A Decision Aiding System Based On Multiple Criteria For The Support Of The Hellenic Coast Guard in Maritime Search And Rescue Operations

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Abstract. Search and Rescue maritime operations depend on the suitable choice of ships that can complete satisfactorily their mission and rescue every person in danger, despite the circumstances. To achieve that, one must possess the proper type of ships for this kind of missions to endure weather and sea conditions and deploy at maximum speed. This paper proposes the necessary criteria to be assessed by the UTAstar method to achieve optimal selection.

Keywords: Search and Rescue, SAR, Hellenic Coast Guard, UTAstar method, multiple criteria decision making.

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. [7] The efficient use of such key tools will optimize the necessary quality of accurate information typically linked to the decision making and will enable the decision makers to accurately analyze and decide more precisely the possible alternatives. The possible selection of specific types of ships involved at maritime operations for Search and Rescue is undoubtedly in need of such a procedure.

The specific type of boats used at maritime Search and Rescue operations naturally have to be carefully selected with a complex decision making procedure in order to take under consideration the time response, the work load, the unpredictable weather and sea conditions and the continuous economic demands.

This paper describes and discusses 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 address the problem of choosing Search and Rescue (SAR) ships, we use a multicriteria method called UTAstar [2] (Siskos and Yannacopoulos, 1985) which is an optimization of UTA[3] method (Lagreze and Siskos, 1982).

Solutions are obtained for the existing fleet of the Hellenic Coast Guard. For security reasons, none of the ships' capabilities will be presented.

The main goal is to provide an executive committee with a practical tool to delegate the choosing of new coast guard ships for specific missions.

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II. METHODOLOGY

As aforementioned, the method used to assess the alternative SAR ships is UTAstar [2]. UTAstar presents a low structural indicator and the capability to compare the alternative ships pairwise. It can also handle effectively both qualitative and quantitative criteria. UTAstar method is characterized as a monotonic regression method for analyzing the decision makers' a priori preferences (Matsatsinis, 2005) [7].

UTAstar is a set of utility functions that are models consistent with the decision maker's a priori preferences. In order to assess this set of utility function, the method uses ordinal regression method. Using linear programming, it adjusts optimally additive non-linear utility functions so that they fit data which consist of multicriteria evaluations of some alternatives and a subjective ranking of these alternatives given by the decision maker.

Concluding the procedure, the UTAstar method will have ranked the types of ships from the most suitable to the least suitable one for maritime SAR operations.

UTAstar Method [2, 4, 5, 7]

Overview

This method consists of three things: a set of decision makers, a set of quantitative and qualitative criteria and a set of alternatives. At first, a questionnaire must be completed by each decision maker so as to evaluate each alternative over each criterion. Each criterion can be evaluated with a value within the boundaries (best and worst value) that have been a priori set and given to the decision maker. After that, the decision maker ranks all the alternatives. There is predefined structure of preferences (>, ~) with which one declares either absolute preference (>) or indifference (~) over a set of alternatives; this means that one can rank two or more alternatives at the same place.

Once the decision maker expresses his judgment in a form of a ranking, the method estimates an additive utility function that is as consistent as possible with the decision maker's opinion. This allows the decision makers to do an empirical evaluation and rank the ships regardless of the quantitative criteria.

Then, all questionnaires are fed to the method in order to process them following four simple steps that are defined below. The result is a table of alternatives with a specific value that defines the final rank of each alternative.

