the Main Particulars the weight of which is higher (30%), because of their relative importance as indicated by the Hellenic Navy requirements. We observe that, according to our methodology, the order of the vessels, concerning the operational benefits, is as follows: FDI (0.186), MEKO (0.186), FREMM (0.175), SIGMA (0.169), MMSC (0.146) and TYPE 31 (0.138).

INSERT TABLE 9 HERE

At the next step, we calculate the total cost of purchasing each vessel. Due to the lack of relevant data, we ignore the cost of maintenance of the vessels, thus focusing on the purchasing cost. Row 2 of Table 10 depicts the purchasing cost for each vessel and row 3 the average price of the vessels. The fourth row shows the ratio of each vessel's price over the average price while the Total Cost Index (row 5) is given by the ratio of percentage average price over the sum of the percentage average prices. Therefore, the sum of the Total Cost Index yields the ordering of the vessels in a form comparable to the Total Benefit Index.

INSERT TABLE 10 HERE

Finally, Table 11 shows the Net Benefit Index (NBI) for each vessel, which is the difference between the Total Benefit Index (TBI) and the Total Cost Index (TCI). In order to have a clearer picture of the differences among the indices of the vessels we multiply the NBI index by 1,000.

INSERT TABLE 11 HERE

4.4 Vessel selection under geopolitical uncertainty

Introducing a stochastic element in the selection process, in the sense of geopolitical uncertainty presupposes a theoretical framework and a set of assumptions in our model. In fact, our theoretical approach uses the political realism assumption arguing that the international system consists of states aiming at overpowering other rival states and thus dominate in the international power hierarchy (Hobbes, 1946; Morgenthau, 1985). In that sense, power is a tool for a state to serve its national interests and such a strategy demands primarily the formation of a political or military alliance, technology transfer and strengthening of the national Defence Industrial Base (DIB). Such power determinants contribute to overcoming the consequences of the security dilemma (Herz, 1951), as this is rooted in the anarchy of the state system (Sørensen et al., 2022).

The problem according to the political realism approach is that the target of international peace is a non-realistic one and that states are bound to face, sooner or later, the threat of war as a means of influence of rival states (Schelling,1996). It is straightforward that those threats increase geopolitical uncertainty faced by the states, which, in their turn, as a reaction to the threat of the adversary state, seek to increase their power, thus contributing to uncertainty reduction. Suppliers of military equipment are not only in a position to consider such threats faced by states but to offer, in addition, extra benefits to potential buyers, in order to counterbalance the uncertainty caused by the threat. It goes without saying that such a contribution is expected to be over and above all conventional operational benefits that the state receives from the purchase of new military equipment per se. We consider those extra benefits as being of strategic nature as they include, among others, a formation of a political or military alliance, technology transfer and strengthening of the national Defence Industrial Base (DIB) of the buyer. Strategic benefits can be interpreted as an extra cost (benefit) paid (received) by the seller (buyer) to increase its ability to face uncertainty caused by threats of its adversaries. Therefore, the higher the uncertainty, the higher the threat that the seller undertakes to counterbalance and therefore, the higher the expected net benefit for the buyer country. Equivalently, the higher the uncertainty, the higher the strategic benefits offered by the seller. In both interpretations, we expect a positive relationship between the value of the NBI_u and the volatility as this is described by Eq.12 and proxied, according to our theoretical approach, by different types of geopolitical uncertainty.

In the light of the analysis developed in this section, the main advantages of introducing uncertainty are the following: First, the military selection process accounts for the impact of geopolitical uncertainty and second, the selection process considers the extra benefits that a country receives from a potential supplier of military equipment, in order to counterbalance uncertainty.

Focusing on our case, the sellers that offered strategic benefits to the Hellenic Navy were Naval Group (French-Greek Military Partnership) and Lockheed Martin, because of the leading role of the US in NATO and the strengthened cooperation between Greece and US in the last decades. Thus, figure 1 presents the evolution of the Net benefit Index (NBI_u) under various values (scenarios) of volatility for each type of vessel. It should be noted that with the exception of Lockheed Martin (MMSC HF2) and Naval Group (FDI), the other sellers did not offer any strategic benefit, in the sense defined above, and consequently, no matter what the level of volatility is, the net benefits received by each vessel remain unchanged, and equal the net benefits shown in table 8, namely it holds that $NBI_u = NBI$.

