Evaluating Hellenic Coast Guard Vessels to Respond to a Maritime Operation Using the ELECTRE Method

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Abstract. Choosing the correct vessel to respond to an incident is of crucial importance for an officer stationed at the Hellenic Coast Guard Operations' Center or at the Joint Rescue Coordination Centre (JRCC). It has to be a vessel that meets more than one criterion, and the officer who makes the decision has to be absolutely certain of his choice. It must be a ship that can accomplish the mission in a satisfactory manner, in spite of the circumstances. This paper proposes the use of ELECTRE as a method of multicriteria assessment to make the optimal selection for the proper vessel for this kind of maritime missions in order to endure the weather and sea conditions and at the same time deploy at the required speed.
Keywords: Search and Rescue, SAR, Hellenic Coast Guard, ELECTRE, multiple criteria, decision-making, maritime operations.

I. INTRODUCTION

Decision making is admittedly a complex procedure aiming at the study and extensive analysis of the critical impact of all alternatives. It then tries to assemble all the demanding requirements of everything involved at the procedure. [5] The efficient use of such tools will optimize the quality of necessary information typically linked to the decision making and will enable the decision maker to accurately analyze the possible alternatives and decide with accurate precision. The possible selection of specific HCG vessel involved at maritime operations (e.g., search and rescue, patrolling, responding to an illegal action incident) is undoubtedly in need of such a procedure.

ISSN:1791-4469

There have been papers focusing on how to select the location of the stations of the search and rescue resources (R. Pelot et al, 2015 and M. Karatas, 2021), but as a permanent solution or for a period of months. In this paper, we consider that the resources, and more specifically the patrol boats, are placed at various Hellenic Coast Guard stations all over Greece ad hoc and can change at any time; a placement linked to other activities of each station, the capabilities of each port and the geographic complexity of Greece. Another key aspect that this paper takes into consideration is the human resources that are involved in the process, and more specifically the ability of the captain and its crew to address specific issues.

The vessel that will be engaged at a maritime operation has to be carefully selected with a complex decision-making procedure in order to take under consideration the response time, the number of persons involved, the work load, the unpredictable weather and sea conditions and the continuous fuel demands.

This paper describes the various criteria that need to be carefully considered, both quantitatively and qualitatively, and the used methodology that has to be followed for the aforementioned procedure.

To solve the problem of selecting the appropriate ship, we use a multicriteria method called ELECTRE. We choose this method because its primary aim is to extract the best or most satisfying alternative. Moreover, it results to a single alternative. That is what an officer needs; a decision and not a ranking of options, and most importantly an instant answer from a process that can be verified easily.

The vessels to choose from are the existing fleet of the Hellenic Coast Guard; data collected online and without containing any classified information. The data concerning the captains and the crew were created online with a random generator.

The main goal is to provide an officer of the JRCC or the Operations' Center with a practical tool to delegate the choosing of vessels for specific missions.

II. METHODOLOGY

As aforementioned, the method used to assess the alternative vessels is ELECTRE. Concluding the procedure, the ELECTRE method will have favored a specific vessel stationed at a specific port to respond based upon the specific type and location of maritime operation.

ELECTRE Method

Overview

This method consists of: a decision maker, a set of quantitative and qualitative criteria$\{C_1,C_2,\dots,C_n\}$ their respective weights$\{w_1, w_2,\dots,w_n\}$, a set of alternatives and their evaluation for each criterion. The user has to define a threshold of consensus $\hat{c}$and if he wants, he can also set a veto threshold that will disqualify some alternatives depending on their evaluation at s certain criterion.

