T.C.
MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES IN
PURE AND APPLIED SCIENCES

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

Ali ATA

(Electrical Engineering)

THESIS

FOR THE DEGREE OF MASTER OF SCIENCE

IN

ENGINEERING MANAGEMENT PROGRAMME

SUPERVISOR

Asst. Prof.Dr. Bahar SENNAROĞLU

ISTANBUL 2006

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ACCEPTANCE AND APPROVAL DOCUMENT

THE USAGE OF MULTIPLE CRITERIA DECISION MAKING TECHNIQUES IN DETERMINING THE CONSTANTS OF CRITERIA'S WEIGHT OF WARSHIP DESIGN

Established committee listed below, on ..... and ..... by the *INSTITUTE FOR GRADUATE STUDIES IN PURE AND APPLIED SCIENCES*' Executive Committee, have accepted Mr. Ali ATA's Master of Science thesis, titled as "THE USAGE OF MULTIPLE CRITERIA DECISION MAKING TECHNIQUES IN DETERMINING THE CONSTANTS OF CRITERIA'S WEIGHT OF WARSHIP DESIGN" in Engineering Management.

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APPROVAL

Mr. Ali ATA has satisfactorily completed the requirements for the Master of Science in Engineering Management at Marmara University.

Mr. Ali ATA is eligible to have the degree awarded at our convocation on ..... Diploma and transcripts so noted will be available after that date.

Istanbul DIRECTOR

ACKNOWLEDGEMENT

I would like to thank Asst Prof. Bahar SENNAROĞLU for her valuable support and her continuous help to make everything clear during my thesis work. I also need to thank Asst. Prof. Serol BULKAN for his help to orient me towards to this thesis topic.

I want to express my special appreciations to the TURKISH Navy Research Center EW Department Head Mehmet KUTLU and my supervisor Murat KOCAKANAT for providing the opportunity of taking this master degree.

In my last sentences I would like to thank my daughter Azra and my wife Arzu for their support and help. Arzu, my wife has been always up when I was down, with her courage and her love during these two years; be with me to the end of my life.

September, 2007 **Ali ATA**

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ÖZET

ÇOK KRİTERLİ KARAR VERME YÖNTEMLERİNİN SAVAŞ GEMİSİ TASARIMINA YÖNELİK KRİTERLERİN AĞIRLIK KATSAYILARININ BELİRLENMESİNDE KULLANIMI

Günümüzde gerçekleşen birkaç deniz çatışmasında da görüldüğü üzere; deniz harekatlarının soğuk savaşın açık deniz filo reaksiyonlarından kıyıya yakın sahalarda düşük ve orta yoğunluk seviyelerinde yaşanan çatışmalara doğru yönelmesinden dolayı; Kıyıya Yakın Görev Yapabilen Savaş Gemisi (LCS) kavramı yeni harekat konseptlerinin entegrasyonu için çok önemli bir uygulama olarak kabul edilmektedir. Bu sınıf savaş gemileri, kıyıya yakın sularda mayın tehditlerini etkisiz hale getirmek, denizaltı ve terörist saldırı botlarını da kapsayan suüstü tehditlerine karşı savaşmak amacıyla müşterek operasyonlar için geliştirilmektedirler.

Bu tez çalışması, tezin yazarı tarafından belirlenen Kıyıya Yakın Görev Yapabilen Savaş Gemisi tasarım kriterlerinin ağırlıklarının Analitik Hiyerarşi Yöntemi (AHP) ile hesaplanabilmesi amacıyla yapılmıştır.

AHP en yaygın olarak kullanılan çok kriterli karar verme tekniklerinden biridir. Bu metodda tercihin belirlenmesi, karar verme elementlerinin ikili karşılaştırma oran ölçekleri yardımıyla kıyaslanması sonucu olmaktadır. Bu metod birçok parametre ihtiva eden karar verme işlemini özetlemek, çözümlemek, organize etmek ve kontrol etmek için hiyerarşik bir yapı kullanmaktadır. Aynı zamanda verilecek karar hakkında bilgiye dayanan yargılamalar veya uzman görüşleri de nispi değerleri belirlemede kullanılır ve problem çözümlenir.