Definitions

Assume $\mathrm{A} = \{\mathrm{a}_1, \mathrm{a}_2, \dots, \mathrm{a}_\mathrm{m}\}$ is the set of the alternative ships offered for evaluation by the set $J = \{1, 2, \dots, p\}$ of decision makers over the set of criteria $g: g_1, g_2, \dots, g_n$. Each criterion g represents a quantitative/qualitative monotonic variable. For each $\mathrm{a_i} \in \mathrm{A}$, $g(\mathrm{a_i}) = [g_1(\mathrm{a_i}), g_2(\mathrm{a_i}), \dots, g_n(\mathrm{a_i})]$ depicts the multicriteria judgment of the i^{th} alternative ship expressed by each decision maker.[7]

FIGURE 1. Depiction of vector g(a$_i$) for quantitative criteria.[7]

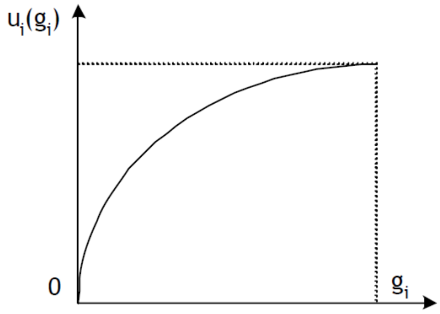
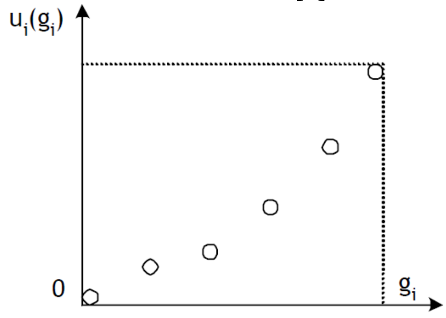


FIGURE 2. Depiction of vector g(a$_i$) for qualitative criteria.[7]



It is vital to clarify the scales of measurement for each criterion. Thus, g_{i*} is the worst value for the criterion and g_i^* is the best value. All the values in between are put in $\alpha_i - 1$ spacing. And so the scales for the i criterion is as follows: $G_i = \{g_{i*} = g_i^1, g_i^2 = g_i^l, \dots, g_i^{\alpha_i} = g_i^*\}$. The value for the best and worst value, the monotony, the spacing α_i for each criterion is given beforehand by the system.

TABLE 1. Spacing, value range, monotony of criteria.

Best Value	$r^* = 1$	$g_1 *$	$g_2 *$	...	g_{n*}
Worst Value	$r *$	$g_1{}^*$	$g_2{}^*$	...	$g_n{}^*$
Monotony	0 if Best Value > Worst Value, else 1				
Spacing		s_1	s_2	...	s_n

The k^{th} decision maker expresses his judgement and ranks each type of ship, which is then introduced at the vector $r_k(a) = [r_k(a_1), r_k(a_2), \dots, r_k(a_n)]$. The alternatives with small numbers signify better suitability and the alternative with $r_1^* = 1$ is the most suitable. The set of alternatives $A_k = \{a_1, \dots, a_k\}$ is sorted according to the ranking of the decision maker. The judgment for each alternative over each criterion for the k^{th} decision maker produces the table below.

TABLE 2. Criteria and alternatives for $\boldsymbol{k^{th}}$ decision maker.

Alternative\Criterion	$\boldsymbol{g_1}$	$\boldsymbol{g_2}$	...	$\boldsymbol{g_n}$	**Ranking**
$\boldsymbol{a_1}$	$g_{1_k}(a_1)$	$g_{2_k}(a_1)$	...	$g_{n_k}(a_1)$	$r_{1_k}(a_1)$
$\boldsymbol{a_2}$	$g_{1_k}(a_2)$	$g_{2_k}(a_2)$	...	$g_{n_k}(a_2)$	$r_{2_k}(a_2)$
...	...	...	...	...	...
$\boldsymbol{a_m}$	$g_{1_k}(a_m)$	$g_{2_k}(a_m)$	...	$g_{n_k}(a_m)$	$r_{m_k}(a_m)$

The first thing one must do is to sort the alternatives according to the ranking for each decision maker. In this method, one can rank the same two or more alternatives. Hence, there are two cases compared pairwise; either one alternative is preferred (>) or both alternatives are ranked the same (~).