INSERT FIGURE 1 HERE

Figure 1 depicts the importance of incorporating possible strategic benefits in the selection process of military equipment, based on different volatility (uncertainty) scenarios. Thus, based on the net benefits under uncertainty index, NBI_u for the FDI and MMSC HF2 frigates exceed those of other competitors that did not offer any specific strategic benefit. Therefore, the selection ordering changes, depending on the existence of such strategic offers and the level of volatility.

A final important issue that remains to be examined is a robustness check of these findings that favour the selection of FDI and MMSC HF2, not under scenarios, but in the context of an application of our model as this is described in section 3. 2. To do so we use as a proxy the Geopolitical Risk Index (GPR) and specifically three different versions of it: (a) Geopolitical Threats Index, (b) Geopolitical Acts Index and (c) Geopolitical Risk index, which is the average of the previous two indices. Table 12 depicts the NBI_u values for FDI and MMSC HF2 under the above three indices. For comparison reasons we add the corresponding NBI for the other frigates, that remains unaffected by the geopolitical environment, due to the lack of strategic benefits.

INSERT TABLE 12 HERE

According to our results FDI has by far the highest NBI_u value, with MEKO being in the second place, with a minimal difference from MMSC HF2. We conclude, therefore, that any suppliers' selection procedure concerning defence equipment must necessarily include considering the benefits that arise from possible strategic offers and their importance in strengthening a country's position in the global or regional hierarchy, depending on the prevailing geopolitical environment.

5. Sensitivity analysis

In this section we present two alternative scenarios concerning the evaluation of the vessels under uncertainty. If we accept that the weights assigned to the different systems and main particulars can be regarded as the standard ones, we shall move to examining the ordering of the vessels under two extreme scenarios. In these scenarios we consider assuming criteria regarding the propulsion and power generation, armament, electronics as well as the main particulars. In our initial scenario we have assumed that the weights of the main designs and the particulars were 25% for the propulsion and power generation, 25% for the armament, 20% for the electronics and 30% for the main particulars. This distribution ensures that the frigates can serve multiple roles in a balanced way.

However, to check the sensitivity of our results we now assume that the requirements of the HN are such that the operational capabilities of the frigates focus more on the Aegean Sea, which means that distances are very short and therefore speed and autonomy do not play a primary role. In fact, there may be higher requirements for multiple role missions with stronger armaments and electronics, rather than patrol missions far from the naval base of the frigates. Of course, each navy would prefer a vessel that covers all different types of missions, but due to scarcity there are always tradeoffs and opportunity costs. The new distribution of the weights becomes 20% for the main particulars, 30% for electronics, 30% for armaments and 20% for propulsion-power generation. Table 13 shows the net benefit index under alternative geopolitical threats for the above "Aegean Sea" system weight distribution scenario. The evolution of the corresponding NBI_u is shown in Figure 2. We observe that there is no substantial change in the ordering of the vessels. However, we find that the net benefit under uncertainty of the MMSC exceeds that of the MEKO for lower level of uncertainty $(\sigma^2 \geq 0.300)$, namely even when the strategic benefits are of lower importance. This evidence is in line with the fact that the MMSC vessel was initially designed as a littoral vessel and therefore it performs more efficiently in close seas as the Aegean Sea of this scenario.

INSERT TABLE 13 HERE

INSERT FIGURE 2 HERE

In the second sensitivity scenario the operational requirements of the vessels change in an attempt to focus more on operations far from the Aegean Sea reaching as far as the Red Sea, considering the recent geopolitical events. In such case the distribution of the weights becomes 50% for the main particulars, 15% for electronics and 17.50% for propulsion-power generation and 17.50% for armament. Table 14 shows the net benefit index under alternative geopolitical threats for the above "Red Sea" system weight distribution scenario. The evolution of the corresponding NBI_u is shown in Figure 3. We now observe that the net benefit under uncertainty of the MMSC vessel exceeds that of MEKO only for very high levels of uncertainty $(\sigma^2 \geq 0.700)$, namely when the strategic benefits play a major role. These findings are in line with the fact that the MMSC vessel was initially developed as a littoral vessel which means that it has less capabilities for operations far from the naval base, as the "Red Sea" scenario requires.