Tez çalışmasının literatür araştırması bölümünde Çok Kriterli Karar Verme

Teknikleri, Grup Karar Verme Teknikleri, Savaş Gemisi Tasarım Kriterleri ve LCS Tasarım Kriterlerini ihtiva eden geniş bir araştırma yapılmıştır.

Sonraki bölümde ise bu tez çalışmasının ne şekilde ele alındığının anlatıldığı bölüm yer almaktadır. Bu bölümde tez çalışması için uygulanan anketin hazırlanması, anketin uygulanması ve üç farklı metod ile verilerin analiz edilmesinin de içinde yer aldığı izlenen metedoloji kısmı ele alınmıştır.

Nihai olarak, bu tez çalışmasıyla LCS tasarım kriterlerinin analizi ve önceliği saptanmaya çalışılmıştır. Deniz harekatlarındaki yeni konseptler ve Türkiye'nin çoğunluğu kıyıya yakın sular olarak var olan deniz sınırları dikkate alındığında, bu tez çalışması toplam gemi mühendisleri, savaş gemisi sistem tasarımı ile uğraşan elektronik mühendisleri ve bu alanda çalışan sistem mühendisleri için bir başlangıç olarak kabul edilebilir. Ayrıca bu tez çalışmasının ortaya koyduğu diğer katkı ise; grup karar verme uygulamalarındaki ağırlık hesaplamalarında üç farklı metotu önermesi ve bu üç farklı metodla elde edilen sonuçların göstermiş olduğu tutarlılıkdır. Bu metotlar Geometrik Ortalama, Trimmean ve Grup Ağırlıklarının Geometrik Ortalaması metotlarıdır.

Eylül, 2007 **Ali ATA**

ABSTRACT

THE USAGE OF MULTIPLE CRITERIA DECISION MAKING TECHNIQUES IN DETERMINING THE CONSTANTS OF CRITERIA'S WEIGHT OF WARSHIP DESIGN

Since the focus of the naval operations has moved away from the cold war blue water fleet actions towards low and medium intensity operations in the littoral regions within a joint integrated battlespace as has been demonstrated in recent conflicts; Littoral Combat Ship (LCS) is considered crucial in implementing new operational concepts. These class warships are developed for joint force operations to maintain consistency in littoral waters by overcoming the threats of mines, submarines and surface forces such as terrorist attack boats.

This study was conducted to determine LCS design criteria's weights via Analytic Hierarchy Process (AHP) by using the author's classification of criteria.

AHP is one of the widely used multi criteria decision making techniques. In this method the assessment of preference is performed through ratio–scale pairwise comparisons of the decision elements. It uses a hierarchical structure to abstract, decompose, organize and control the complexity of decision involving many attributes. Also it uses informed judgment or expert opinion to measure the relative value or contribution of these attributes and synthesize a solution.

In the literature review part of the thesis a wide research is conducted in order to define Multi Criteria Decision Making (MCDM) Techniques, Group Decision Making (GDC), Warship Design Process and more specifically Littoral Combat Ship (LCS) Design Process.

The next part is a description of the implementation of the said techniques.

This includes preparation of the questionnaire, application of the questionnaire and analysis of the results by three different methods used in group decision making situations.