Next step is the aggregation of the n criteria and the errors of underestimation $\sigma^+(a_i)$ and overestimation $\sigma^-(a_i)$ in one global value $u(g(a_i))$ as follows:

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$$u(g(a_i)) = u_1(g_1(a_i)) + u_2(g_2(a_i)) + \cdots + u_n(g_n(a_i)) - \sigma^+(a_i) + \sigma^-(a_i) = \sum_{j=1}^{n} u_j\left(g_j(a_i)\right) - \sigma^+(a_i) + \sigma^-(a_i), i = 1..m$$

This global value is broken into additive utility functions $u_j\left(g_j(a_i)\right)$. For the evaluation of the partial utility functions, all values of u must be always expressed in terms of the values of the boundaries of each spacing of the i^{th} criterion,

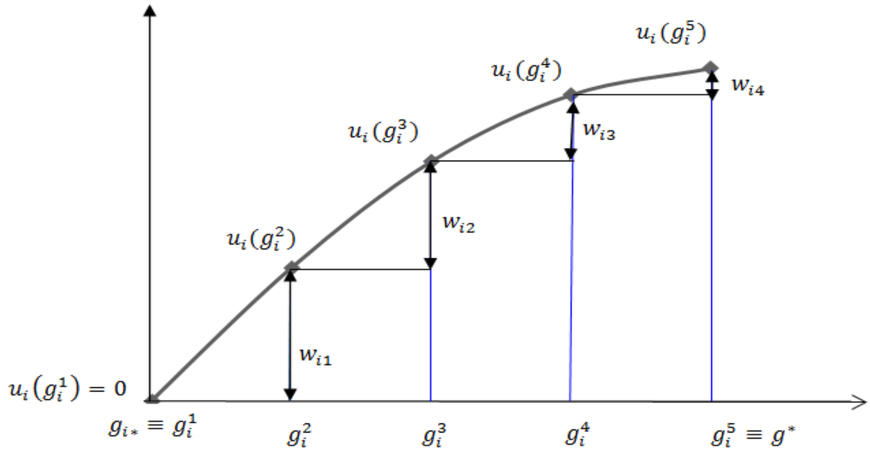
$$u_i(g_i(\alpha_l)) = u_i(g_i^j) + \frac{g_i(x) - g_i^j}{g_i^{j+1} - g_i^j}[u_i(g_i^{j+1}) - u_i(g_i^j)]$$

These partial utility functions represent the preferences of the decision maker from the least desirable alternative, where $u_i(g_i^1) = 0$, to the most desirable one $u_i(g_i^*)$. This is clearly shown in Figure 4.

The restrictions of monotony are modeled with the variables w_{ij}

$$w_{ij} = u_i(g_i^{j+1}) - u_i(g_i^j) \geq 0, \forall i = 1,2,\dots,n, \qquad j = 1,2,\dots,s_i - 1$$

FIGURE 4. Additive utility function versus criteria. [9]



The total value of the alternatives $u(g(\alpha_k))$, $k = 1,2,\dots,m$ is expressed as the sum of all weights and is zero for the worst value.

$$\begin{cases} u_i(g_i^1) = 0, \quad \forall i = 1,2,\dots,n \\ u_i(g_i^j) = \sum_{i=1}^{j-1} w_{ij}, \forall i = 1,2,\dots,n \quad j = 2,3,\dots s_i - 1 \end{cases}$$

The process of comparing pairwise follows. It is symbolized with Δ. It takes into account the initial ranking and the utility functions.

$$\Delta(a_k, a_{k+1}) = u_i(g(\alpha_k)) - \sigma^+(\alpha_k) + \sigma^-(\alpha_k) - u_i(g(\alpha_{k+1})) + \sigma^+(\alpha_{k+1}) - \sigma^+(\alpha_{k+1})$$

with the following restrictions where δ is the threshold and defined by the system. In this particular scenario is set to 0.05.

$$\Delta(a_k, a_{k+1}) \begin{cases} \geq \delta, & if \;\; a_k > a_{k+1} \\ = 0, & if \;\; a_k \sim a_{k+1} \end{cases}$$

Linear Program

To complete the process one must solve the Linear Program of minimizing the sum of the underestimating and overestimating errors of all the alternatives.

