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THE USAGE OF MCDM TECHNIQUES IN DETERMINING THE CONSTANTS OF CRITERIA'S WEIGHT OF WARSHIP DESIGN

SAVAŞ GEMİSİ TASARIMINDAKİ KRİTER KATSAYI AĞIRLIKLARININ SAPTANMASINDA ÇOK KRİTERLİ KARAR VERME TEKNİKLERİNİN KULLANIMI

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Abstract

This research is focused on determining the constants of criteria's weights of warship design by using the Analytic Hierarchy Process (AHP), one of the Multiple Criteria Decision Making (MCDM) Techniques. The ship type is chosen as Littoral Combat Ship (LCS) that is a new and very operational warship class. The study is based on the classification of the criteria of LCS and a questionnaire which is held among the experts on ship design, sensor systems, weapon systems and operators from different class of warships.

With this study an initial research for analysing or prioritizing the importance of the LCS design criteria is determined. By regarding the new concept of naval operations in littoral waters and the sea borders of TURKEY connected to mostly littoral waters; this study may be accepted as a trigger for the total ship engineers, electrical engineers who work on system design for warships and system engineers on this area. The other contribution of this study is to offer three different methods for computing weights in group decision making applications and the consistency of the results of these three different methods. These methods are Geometric Mean, Trimmean and Geometric Means of the Group's Weights.

Özetçe

Bu araştırma Çok Kriterli Karar Verme Tekniklerinden biri olan Analitik Hiyerarşi Proses metodu ile savaş gemisi tasarımındaki kriterlerin ağırlık katsayılarının hesaplanmasına odaklanmıştır. Gemi tipi olarak yeni ve çok operasyonel bir tip olan LCS sınıfi bir gemi seçilmiştir. Bu çalışma LCS'in kriterlerinin sınıflandırılmasını ve gemi inşaa, sensor sistemleri, silah sistemleri ve farklı tip gemilerde operatorlük konularında uzman sayılan personel tarafından yapılmış bir anket uygulamasına dayanmaktadır.

Bu çalışma ile LCS tasarım kriterlerinin analiz edildiği ve önceliklerinin belirlendiği başlangıç mahiyetinde bir araştırma icra edilmiştir.Kıyıya yakın sahalarda icra edilen deniz operarasyonları konsepti ve büyük çoğunluğunun kıyıya yakın sahalara bağlantılı olduğu kabul edilen Türkiye deniz sınırları düşünüldüğünde, bu çalışma toplam gemi inşaa mühendislerine, savaş gemileri için sistem tasarımında çalışan elektronik mühendislerine ve bu alanlarda çalışan sistem mühendislerine bir ilk adım olarak görülebilir.Bu çalışmanın diğer bir katkısı ise, grup karar verme uygulamalarındaki ağırlık hesaplamalarının üç farklı metodla yapılmış olması ve bu üç farklı metod sonuçlarının birbirleri ile uyumlu olmasıdır. Bu metodlar, Geometrik Ortalama, Kesik Ortalama, Grup Ağırlıklarının Geometrik Ortalaması metodlarıdır.

Keywords: LCS, AHP, Multiple Criteria Decision Making, Group Decision Making

Anahtar Kelimeler: LCS, AHP, Çok Kriterli Karar Verme, Grup Karar Verme.

1. Introduction

Decision making problems with multiple criteria consist of a multitude of subjects such as decision alternatives, criteria and performance evaluations. Moving from single decision maker to multiple decision makers' setting introduces a great deal of complexity into the analysis since individuals in a group might have different preferences about alternatives, criteria and consequences. In multiple criteria decision making, the overall performance of the decision alternatives is evaluated with respect to several conflicting decision criteria.

Ship design is a very important application area of multiple criteria decision making techniques with the heavy number of parameters on which needed to be decided in a logical, realistic and scientific way.

One of the widely used multiple criteria decision making techniques is the Analytic Hierarchy Process (AHP). In this method the assessment of preference is performed through ratio–scale pairwise comparisons of the decision elements.