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

September, 2007 **Ali ATA**

CLAIM OF ORIGINALITY

THE USAGE OF MULTIPLE CRITERIA DECISION MAKING TECHNIQUES IN DETERMINING THE CONSTANTS OF CRITERIA'S WEIGHT OF WARSHIP DESIGN

Since the focus of the naval operations has moved away from the cold war blue water fleet actions towards low and medium intensity operations in the littoral regions within a joint integrated battlespace as has been demonstrated in recent conflicts; this thesis study is held to determine Littoral Combat Ship (LCS) design criteria's weights via Analytic Hierarchy Process (AHP). By this thesis an initial research for analysing or prioritizing the importance of the LCS design criteria is applied using the criteria classified by the author of the thesis. Regarding the new concept of naval operations in littoral waters and the sea borders of TURKEY connected to mostly littoral waters; this thesis 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 will use these weights or the constants of the criteria of LCS in the new LCS design projects in TURKEY or in any country. The other contribution of this thesis study is to offer three different methods for computing weights in group decision making applications and the consistency of the results obtained from these three different methods. These methods are Geometric Mean, Trimmean and Geometric Means of the Group's Weights.

September, 2007 Asst. Prof. Dr. Bahar SENNAROĞLU Ali ATA

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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PART I

I. INTRODUCTION AND OBJECTIVES

I.1. DESCRIPTION OF THE STUDY

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

I.2. INTRODUCTION

Decision making is a hard and cognitive process of selecting any issue among multiple alternatives. Eventhough they might vary according to their importance, a lot of decision making applications can be seen very easily in every moment of life such as choosing a car, selecting a place to get lunch, to decide a treatment about an illness for a doctor or to select the investment type for a company manager.

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 multi-criteria decision making, the overall performance of the decision alternatives is evaluated with respect to several conflicting decision criteria.

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. It uses a hierarchical structure to abstract, decompose, organize and control the complexity of decision involving many attributes, and it uses informed judgment or expert opinion to measure the relative value or contribution of these attributes and synthesize a solution. [5]

The primary goal of the AHP is to select an alternative that best satisfies a given set of criteria out of a set of alternatives or compute the weights of the criteria. AHP incorporates judgments or personal standards in a logical way. It depends on imagination, experience and knowledge to construct the hierarchy of the main focus and on logic, instinct and experience to provide judgment.

The aim of this study is declared as to define the weights or constants of design criteria of a chosen type of war ship (Littoral Combat Ship-LCS) by using AHP. The scope of the thesis consists of only determining the weights of criteria in LCS design. A decision maker will use these weights or the constants 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 thesis 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.

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.

The first part of this thesis involves the research of previous studies in order to visualize the general aspect of decision making techniques, multiple criteria decision making techniques and AHP.

The second part of the study is about designing a war ship and the configuration of LCS, basic LCS missions and inherent LCS capabilities.

In the third part of this study the whole applications including in which way the problem is delaed, how the parameters are chosen, how the hierarchies for the AHP are configured and how the questionnaire is applied are defined.

The final part involves analysis of the results (the weights computed by the AHP) and the conclusion of the whole study. This analysis is based on the information and application procedures emphasized in previous parts. In addition these basic result, how and where these results are going to be used for further studies, the open parts for the future work and the limitations during this thesis research were held in this last part.

PART II

II. LITERATURE REVIEW

The literature review applied through this thesis is basically done in three areas. It is possible to classify these areas as Multi Criteria Decision Making (MCDM) Techniques, Group Decision Making Techniques and Warship Design Procedures. Multi Criteria Decision Making Techniques section involves with the description of MCDM, definitions of the mostly used MCDM Techniques and Analytic Hierarchy Process (AHP).

The literature review which contains the Multi Criteria Decision Making Techniques and the Group Decision Making Techniques are given in this part of the thesis due to their close relationship from the view of Industrial Engineering.

The literature review contains Warship Design Procedures and Littoral Combat Ships are given on the next part of the thesis by regarding that those topics come from different disciplines.

II.1. MULTI CRITERIA DECISION MAKING TECHNIQUES

Multi Criteria Decision Making (MCDM) is the process of the selection of an alternative or alternatives in the presence of the multiple and potentially conflicting option items. In another words , MCDM is choosing the alternative that gives the best overall value by identifying the criteria and judging the alternatives.