INSERT TABLE 14 HERE

INSERT FIGURE 3 HERE

6. Conclusions – Policy Implication

This paper provides empirical evidence on the issue of supplier selection as regards combat vessels, applied to the case of the order placed by the Hellenic Navy (HN) in 2021. Our scope is to present a new methodology of the supplier selection process that considers the technical aspects of the evaluation together with the uncertainty of the international environment. This methodology is developed in two stages. We first apply the AHP method to quantify the characteristics of each of the vessels and calculate the Net Benefits for each vessel following a deterministic selection process. At a second step, to account for possible geopolitical threats we introduce a stochastic element in our model's selection process in the sense of geopolitical uncertainty. On the basis of this, we consider the extent to which the initial hierarchy ordering of the vessels is altered when introducing the geopolitical threats variable and possible strategic benefits from military alliances. To the best of our knowledge geopolitical uncertainty has not been examined before in a military supply selection model.

Our empirical results point to the conclusion that geopolitical uncertainty may affect the preference ordering of a supplier selection in the case of combat vessels. Specifically, when uncertainty and strategic benefits are introduced in the analysis, we observe that the initial supplier selection order based on the deterministic AHP is affected to a considerable extent. Therefore, the paper underlines the necessity to consider not only the technical, operational and economic benefits related to the purchase of defense equipment, naval vessels in our case, but also possible relevant geopolitical benefits during the selection process, following strategic alliances.

Author contributions

The authors have equally contributed to all parts of this paper. All the authors have read and approved the final manuscript.

Data Availability Statement

The data employed in this research paper and the codes to replicate the results are available upon request.

Declarations

Consent for publication

This study presents original material that has not been published elsewhere.

Disclosure Statement

The authors declare that they have no competing interests, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

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Appendix to "Supplier Selection of Combat Vessels under Geopolitical Uncertainty: The Case of the Hellenic Navy"

Table A1: Designs

Design	Website
MMSC HF2	https://www.lockheedmartin.com/en-us/products/multi-mission-surface-combatant.html
FDI	https://www.naval-group.com/en/greece-launches-its-program-three-defence-and-intervention-frigates-fdi-hn-naval-group
SIGMA 11515 HN	https://www.damen.com/vessels/defence-and-security/sigma-frigates/sigma-multi-mission-frigate-11515
MEKO A300	https://www.thyssenkrupp-marinesystems.com/en/products-services/surface-vessels/frigates
FREMM-IT	https://www.fincantieri.com/en/products-and-services/naval-vessels/bergamini-class/
TYPE 31HN	https://www.babcockinternational.com/what-we-do/marine/defence/type-31/

Table A2: Evaluation of Armament system, each vessel and criteria, using AHP.

Reliability							
	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN	Ranking vector
MMSC HF2	1	0.2	0.2	0.2	0.2	0.2	0.038
FDI	5.000	1	1	0.5	0.5	1	0.147
SIGMA 11515 HN	5.000	1.000	1	0.5	0.5	1	0.147
MEKO A300	5.000	2.000	2.000	1	1	2	0.261
FREMM-IT	5.000	2.000	2.000	1	1	2	0.261
TYPE 31 HN	5.000	1.000	1.000	0.5	0.5	1	0.147
Effectiveness							
	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN	Ranking vector
MMSC HF2	1	0.250	0.333	0.333	0.333	0.333	0.057
FDI	4.000	1	2	2	2	3	0.313
SIGMA 11515 HN	3.000	0.500	1	1	1	2	0.174
MEKO A300	3.000	0.500	1.000	1	1	2	0.174
FREMM-IT	3.000	0.500	1.000	1	1	2	0.174
TYPE 31 HN	3.000	0.333	0.500	0.5	0. 5	1	0.106
Flexibility							
	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN	Ranking vector
MMSC HF2	1	0.25	0.25	0.25	0.25	0.25	0.048
FDI	4.000	1	1	1	1	1	0.190
SIGMA 11515 HN	4.000	1.000	1	1	1	1	0.190
MEKO A300	4.000	1.000	1.000	1	1	1	0.190
FREMM-IT	4.000	1.000	1.000	1	1	1	0.190
TYPE 31 HN	4.000	1.000	1.000	1	1	1	0.190
Redundancy							
	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN	Ranking vector
MMSC HF2	1	0.25	0.25	0.25	0.25	0.25	0.048
FDI	4.000	1	1	1	1	1	0.190
SIGMA 11515 HN	4.000	1.000	1	1	1	1	0.190
MEKO A300	4.000	1.000	1.000	1	1	1	0.190
FREMM-IT	4.000	1.000	1.000	1	1	1	0.190
TYPE 31 HN	4.000	1.000	1.000	1	1	1	0.190

Final evaluation							
	0.047	0.214	0.168	0.213	0.213	0.145	

Table A3: Evaluation of Electronics system, each vessel and criteria, using AHP.