The aim of this study is to define the constants of weights of design criteria of a chosen type of war ship (Littoral Combat Ship-LCS) by using AHP. A decision maker can use these constants of weights of the criteria of LCS in the new LCS design projects in TURKEY or in any country. The general examples of AHP in the literature include comparisons of alternatives based on objectives. In this study criteria's weights for objectives are determined since comparison of LCS and the other warship types requires the identification of some secret information related to Turkish Navy, the warships and naval operations.

2. Multiple Criteria Decision Making (MCDM) and Analytic Hierarchy Process (AHP)

The process of decision making is the selection of an act or courses of action from among alternative acts or courses of actions such that it will produce optimal results under some criteria of optimization. What makes MCDM complex is the plurality of the criteria involved in the problem [1].

The process of making quality choices using MCDM depends on the procedures for scoring alternatives, discovering relevant criteria, weighting the criteria and not the least, for structuring the criteria trees [2].

Since last 50 or 60 years, operation researchers and practitioners have developed a wide range of methods to find an answer to the question of "How a decision should be selected from a given set of competing alternatives that are evaluated against conflicting objectives". Some of the methods may be listed as follows. Von Neumann and Morgenstern's Expected Utility Theory (EUT), Savage's Subjective Expected Theory

(SEUT) with the extensions to Multiattribute Utility Theory (MAUT), PROMETHEE (Preference Ranking Organisation METhod for Enrichment Evaluations) by Brans, and the Analytic Hierarchy Process (AHP) developed by Saaty, Multiattribute Value Theory (MAVT), Roy's ELECTRE (Election et Choix Traduisant La Realite), TOPSIS (Technique for Order Preferences by Similarity to Ideal Solutions) by Hwang and Yoon and Mathematical (Goal) Programming.

The Analytical Hierarchy Process (AHP) is a method developed by Thomas Saaty in 1996 for solving multi-attribute decision problems. Basically AHP is a method of breaking down a complex, unstructured situation into its components parts; arranging these parts, or variables, into a hierarchic order; assigning numerical values to subjective judgments on the relative importance of each variable; and synthesizing the judgments to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation [3]. AHP starts with a hierarchy of objectives. The top of the hierarchy provides the analytic focus in terms of a problem statement. At the next level, the major considerations are defined in broad terms. This is usually followed by a listing of the criteria for each of the foregoing considerations. Depending on how much detail is called for in the model, each criterion may then be broken down into individual parameters whose values are either estimated or determined by measurement or experimentation. The bottom level of the hierarchy contains the alternatives or scenarios underlying the problem. [4]

Expert opinions or a questionnaire application is mostly used on the pairwise comparisons. The people who attend any questionnaire may or may not be experts but it is expected that they are familiar with the problem. The scale shown on the Table 2.1 is used for the pair-wise comparisons in AHP applications.

Table 2.1 AHP Scale[4]

Value	Definition	Explanation
1	**Equal importance**	**Both factors contribute equally to the objective or criterion**
3	**Weak importance of one over another**	**Experience and judgment slightly favor one factor over another**
5	**Essential or strong importance**	**Experience and judgment strongly favor one factor over another**
7	**Very strong or demonstrated importance**	**A factor is favored very strongly over another; its dominance is demonstrated in practice**
9	**Absolute importance over another**	**The evidence favoring one factor is unquestionable**
2,4,6,8	**Intermediate values**	**Used when a compromise is needed**

Assuming that n criteria are being treated at a given hierarchy, the procedure establishes (n x n) pair-wise comparisons. The entries which show the relative importance values according to the Table 2.1 are organized in a comparison matrix (A). Let A will be defined as;

$$A= a_{ij} \quad (i, j = 1, 2, 3 \ldots n). \qquad (2.1)$$

$$A=\begin{pmatrix} 1 & a_{12} & ...a_{1n} \\ 1/a_{12} & 1 & ...a_{2n} \\ 1/a_{1n} & 1/a_{2n} & ...1 \end{pmatrix} \tag{2.2}$$

There are two basic rules to define the entries a_{ij}.