Preferences in ELECTRE are modeled using binary outranking relations, S that means at least as good as. Assuming two alternates, a_1 and a_2, the above situations may occur:

- $a_1\ S\ a_2$ and not $a_2\ S\ a_1$, thus $a_1 > a_2$ meaning that a_1 is preferred to a_2
- $a_2\ S\ a_1$ and not $a_1 S\ a_2$, thus $a_2 > a_1$ meaning that a_2 is preferred to a_1
- $a_1\ S\ a_2$ and $a_2\ S\ a_1$, that a_1 is indifferent to a_2

All the criteria should be coded in numerical scales with identical ranges. We can assert that the statement "a_1 outranks a_2" denoted as $a_1\,S\,a_2$, only when two conditions hold; the first condition has to do with the concordance $C(a_1, a_2) \geq \hat{c}$ and the second has to do with the disagreement $D(a_1, a_2) \leq \hat{d}$.

For a given criterion the weightw_j reflects its voting power when it contributesto the majority which is in favor of an outranking. The weights do not depend neither on the ranges nor the encoding of the scales.

Concordance and discordance

To evaluate the relations and create an outranking relation, we have to create a table of concordance and a table of discordance; tables that comprise of a pairwise compare.

To build the table of concordance C one must first define the strength of the concordant coalition which is the sum of the weights associated with the criteria. The value in the (i,j) cell of the table, when $i \neq j$,is defined with the following concordance index:

$$C_{i,j} = C(a_i, a_j) = \frac{1}{W} \sum_{\{j:g_j(a_i) \geq g_j(a_j)\}} w_j$$

where $\{j: g_j(a_1) \geq g_j(a_2)\}$ is the set of indices for all criteria belonging to the concordant coalition with the outranking relation $a_1\,S\,a_2$ and $W = \sum_{j=1}^{n} w_j$.

After building the table of concordance, one must build the table of disagreement. The value in the (i,j) cell, when $i \neq j$, of the table expresses the measure of the discordance and the discordance level is defined as:

$$D_{i,j} = D(a_1, a_2) = \frac{1}{\delta} \max\,(g_j(a_1) - g_j(a_2))$$

where $\delta = max_{c,d,j}(g(c) - g_j(d))$ is the maximum difference found among all values per each criterion.

Core of alternatives

After having created both tables we proceed to create the core and result to the final alternative. The core at the beginning of the process contains all alternatives. The number of the number of alternatives inside the core is reduced while the threshold of concordance $\hat{c}$diminishes from 1 and the threshold of discordance $\hat{d}$increases from 0.

Next step is to eliminate alternatives from inside the core. For each pair ($\hat{c}$,$\hat{d}$), we check every cell in both tables and if $C_{i,j} = \hat{c}$ and $D_{i,j} = \hat{d}$ then the alternative $a_i$is stronger (more preferable) than a_j. If both criteria hold, then the alternative $a_j$is excluded from the core. We continue this process for each pair ($\hat{c}$,$\hat{d}$) until one alternative remains in the core. The alternative that remains in the core at the end of the process is the most preferable one.

Criteria and Alternatives

Criteria Used for the Decision Making

To correctly decide upon the vessel, one must carefully look upon many a criterion to judge wisely and derive scientifically to a conclusion. Therefore, each decision maker judges over the following 8 criteria. All criteria are numerical. To

ISSN:1791-4469

comply with the condition of identical scale that ELECTRE demands, all the values of the criteria are rescaled to 0-10 scale.

They cover as many key aspects as possible of a vessel and sufficiently examine the ability to be engaged in any operation and the fuel consumption to do so.

TABLE 1. Description of the criteria used for the decision making.

Criteria	Description
Maximum speed (miles/hr)	Top speed for the vessel.
Autonomy (miles)	Distance that the boat can travel and return to port without refueling.
Transportation capability (persons)	Number of persons (survivors, etc) that can carry safely back to shore/port
Readiness	Evaluation of the state of the vessel and the time needed for all personnel to assemble.
Captain's evaluation	Evaluation of the captain's capabilities.
Fuel Consumption (liters/hour)	The fuel consumption per hour of the vessel
Weather Capabilities (BF)	The maximum weather condition that the vessel is sea-worthy.
Distance (miles)	The distance from the position of the incident.