Reliability							
	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN	Ranking vector
MMSC HF2	1	1	1	1	1	1	0.167
FDI	1.000	1	1	1	1	1	0.167
SIGMA 11515 HN	1.000	1.000	1	1	1	1	0.167
MEKO A300	1.000	1.000	1.000	1	1	1	0.167
FREMM-IT	1.000	1.000	1.000	1	1	1	0.167
TYPE 31 HN	1.000	1.000	1.000	1	1	1	0.167
Effectiveness							
	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN	Ranking vector
MMSC HF2	1	0.333	0.333	0.333	1	0.333	0.071
FDI	3.000	1	1	1	3	1	0.214
SIGMA 11515 HN	3.000	1.000	1	1	3	1	0.214
MEKO A300	3.000	1.000	1.000	1	3	1	0.214
FREMM-IT	1.000	0.333	0.333	0.333	1	0.333	0.071
TYPE 31 HN	3.000	1.000	1.000	1	3	1	0.214
Flexibility							
	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN	Ranking vector
MMSC HF2	1	1	1	1	1	1	0.167
FDI	1.000	1	1	1	1	1	0.167
SIGMA 11515 HN	1.000	1.000	1	1	1	1	0.167
MEKO A300	1.000	1.000	1.000	1	1	1	0.167
FREMM-IT	1.000	1.000	1.000	1	1	1	0.167
TYPE 31 HN	1.000	1.000	1.000	1	1	1	0.167
Redundancy							
	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN	Ranking vector
MMSC HF2	1	1	1	1	1	1	0.167
FDI	1.000	1	1	1	1	1	0.167
SIGMA 11515 HN	1.000	1.000	1	1	1	1	0.167
MEKO A300	1.000	1.000	1.000	1	1	1	0.167
FREMM-IT	1.000	1.000	1.000	1	1	1	0.167
TYPE 31 HN	1.000	1.000	1.000	1	1	1	0.167
Final evaluation							
	0.135	0.183	0.183	0.183	0.135	0.183	

TABLES (of main body)

Table 1: Saaty's (2005) scale of relative importance

Scale	Numerical rating $(v_{i,j})$	Explanation according to Saaty (2008)	Reciprocal $\left(\frac{1}{v_{i,j}}\right)$
Extremely preferred	9	The evidence favouring vessel *i* over vessel *j* for the selected criterion of the system is of the highest possible order	1/9
Very strong to extremely	8	Intermediate stages of relative contribution of vessels (i, j) to the selected criterion of the system	1/8
Very strongly preferred	7		1/7
Strongly to very strongly	6		1/6
Strongly preferred	5		1/5
Moderately to strongly	4		1/4
Moderately preferred	3		1/3
Equally to moderately	2		1/2
Equally preferred	1	Two vessels (i, j) contribute equally to the selected criterion of the system	1

Table 2: Saaty's (2005) matrix of relative assessments $(x_{i,m})$ for each criterion of the design-vessel $(v_{i,j})$ and their ranking vector

Type of Vessel	Vessel 1 $(j = 1)$	Vessel 2 $(j = 2)$	.... $(j = \cdots)$	Vessel N $(j = N)$	Vessel's ranking vector $(x_{i,m})$
Vessel 1 $(i = 1)$	1	$\left(\frac{1}{v_{1,2}}\right)$	$\left(\frac{1}{v_{1,\ldots}}\right)$	$\left(\frac{1}{v_{1,N}}\right)$	$\frac{1}{N}\sum_{j=1}^{N}\left(\frac{v_{1,j}}{\sum_{i=1}^{N} v_{i,j}}\right)$
Vessel 2 $(i = 2)$	$(v_{2,1})$	1	$\left(\frac{1}{v_{2,\ldots}}\right)$	$\left(\frac{1}{v_{2,N}}\right)$	$\frac{1}{N}\sum_{j=1}^{N}\left(\frac{v_{2,j}}{\sum_{i=1}^{N} v_{i,j}}\right)$
.... $(i = \cdots)$	$(v_{\ldots,1})$	$(v_{\ldots,2})$	1	$\left(\frac{1}{v_{\ldots,N}}\right)$	$\frac{1}{N}\sum_{j=1}^{N}\left(\frac{v_{\ldots,j}}{\sum_{i=1}^{N} v_{i,j}}\right)$
Vessel N $(i = N)$	$(v_{N,1})$	$(v_{N,2})$	$(v_{N,\ldots})$	1	$\frac{1}{N}\sum_{j=1}^{N}\left(\frac{v_{N,j}}{\sum_{i=1}^{N} v_{i,j}}\right)$