Rule 1: If a_{ij} = k, then a_{ji}=1/ k; k ≠ 0

Rule 2: If two of the alternatives are considered that they have equal importance, the entries a_{ij} and a_{ji} = 1; in particular a_{ii} = 1.

After filling out the comparison matrix A, the normalized vector (N) is reached by dividing the elements of each column of A by the sum of the elements of the same column (Column Sum: CS). Successively the averages of the all rows in N are taken and by this last computation relative weights of the major criteria are calculated.

$$N=\begin{pmatrix} 1/CS_1 & a_{12}/CS_2 & ...a_{1n}/CS_n \\ (1/a_{12})/CS_1 & 1/CS_2 & ...a_{2n}/CS_n \\ (1/a_{1n})/CS_1 & (1/a_{2n})/CS_2 & ...1/CS_n \end{pmatrix} \begin{matrix} RowAve = & w_1 & (1st\ CriWeight) \\ RowAve = & w_2 & (2nd\ CriWeight) \\ RowAve = & w_3 & (3rd\ CriWeight) \end{matrix} \tag{2.3}$$

The procedure for getting the normalized matrix and row averages are repeated for each set of alternatives on the lowest level of the hierarchy. By doing this, all weights will be computed in the hierarchy and the process will be completed.

3. Group Decision Making

When more than one person or decision maker is responsible to decide on any problem, then this case becomes a group decision making application. Rational procedures must be developed to structure the problem, requiring opinions and making use of information provided.

Generally there are two types of procedures to handle the Group Decision Making issues. These are Live Sessions and Form of Correspondence [4].

The critical issue in Group Decision Making applications is the consensus. Consensus or the group consensus is a position of the decision process on which the whole group members agree. As a general case, a group consensus is not usually reached at a single step when three parameters such as attribute weights, values and possibly group member's importance weights are articulated incompletely [5]. But the group consensus can be inspected only in Live Session method as a property due to its nature, included organised meetings with all group members.

According to Saaty [6] taking Geometric Mean is the proper method to be able to obtain weights in a group to decide.

4. LCS Design

Ship design is a complex endeavor requiring the successful coordination of many different disciplines, both technical and non-technical. Designing a naval warship requires more complex tasks to develop an efficient and effective weapons and sensors platform, capable of operating in a hostile environment against enemies. The origin of warship design comes from the desired functions and the level of performance of the vessel against an expected or possible threat.

Littoral or coastal waters of the world can be chocked with mines, blocked by submarines, or subject to raids by small, armed boats. These are the threats that can not be ignored, or avoided at any time.

Littoral Combat Ship is a new type of warship designed to provide required warship responsibilities in basically Mine Warfare, Anti-Submarine Warfare or Anti-Surface Warfare at waters close to shore. As a transformation platform, the LCS will be a critical in implementing new operational concepts and in providing focused mission platform for joint forces. Its superior speed and maneuverability; low radar, infrared and acoustic signatures; and ability to lay distributed sensor fields are all fundamental issues to mission success [7]. In addition to these primary missions an LCS may be used also for Intelligence, Surveillance and

Reconnaissance (ISR), Homeland Defense/ Maritime Intercept, Special Operation Forces support, Logistic support for the transfer of personnel and supplies.

The LCS shall be configured with core systems and a Mission Package that will enable the ship to perform all core ship functions and at least one focused mission or inherent capability.

5. Application

The flow chart of the methodology used in the application phase can be illustrated in the Figure 5.1.