$$Minimize\ z = \sum_{k=1}^{m} (\sigma^+(\alpha_k) + \sigma^-(\alpha_k))$$

Subject to

$$\Delta(a_k, a_{k+1}) \geq \delta, \qquad if \;\; a_k > a_{k+1} \; \forall k = 1,2, \ldots m$$

$$\Delta(a_k, a_{k+1}) = 0, \qquad if \;\; a_k \sim a_{k+1} \;\; \forall k = 1,2, \ldots m$$

$$\sum_{i=1}^{n} \sum_{j=1}^{s_i - 1} w_{ij} = 1$$

$$w_{ij} \geq 0, \sigma^+(\alpha_k) \geq 0, \sigma^-(\alpha_k) \geq 0, \forall i, j, k$$

Final Step[9]

In the final step, one must test the multiple or near optimal solutions of the linear program and in case of non uniqueness one should find the mean additive value function of those (near) optimal solutions which maximize the objective functions:

$$\sum_{i=1}^{m} [\sigma^+(\alpha_i) + \sigma^-(\alpha_i)] \leq z^* + \varepsilon$$

where z^* is the optimal value of the linear program and ε a very small positive number.

Advantages

The greatest advantage in using the UTAstar method is the use of a double error equation, both for underestimation (σ^+) and overestimation (σ^-), leading to an optimized decision (figure 3). The double error equation is used to make the alternative regain its position in the predefined ranking. It is an amount of utility that will be added or subtracted depending on the position of the alternative on the curve as shown in the following figure.

Another advantage is the ability to take into account both qualitative and quantitative criteria; the experience one has is very important in search and rescue as the numbers cannot depict fully the sea conditions.

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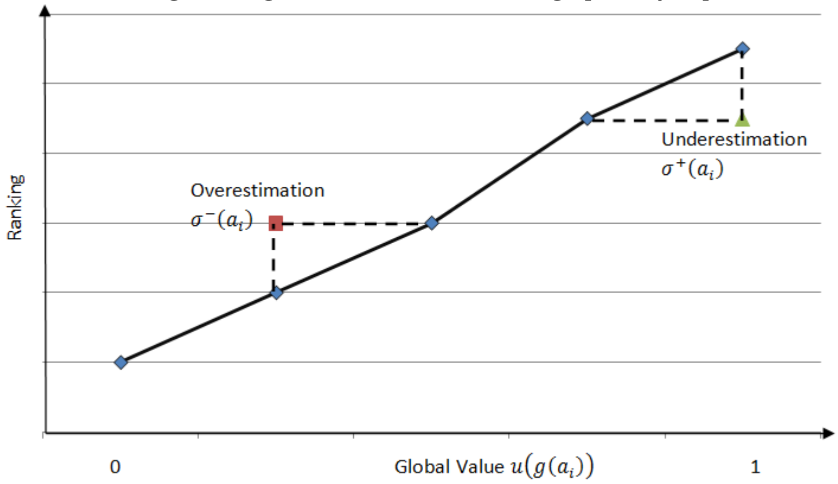
FIGURE 3. Ranking versus global value. Double error graphically explained. [9]



Criteria and Alternatives

Criteria Used for the Decision Making

To correctly decide upon the types of the ships considered, 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 20 criteria, 13 quantitative and 7 qualitative. They cover as many key aspects as possible of a SAR ship and sufficiently examine the ability to be engaged in a SAR operation and the economic cost to do so.

TABLE 3. Description and characteristics of the criteria used for the decision making. Values with (-) cannot be disclosed for security reasons.