Table 3: Matrix of relative importance for the selected criteria (m_i) and their ranking vector

criterion	Reliability ($j = 1$)	Effectiveness ($j = 2$)	Flexibility ($j = 3$)	Redundancy ($j = 4$)	Criterion ranking vector (m_i)
Reliability ($i = 1$)	1	$\left(\frac{1}{m_{1,2}}\right)$	$\left(\frac{1}{m_{1,3}}\right)$	$\left(\frac{1}{m_{1,4}}\right)$	$\frac{1}{4}\sum_{j=1}^{4}\left(\frac{m_{1,j}}{\sum_{i=1}^{4} m_{i,j}}\right)$
Effectiveness ($i = 2$)	$(m_{2,1})$	1	$\left(\frac{1}{m_{2,3}}\right)$	$\left(\frac{1}{m_{2,4}}\right)$	$\frac{1}{4}\sum_{j=1}^{4}\left(\frac{m_{2,j}}{\sum_{i=1}^{4} m_{i,j}}\right)$
Flexibility ($i = 3$)	$(m_{3,1})$	$(m_{3,2})$	1	$\left(\frac{1}{m_{3,4}}\right)$	$\frac{1}{4}\sum_{j=1}^{4}\left(\frac{m_{3,j}}{\sum_{i=1}^{4} m_{i,j}}\right)$
Redundancy ($i = 4$)	$(m_{4,1})$	$(m_{4,2})$	$(m_{4,3})$	1	$\frac{1}{4}\sum_{j=1}^{4}\left(\frac{m_{4,j}}{\sum_{i=1}^{4} m_{i,j}}\right)$

Table 4: AHP Matrix for selected criteria.

Criteria	**Reliability**	**Effectiveness**	**Flexibility**	**Redundancy**
Reliability	1.000	3.000	6.000	1.000
Effectiveness	0.333	1.000	8.000	3.000
Flexibility	0.167	0.125	1.000	0.200
Redundancy	1.000	0.333	5.000	1.000

Table 5: Ranking vector for the selected criteria using AHP.

Ranking Vector	
Reliability	0.3913
Effectiveness	0.3336
Flexibility	0.0458
Redundancy	0.2293

Table 6: Evaluation of Propulsion and Power Generation system, each vessel and criteria, using AHP.

Reliability							
	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN	Ranking Vector
MMSC HF2	1	0.125	0.125	0.125	0.2	0.5	0.028
FDI	8.000	1	1	1	0.333	1	0.168
SIGMA 11515 HN	8.000	1.000	1	1	1	4	0.211
MEKO A300	8.000	1.000	1.000	1	4	7	0.313
FREMM-IT	5.000	3.000	1.000	0.25	1	5	0.216
TYPE 31 HN	2.000	1.000	0.250	0.142	0.2	1	0.064
Effectiveness							
	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN	Ranking Vector
MMSC HF2	1	8	5	3	4	4	0.373
FDI	0.125	1	4	0.25	1	4	0.121
SIGMA 11515 HN	0.200	0.250	1	3	6	8	0.200
MEKO A300	0.333	4.000	0.333	1	6	8	0.198
FREMM-IT	0.250	1.000	0.167	0.166	1	5	0.074
TYPE 31 HN	0.250	0.250	0.125	0.125	0.2	1	0.034
Flexibility							
	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN	Ranking Vector
MMSC HF2	1	0.5	0.333	0.5	1	0.5	0.090
FDI	2.000	1	3	0.5	3	2	0.224
SIGMA 11515 HN	3.000	0.333	1	0.333	2	3	0.162
MEKO A300	2.000	2.000	3.000	1	4	5	0.339
FREMM-IT	1.000	0.333	0.500	0.25	1	3	0,101
TYPE 31 HN	2.000	0.500	0.333	0.2	0.333	1	0.083
Redundancy							
	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN	Ranking Vector
MMSC HF2	1	6	5	7	3	5	0.418
FDI	0.167	1	0.25	0.333	0.142	0.2	0.034
SIGMA 11515 HN	0.200	4.000	1	1	0.25	0.333	0.076
MEKO A300	0.143	3.000	1.000	1	0.166	0.2	0.060
FREMM-IT	0.333	7.000	4.000	6	1	4	0.265
TYPE 31 HN	0.200	5.000	3.000	5	0.25	1	0.149
Final Evaluation							
	0.235	0.124	0.174	0.218	0.175	0.074	