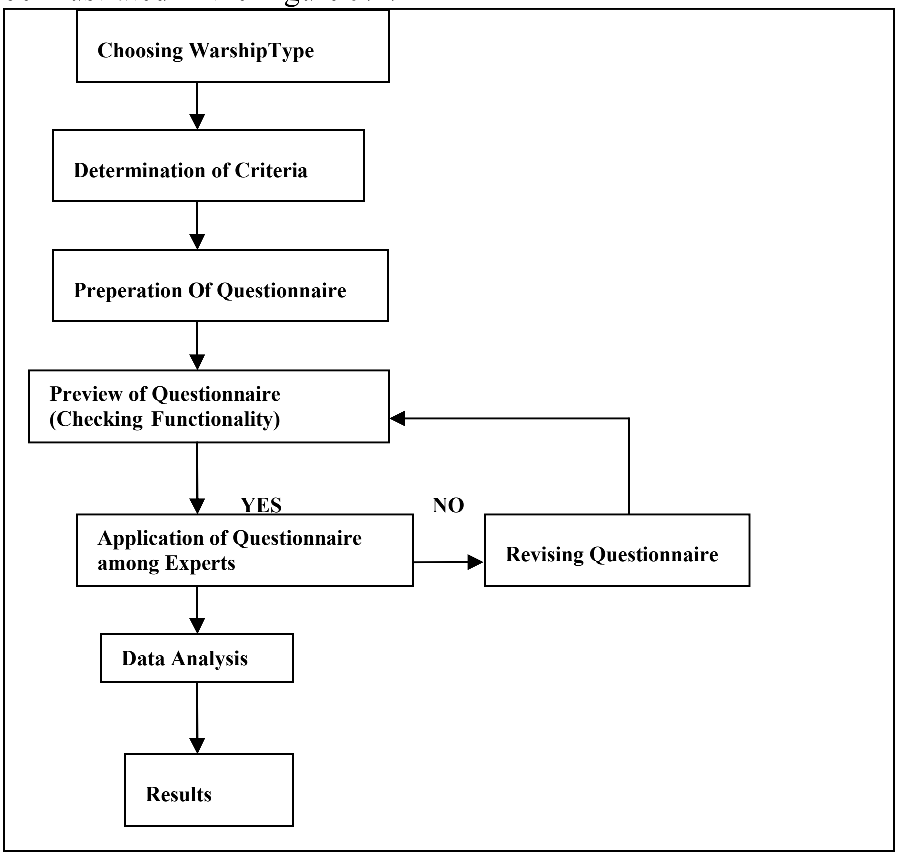

Figure 5.1 Flow Chart of The Methodology

After reviewing the literature about warship design procedures, the criteria list are finalised as in the Table 5.2. The whole data gathered through the questionnaire is switched into the soft data by using special tables prepared for this study and finally analysed to be able to determine the criteria weights.

Table 5.2 Warship Design Parameters Used in This Study

SHIP DESIGN	**Mobility**	**Sustained Speed**
		Stability
	Independent Capability	**Missile Capacity**
		Gun and Ammunition Capacity
		Endurance Range
	Weapon Systems	**Configuration 1** **(SSM + CIWS +Land Attack Gun + Torpedo + VLS SAM + RF/ IR Decoys)**
		Configuration 2 **(SSM + CIWS + Land Attack Gun + Torpedo + Trainable Automatic Decoy Launching Systems + Active Off-Board Decoys + Floating Decoys + EA System + RF/ IR Decoys)**
		Configuration 3 **(SSM + CIWS + Land Attack Gun + Torpedo + RF/ IR Decoys + Torpedo Jamming System)**

	Sensor Capability	**Configuration 1** **(Navigation Radar + Multi Function Radar + ESM+ IRST+ EO Director + Sonar)**
		Configuration 2 **(Navigation Radar + Multi Function Radar + ESM + IRST + EO Director)**
		Configuration 3 **(LPI Navigation Radar + Fire Control Radar + ESM + 3D Search Radar + Sonar + EO Director)**
	Susceptibility	**IR Signature**
		RCS
		Acoustic Signature
		EM Signature
	Cost	**Follow-Ship Acquisition Cost**
		Life Cycle Fuel Cost
		Maintenance Cost
		Construction Cost

At the beginning of data analysis all weights are calculated according to the theory of AHP and weights for all criteria coming from each experts are listed with the ID number of each experts between 1 and 20. By this way twenty weights are calculated for each criterion. After this one the next step is to shrink these twenty weights into only one weight for each criterion as a group decision making process.