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.[10]

By gathering the given definition and information so far in this chapter , the process of MCDM can be transferred into an algorithm as in the Figure II-1.

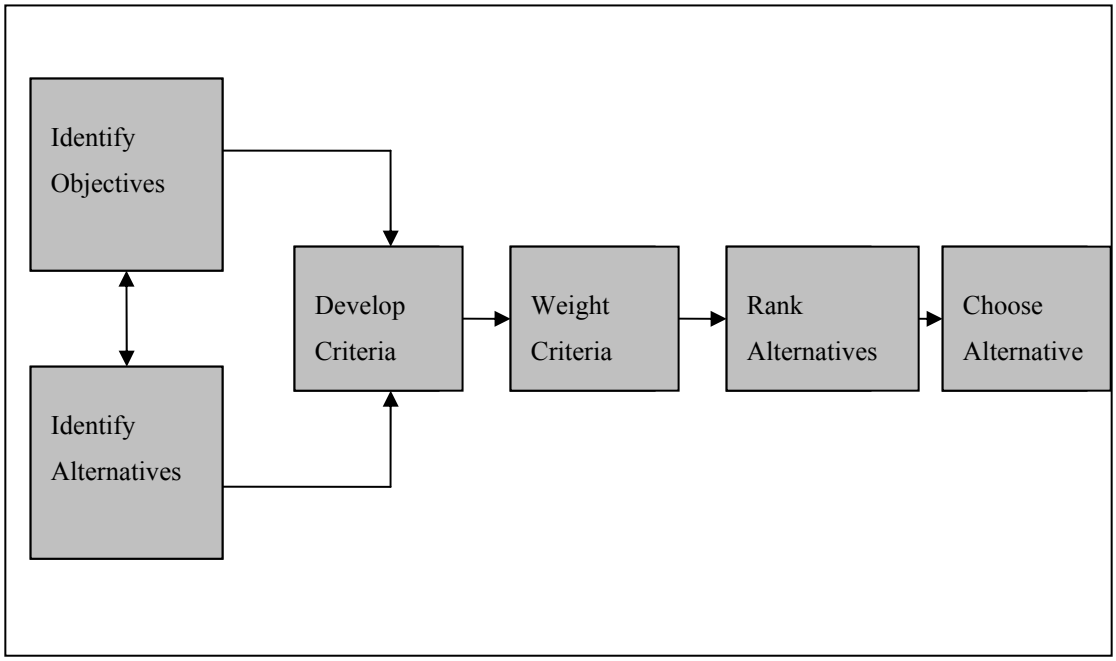

Figure II-I MCDM Process

The objectives or goals are the outcomes of the whole multicriteria decision making process.

The early developments in MCDM grew out of consultancy projects where the problems were clearly real. Consequently decision analysts may not have had to emphasize the need to find alternatives or attributes. Keeney listed alternatives as one of 10 devices for identifying objectives, but also said " often one begins to think hard about a decision situation only after at least two alternatives become apparent." Attributes are aspects of alternative choices that can be matched to criteria. [10]

After defining objectives and alternatives the next step is to develop the criteria. At this part of the process a decision maker needs to understand the objectives and the alternatives that can provide to reach these objectives. In a fully understanding manner decision maker should list the criteria clearly.

The following step will be the weighting these criteria in a MCDM process. Weighting the criteria may be done according to different algorithms in various

methods.

Ranking the alternatives is the next milestone in MCDM process. In this part of the application, all of the alternatives are focused separately and calculated their outcome by regarding the pre-defined objectives. Various algorithms may also be used to rank the alternatives as in the weighting the criteria.

The final step will be choosing the best alternative. The decision is taken seriously when the decision makers have a real commitment to resolving the tension between the alternatives and their criteria.

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". The methods that are mentioned in this thesis 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. Eventhough they are not mentioned in this thesis, there are more MCDM techniques in the literature. Some of those are 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.