Table 7: Grade scales of Main Particulars.

Complement		**Range**		**Service Speed**		**Endurance/autonomy**	
personnel	grade scale	nautical miles	Grade scale	Knots	Grade scale	days	Grade scale
80-100	0.25	3000-3500	0.05	25-30	0.05	15-24	0.05
100-120	0.20	3500-4500	0.10	30-35	0.10	25-34	0.10
120-140	0.15	4500-6000	0.15	35-40	0.15	35-44	0.15
140-160	0.10	6000-7500	0.20	40-45	0.20	45-54	0.20
160-180	0.05	7500-9000	0.25	45-50	0.25	55-60	0.25

Table 8: Evaluation of Main Particulars.

Criteria	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN
Complement (25%)	0.222	0.222	0.222	0.111	0.111	0.111
Speed (25%)	0.250	0.250	0.125	0.125	0.125	0.125
Range (25%)	0.053	0.158	0.158	0.211	0.211	0.211
Endurance/Autonomy (25%)	0.118	0.235	0.118	0.118	0.235	0.176
Average	**0.161**	**0.216**	**0.156**	**0.141**	**0.170**	**0.156**

Table 9: Total Benefit Index

Total criteria (main + particulars)	MMS C HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN
Propulsion and Power Generation (25%)	0.235	0.124	0.174	0.218	0.175	0.074
Armament (25%)	0.047	0.214	0.168	0.213	0.213	0.145
Electronics (20%)	0.135	0.183	0.183	0.183	0.135	0.183
Main Particulars (30%)	0.161	0.216	0.156	0.141	0.170	0.156
Total Benefit Index (TBI)	**0.146**	**0.186**	**0.169**	**0.186**	**0.175**	**0.138**

Notes: The sum of all the TBI indices equals 1.

Table 10: Total Cost Index

	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM -IT	TYPE 31 HN
Cost of Purchase (in mil. Euros)	510	765	600	575	750	500
Average price	616.67					
% Average Price	0.827	1.241	0.973	0.932	1.216	0.811
Total Cost Index (TCI)	**0.138**	**0.207**	**0.162**	**0.155**	**0.203**	**0.135**

Notes: The sum of all the TCI indices equals 1.

Table 11: Net Benefit Index

	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN
Net Benefit Index (NBI)	0.051	0.055	0.058	0.072	0.049	0.047
NBI X 1,000	**51.244**	**55.051**	**58.424**	**72.496**	**49.061**	**47.057**

Table 12: Net Benefit Index under alternative geopolitical threats

	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN
Geopolitical Threats ($\sigma^2 = 0.459$)	71.188	83.028	58.424	72.496	49.061	47.057
Geopolitical Acts ($\sigma^2 = 0.471$)	72.023	84.174	58.424	72.496	49.061	47.057
Geopolitical Risk ($\sigma^2 = 0.463$)	71.467	83.411	58.424	72.496	49.061	47.057

Table 13: Total Benefit Index (Aegean Sea scenario)

	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN
Geopolitical Threats $(\sigma^2 = 0.459)$	74.332	89.266	55.998	63.698	47.932	50.760
Geopolitical Acts $(\sigma^2 = 0.471)$	75.178	90.443	55.998	63.698	47.932	50.760
Geopolitical Risk $(\sigma^2 = 0.463)$	74.615	89.689	55.998	63.698	47.932	50.760

Table 14: Total Benefit Index (Red Sea scenario)

	MMSC HF2	FDI	SIGMA 11515 HN	MEKO A300	FREMM-IT	TYPE 31 HN
Geopolitical Threats $(\sigma^2 = 0.459)$	62.380	83.826	60.010	75.095	47.961	51.204
Geopolitical Acts $(\sigma^2 = 0.471)$	63.178	84.976	60.010	75.095	47.961	51.204
Geopolitical Risk $(\sigma^2 = 0.463)$	62.647	84.210	60.010	75.095	47.961	51.204