Three methods are used to shrink these twenty weights into only one weight for each criterion and a comparison is done to reach the answer to the question of which method or methods more suitable are to compute the weights. These methods are geometric mean, trimmean, and geometric mean of groups' weights.

5.1 Geometric Mean Method

According to Saaty [3] taking Geometric Mean is the proper method to be able to obtain weights in a group to decide. After listing weight of each criterion the Geometric Mean is calculated by using the formula below

$$\text{Geometric Mean} = \sqrt[n]{(v_1 \times v_2 \times \ldots\ldots \times v_n)} \qquad (5.1)$$

5.2 Trimmean Method

This method is contemplated in this study to reduce the number of weights to one as the weights of the whole groups of experts. The idea behind this method is to except the extreme points of data before going through the analysis. The number of data being excepted in the evaluation is determined by the executer by regarding the total number of data. The whole weights of all criteria are sorted from highest to smallest at the beginning of computing the Trimmean. Afterwards the two highest and the two lowest weights are excepted and the Trimmean is calculated. At the end of this process it is provided that each criterion has only one weight as the result of a group decision making procedure.

5.3 Geometric Mean of Groups' Weights

Computation of Geometric Mean of Groups' Weights is the other method used in this study. In this method experts coming from engineering backgrounds are evaluated and grouped with respect to their experience in warship design process and in warship related system design such as sensor systems and weapon systems. The experts coming from onboard are evaluated in a different group. According to these factors four different groups are occupied. The group formation is shown in the following way:

- Group 1: The experts with the ID number of 5, 7, 8, 11, 12, 13, 15, 16, 18, 19, and 20 are taken into this group. They are ship design engineers and electrical engineers focused on weapon and sensor systems for surface ships.
- Group 2: The experts with the ID number 3, 4, 6, and 17 are taken into this group and they are electrical engineers coming from underwater acoustic engineering and electrical engineering focused general system design.
- Group 3: Two computer engineers are taken into this group basically worked on weapon and sensor systems performance.
- Group 4: There are two officers in this group with their background more than 15 years in navy with many different positions.

After group occupation, each group is given percentage constants by regarding the group experience and knowledge in warship design process. The process of given percentage constants are repeated three times with different percentage shares. After this group formation, weights coming from each expert are listed in each separate group, and geometric mean of these weights is computed. Finally these geometric means of each group are multiplied with the corresponding percentage and these four geometric means are added to compute the Geometric Means of Groups' Weights.

6. Results and Conclusion

Table 6.1 is given for a final comparison of all weights coming from the three different methods. It is a crucial summary for the whole study. According to this table the criterion of Weapon Systems has the greatest weights in all methods within the six main criteria. The criterion of Sustained Speed is the greatest weights in all methods except the GeoSum (2) application as the subcriterion of Mobility. In this application Stability has the greatest weight due to the high percentage share of Group 4 Experts who have background more than 15 years onboard (on the other percentage shares they are given less shares.) Missile capacity has the highest weights in all methods as the subcriterion of Independent Capability. Configuration 2 has the highest weight as the subcriterion of Weapon System. For the main criterion of Sensor System, Configuration 3 has the highest weights in all methods. The subcriteria of RCS take the highest weights in all methods as the subcriterion of Susceptibility. The Maintenance Cost takes the highest weights in all methods as the subcriterion of Cost.