Weights

For the purpose of this study, we created only three scenarios that differentiated the weights of the criteria depending on the criticality of the case and the area to be covered.

The senior officer at JRCC or Center of Operations, depending on the case, will choose one of the abovementioned scenarios:

- SAR – small area: applies to a case of Search and Rescue that is close to land and with specific coordinates given.
- SAR – large area: applies to a case of Search and Rescue that extend to large sea area more than 100 km^2
- Illicit action: applies to a case that involves suspicious ships or illegal fishing activity, but no life is threatened.

TABLE 2. Criteria weights and thresholds used for each scenario.

Criteria \ Scenarios	SAR – small area	SAR – large area	Illicit action
Maximum speed	4	4	3
Autonomy	2	4	4
Transportation capability	2	2	2
Readiness	2	2	1
Captain's evaluation	3	2	4
Fuel Consumption	2	2	3
Weather Capabilities	4	4	4
Distance	2	4	3

Veto Threshold			
Maximum speed (miles/hr)	15		
Autonomy (miles)	400		
Weather Capabilities (BF)	7		
Distance*(nautical miles)	100	50	150

In the case of distance, due to the randomness of the ports where the vessels are stationed, if no vessels meet the threshold and no alternatives are given, we decide a new threshold; the new threshold is the sum of the distance of the nearest vessel and the default threshold for each scenario.

Alternatives

The vessels assessed by the decision makers comprise of specific categories of vessels from the fleet of the Hellenic Coast Guard that are currently in use. For security reasons, only what can be found in open sources will be presented [5] and none other value of the criteria will be disclosed. We will be assessing 54 vessels that are divided into 8 categories. We assign at random (for security reasons) the ports that are stationed at. The state of the vessel at the time of the incident is taking into account and only vessels that are labeled ACTIVE can be chosen.

TABLE 3. Types of Hellenic Coast Guard vessels assessed[1].

Model	Role	Length (meters)	Displacement (tones)	Number of boats in use
Lambro Halmatic 60	Salvage Boat	18	37	10
Sa'ar 4.5	OPV	58	450	3
Stan Patrol 5509	OPV	58.5	700	1
Vosper Europatrol 250 MkI	OPV	47.3	300	1
Class Dilos	Patrol Boat	29	86	6
Class Faiakas	Patrol Boat	24.6	-	2
CB-90 HCG	Patrol Boat - Combat	15.9	20	3
LCS-57 (Lambro 57) Mk I	Patrol Boat	18.2	28	19
LCS-57 (Lambro-57) Mk II	Patrol Boat	19.2	27	16

For security reasons, the captains' evaluation and the readiness of each alternative vessel was randomly generated.