FIGURES

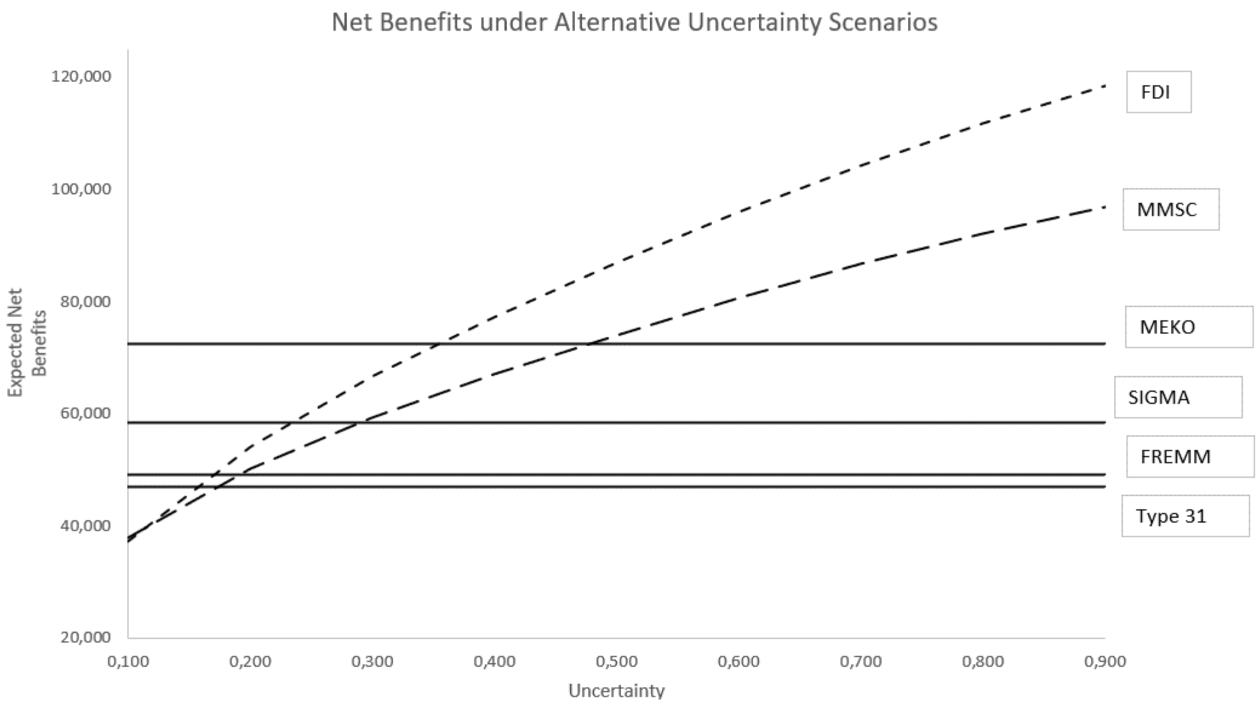

Figure 1: Evolution of NBI_u under alternative volatility scenarios

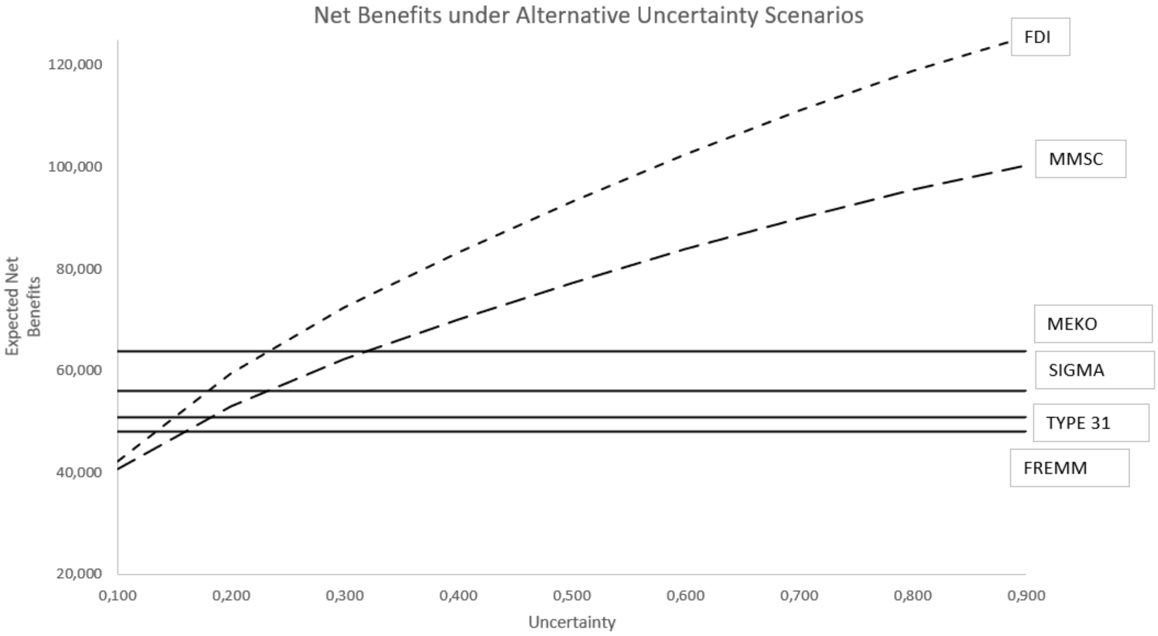

Figure 2: Evolution of NBI_u under alternative volatility scenarios