Consequently, with this study an initial research for analysing or prioritizing the importance of the LCS design criteria is applied by using the criteria established. Regarding the new concept of naval operations in littoral waters and the sea borders of TURKEY connected to mostly littoral waters; this study may be accepted as an ignition for the total ship engineers, electrical engineers who work on system design for warships and system engineers on this area. A decision maker can use these constants of weights of the criteria of LCS in the new LCS design projects in TURKEY or in any country.

The other contribution of this study is to offer three different methods for computing weights in group decision making applications and the consistency of the results of these three different methods. These methods are Geometric Mean, Trimmean and Geometric Means of the Group's Weights.

For the future evaluation of this study it can be thought that a fuzzy AHP application or fuzzy AHP algorithm might be provided. For this possible study a fuzzy logic sets might be planned with the adequate choice of fuzzy operators and the numerical values are given to all criteria of LCS design under a fuzzy AHP algorithm.

Table 6.1 All Weights Determined via the Three Different Method

CRITERIA	GEO.MEAN	Trimmean	GeoSum(1)	GeoSum(2)	GeoSum(3)
Mobility	0.1069	0.1350	0.1048	0.0792	0.0979
Independent Capability.	0.0904	0.1025	0.0788	0.1109	0.0812
Weapon System	0.2398	0.2656	0.1968	0.3407	0.2355
Sensor Capability	0.2085	0.2325	0.1794	0.2328	0.1988
Susceptibility	0.1012	0.1056	0.0832	0.1303	0.0913
Cost	0.0759	0.0981	0.0729	0.0422	0.0686
Sustained Sped	0.4485	0.5481	0.4317	0.3883	0.4363
Stability	0.3849	0.4519	0.3539	0.4299	0.3666
Missile Capacity	0.4657	0.5300	0.4560	0.3358	0.4565
Gun and Ammunition	0.2507	0.2769	0.2286	0.2214	0.2337
Endurance Range	0.1466	0.1488	0.1257	0.2194	0.1363
Configuration 1	0.2698	0.3056	0.2322	0.3094	0.2556
Configuration 2	0.3881	0.4213	0.3878	0.3183	0.3749
Configuration 3	0.1974	0.2213	0.1808	0.1977	0.1900
Configuration 1	0.2965	0.3413	0.2787	0.2529	0.2797
Configuration 2	0.1689	0.1788	0.1599	0.1155	0.1594
Configuration 3	0.3498	0.4481	0.3051	0.5807	0.3584
IR Signature	0.2117	0.2425	0.1847	0.1945	0.1994
RCS	0.3248	0.3631	0.2955	0.3754	0.3070
Acoustic Signature	0.1649	0.1738	0.1549	0.1144	0.1538
EM Signature	0.1364	0.1575	0.1178	0.1277	0.1250
Construction Cost	0.2138	0.2706	0.2148	0.1204	0.2095
Life Cycle Cost	0.1373	0.1538	0.1083	0.2785	0.1343
Maintenance Cost	0.3154	0.3488	0.2789	0.3600	0.2981
Follow Ship Cost	0.1646	0.1669	0.1484	0.1462	0.1504

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ABBREVIATIONS

AHP	: Analytic Hierarchy Process
ASW	: Anti Submarine Warfare
CIWS	: Closing Weapon System
EA	: Electronic Attack
ESM	: Electronic Support Measures
EO	: Electro Optic
EUT	: Expected Utility Theory
EM	: Electro Magnetic
IR	: Infrared
IRST	: Infrared Search and Track
ISR	: Intelligence, Surveillance and Reconnaissance
LCS	: Littoral Combat Ship
LPI	: Low Probability Intercept
MAUT	: Multi Attribute Utility Theory
MAVT	: Multi Attribute Value Theory
MCDM	: Multi Criteria Decision Making
MIW	: Mine Warfare
PDMS	: Point Defense Missile System
RCS	: Radar Cross Section
RF	: Radio Frequency
SEUT	: Subjective Expected Utility Theory
SSM	: Surface to Surface Missile
VLS SAM	: Vertical Launching System Surface to Air Missile
3D	: 3 Dimensions

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