	Criteria	**Description**	g_{i*} **(Worst Value)**	g_i^* **(Best Value)**	s_i	**Mono-tonicity**
General Characteristics	Maximum speed (miles/hr)	Top speed for the type	18	45	3	0
	Autonomy	Distance that the boat can travel and return to port without refueling.	-	-	3	0
	Transportation capability	Number of persons (survivors, etc) that can carry safely back to shore/port	-	-	3	0
	Required personnel	Minimum number of officers needed	-	-	3	0
Engine Characte-ristics	Engine suitability	Check if the engines are proper and can withstand the stress of maritime operations at all weathers	1	10	10	0
	Horsepower	Total horsepower of all the engines on the ship	-	-	5	0
ra ct eri	Technical	The specialization required	1	10	10	0

	Specialization	for a service to the ship or to address major problems on the ship				
	Ease of finding spare parts	The extent of specificity of the parts needed	1	10	10	0
	Fuel Tanks	The total amount of fuels that the ship can carry	-	-	4	0
	Fuel consumption	The amount of liters consumed in an hour	-	-	4	1
	Lubricant consumption	The amount of lubricant oils consumed in an hour	-	-	4	1
Hull Characteristics	Hull suitability	The hull's design (e.g. V-shaped) suitable for extreme weather conditions	1	10	10	0
	Sailing in extreme weather conditions	The seakeeping of the ship and how it responds to extreme sea conditions (>8BF)	1	10	10	0
	Maximum wind speed(BF)	The maximum wind speed that the ship stays seaworthy	1	10	10	0
	Material strength	The material of the hull defines the weather conditions the ship can stay seaworthy	1	10	10	0
	Self-righting	If the ship has the capability to self-right or not	0	1	1	0
Costs	Warranty	If the manufacturer gives a few years warranty	0	1	1	0
	Engine maintenance	The cost of one engine service	-	-	4	1
	Maintenance cost	The cost of all systems service	-	-	4	1
	Buy/Restore	The cost to buy this type of ship or to restore a seized/ decommissioned one	20.000.000	10.000	5	1

Alternatives – SAR Boats Assessed

The types of ships assessed by the decision makers comprise of the specific types of boats that the Hellenic Coast Guard currently uses for maritime SAR operations. For security reasons, only what can be found in open sources will be presented [8] and none other value of the criteria will be disclosed.

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TABLE 4. Type of Hellenic Coast Guard SAR boats assessed.

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

Decision Making Process

A standard questionnaire for the mentioned types of boats was created. The quantitative criteria were precisely defined from the manual specification of each type. 10 decision makers with vast experience in these types of boats were asked to express their judgment over the qualitative criteria. After that, they ranked the considered 9 types of boats from the most suitable to the least suitable one to participate in a maritime SAR operation.

The 10 questionnaires were input to a MATLAB-based UTAstar fully customizable program created for the purpose of this project.

III. RESULTS

The MATLAB-based program solved the linear problem of UTAstar for the 10 evaluations of the 20 criteria for the 9 types of boats and resulted in the final weights of each type of boat. The final rank is presented below.

TABLE 5. Resulting ranking of the existing fleet of HCG boats engaged in SAR operations.

Suitability (Best to Least)	Type
1	CB-90 HCG
2	LCS-57 (Lambro-57) Mk I
3	Class Dilos
4	Vosper Europatrol 250 Mk I
5	Sa’ar 4.5
6	Class Faiakas
7	Stan Patrol 5509
8	Lambro Halmatic 60
9	LCS-57 (Lambro-57) Mk II

IV. CONCLUSION AND PERSPECTIVES

In this paper, a set of criteria for evaluating various types of boats using UTAstar[2] is presented. UTAstar has significant advantages to the evaluation. Firstly, it can be customized accordingly and add more criteria if needed. Moreover, it takes into account, not only the facts and the economic costs, but also the personal opinion of a decision maker.

The result shows that all factors were taken into account. A ship of the Hellenic Coast Guard that costs 20.000.000, 00€ did not rank first, although it is the fastest. There are necessary modifications to be done that will enable a committee to focus on a set of the abovementioned criteria which are more relevant to the nature of the intended use. The possible use of a weighted UTAstar method would benefit the decision making process.

Concluding, the method presented is an extremely effective tool for any committee deciding over which type of boat/ship must be acquired. It can be progressively extended to more than SAR operations. One can accurately evaluate either the helicopters participating in SAR missions or even the types of ships of a naval fleet assigned to different kind of tasks.

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