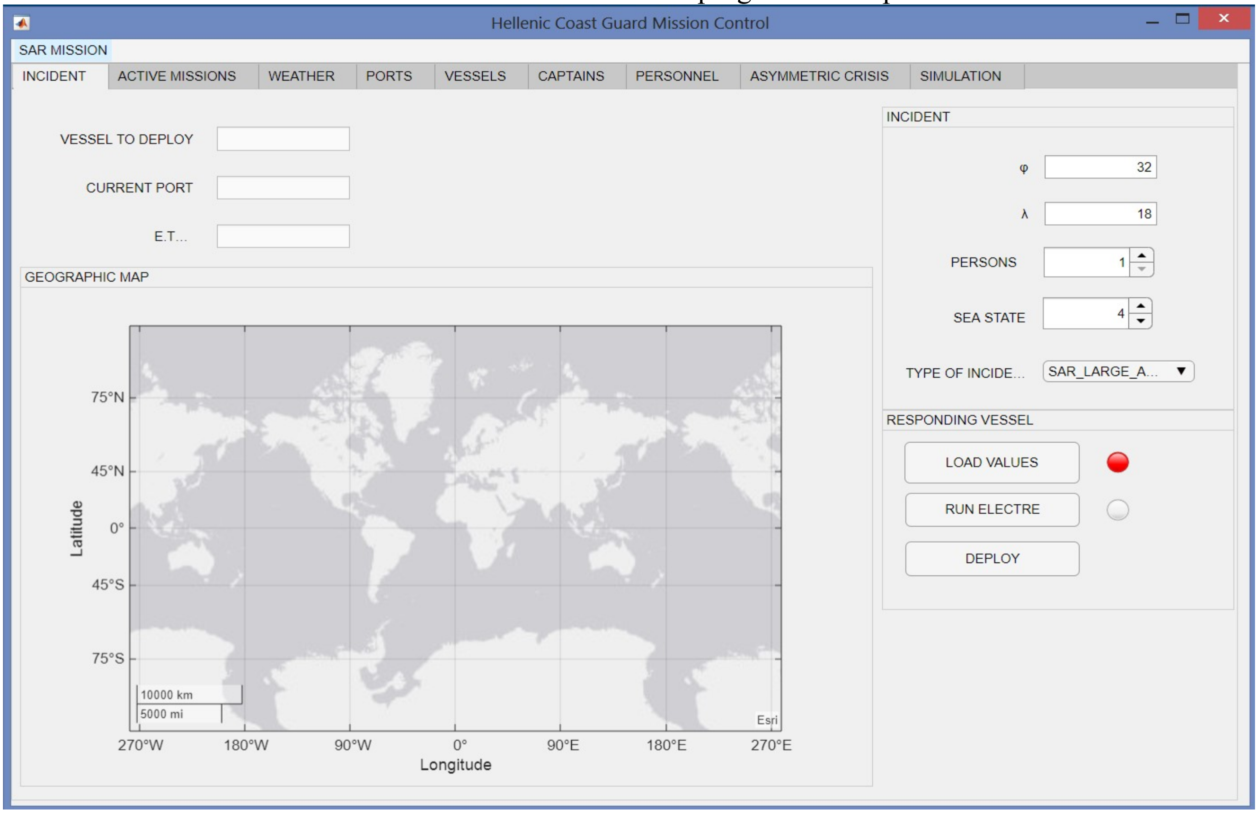
III. RESULTS

A mission control program was created in MATLAB with the data of the vessels pre-loaded. The operator enters all information and chooses the type of incident. Then, one loads the values into the program and runs ELECTRE to choose the most preferable vessel.

[1]Hellenic Coast Guard, https://de.wikipedia.org/wiki/Limeniko_Soma.

ISSN:1791-4469

IMAGE 1. Screenshot from the MATLAB program developed.



Case study

At first, let's assume a SAR call about a sailing yacht somewhere between Thira and Crete with estimated coordinates N 36⁰ 00' – E 025⁰ 00', which is a large sea area. The alternatives in range are the following:

TABLE 4. Hellenic Coast Guard SAR vessels alternatives (original core).

Call sign	Port
PV142	Irakleio
PV147	Irakleio
PV148	Kithira
PV149	Palaioxora Chaniwn
PV169	Kimi
PV601	Irakleio
PV609	Siteia

So the core for evaluation is core

$$\Pi = \{PV142, PV147, PV148, PV149, PV169, PV601,\ PV609\}.$$

TABLE 5. Table of concordance

C	PV142	PV147	PV148	PV149	PV169	PV601	PV609
PV142	0,00	0,91	0,91	0,91	0,91	0,57	0,39
PV147	0,87	0,00	0,91	0,91	0,91	0,57	0,39
PV148	0,87	0,91	0,00	0,91	0,91	0,57	0,39
PV149	0,78	0,91	0,91	0,00	1,00	0,48	0,39
PV169	0,78	0,91	0,91	0,91	0,00	0,48	0,39
PV601	0,78	0,83	0,83	0,83	0,83	0,00	0,83
PV609	0,78	0,78	0,78	0,78	0,78	0,87	0,00

TABLE 6. Table of discordance.