and Aegean Sea scenario for systems weight distribution.

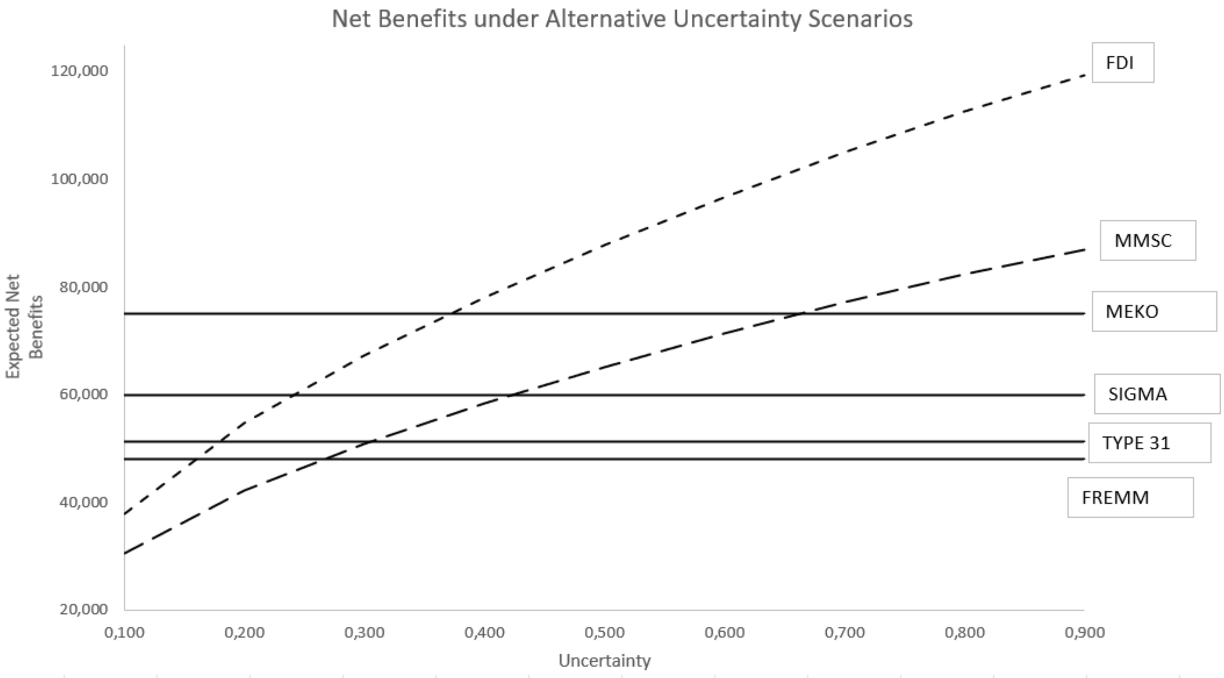

Figure 3: Evolution of NBI_u under alternative volatility scenarios and Red Sea scenario for systems weight distribution.