D	PV142	PV147	PV148	PV149	PV169	PV601	PV609
PV142	0,00	0,33	0,06	0,12	0,07	0,15	0,67
PV147	0,13	0,00	0,06	0,12	0,07	0,15	0,33
PV148	0,13	0,33	0,00	0,06	0,01	0,15	0,67
PV149	0,33	0,67	0,33	0,00	0,00	0,33	1,00
PV169	0,33	0,67	0,33	0,04	0,00	0,33	1,00
PV601	0,13	0,33	0,06	0,12	0,07	0,00	0,67
PV609	0,27	0,13	0,13	0,13	0,13	0,13	0,00

For $\hat{c} = 1$ and$\hat{d} = 0$, the alternative PV169 is discarded from the core as it is weaker alternative against PV149. New core $\Pi = \{PV142, PV147, PV148, PV149, PV601,\ PV609\}$.

For $\hat{c} = 0.91$ and$\hat{d} = 0.04$:PV169S PV149 and PV149 is discarded from the core. New core $\Pi = \{PV142, PV147, PV148, PV601,\ PV609\}$.

For $\hat{c} = 0.91$ and$\hat{d} = 0.06$: PV142 S PV148, PV147 S PV148 and PV148 S PV149; PV148 is discarded from the core. New core $\Pi = \{PV142, PV147, PV601, PV609\}$.

For $\hat{c} = 0.87$ and$\hat{d} = 0.13$:PV147 S PV142, PV148 S PV142 and PV609 S PV601; PV142 and PV601 are discarded from the core. New core $\Pi = \{\ PV147, PV609\}$.

For $\hat{c} = 0.78$ and$\hat{d} = 0.13$:PV609 S PV147, PV609 S PV148, PV609 S PV149 and PV609 S PV169; PV147 is discarded from the core. New core $\Pi = \{\ PV609\}$.

The vessel deployed is PV609 from the port of Siteia and will be in the area in approximately one and a half hours.

Exception

Then, we assume that there is a SAR call in coordinates N 35^{o} 00' – E 020^{o} 00'. The operator will choose the SAR – large area scenario. The closest port is more than 100 nautical miles away, which means that no alternatives can pass the veto threshold set for the distance criterion. Thus, a new threshold is set which is the minimum distance of an existing vessel plus the scenario's threshold.

The alternative chosen for the SAR mission is OPV60 stationed at the port of Gytheion. If there was a case of illicit action and not SAR, the alternative would have been OPV50 stationed at the port of Souda.

ISSN:1791-4469

IV. CONCLUSION AND PERSPECTIVES

In this paper, a set of criteria for evaluating a fleet of vessels is presented using ELECTRE. ELECTRE can present significant advantages to the evaluation. It is a method with no extent to the number of criteria used. Moreover, it takes into account the current status of the ship including the fuel costs, but also the assessment of the personnel involved.

The result shows that all factors were taken into account. Depending on the significance of the incident, the weights were adjusted accordingly. A vessel stationed at Heraklion was the one chosen for a SAR incident at a given point as it was the fastest and not just the closest one. Assuming illegal action and not a SAR incident takes place at the same location, the vessel responding would be the one stationed at Gytheion with slower response time.

There are necessary modifications to be done that will enable an officer to have a system that also tracks ships and fishing vessels to coordinate more effectively. The possible use of a TOPSIS method would benefit the decision-making process.

Concluding, the method presented is an extremely effective tool for any decision maker deciding over which vessel must be engaged at an incident. It can be progressively extended to more than HCG operations. One can accurately evaluate either the helicopters participating in SAR missions or the need to involve a fishing/merchant ship in the area.

ACKNOWLEDGMENTS

This is a work carried out in the framework of “Multicriteria Decision Making Systems” Electrical and Computer Dept. PhD course at National Technical University of Athens after a great feedback and guidance from Professor Dr. Psarras Ioannis.

The opinions of the writer are purely for academic purposes and do not depict at any case those of the Hellenic Ministry of Maritime Affairs and Island Policy or the Hellenic Coast Guard.

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ISSN:1791-4469