II.1.1. Expected Utility Theory (EUT)

Before going further away within this theory it may be better to define what "utility" means in general. Utility means, the real or fancied ability of a good or service to satisfy a human want. In decision theory, utility is a measure of desirability of consequences of courses of action that applies to decision making under risk that is under uncertainty with known probabilities. The basic assumption in utility theory is that a decision maker always chooses the alternative for which the expected value of the utility is maximum.

Expected Utility Theory was provided Von Neumann and Morgenstern in 1947 and it depends basically classical probabilities in economical

assumptions.

The Expected Utility Theory states that the decision maker chooses between risky or uncertain prospects by comparing their expected values. For example, the weighted sums obtained by adding the utility of outcomes multiplied by their respective probabilities.[11] As another definition, EUT is the theory of decision making under risk based on a set of axioms for preference ordering that includes the independence axiom or an alternative that implies that the expected utility function that represents the order is linear in probabilities.[12]

EUT assumptions or applications are mostly about economical theorizing or uncertainties in economy, but methodologists have hardly begun to explore the developments of EUT in every area related to the game theory.

II.1.2. Subjective Expected Theory

Savage advanced this theory in 1954 as a theory of decision making under uncertainty and used that theory to define choice-based subjective probabilities. These probabilities come from decision maker's beliefs and feelings. At this point of view this theory differs from the Expected Utility Theory.

" In the late 1920s and 1930s, Ramsey and de Finetti formalized the concept of choice-based subjective probability assuming that individual seek to maximize expected utility when betting on the truth of propositions. In the behaviorist tardition, they explored the possibility of inferring the degree of confidence a decision maker has in the truth of a proposition from his betting behavior and quantifying the degree of confidence, or belief, by probability. Invoking he axiomatic approach and taking the existence of utilities as given, Ramsey (1931) sketched a proof of existence of subjective probabilities. De finetti (1937) proposed a definition of subjective probabilities assuming linear utility and no arbitrage opportunities.

These developments culminated in the work of Savage. While synthesizing the ideas of de Finetti and von Neumann and Morgenstern, Savage introduced a new analytical framework and conditions that are necessary and sufficient for the existence and joint uniqueness of utility and probability, and the characterization of individual choice as expected utility maximizing behavior.

Savage's analytical framework: Decision making under uncertainty pertains to situations in which a choice of a course of action, by itself, does not determine a unique outcome. To formalize this notion Savage(1954) introduced an analytical frame work consisting of a set S, whose elements are states of the world (or states, for brevity); an arbitrary set C, of consequences; and the set F, of acts (that is functions from the set of states to the set of consequences). Acts corresponds to

courses of action, consequences describe anything that may happen to a person, and states are possible resolutions of uncertainty, that is, "a description of the world so complete that, if true and known, the consequences of every action would be known"(Arrow[1971],p.45). Implicit in this definition is the notion that there is a unique true state. Events are subsets of the set of states. An event is said to obtain if it includes the true states."[13]

II.1.3. PROMETHEE

Preference Ranking Organisation METhod for Enrichment Evaluations(PROMETHEE) was developed by Brans in 1982 first and extended by Brans and Vickie in 1985 and finally by Brans and Mareschal in 1994.

The main issue in PROMETHEE is the decision maker's preference as stated in the name of the model. To be able to define the preference structure of the decision maker, there are two types of information needed. These are information on the relative importance of the criteria considered and information on the decision maker's preference function (This function is used while comparing the contribution of the alternatives in terms of each separate criterion).

Eventhough there is ranking of alternatives in this method, there are no specific guidelines for this ranking. The weights or the ranking can be determined according to any kind of method. The key point on these weights that it is assumed that decision maker can judge the criteria appropriately to provide the weights. To define the difference between the evaluations obtained by two alternatives, the Preference Function (P_j) is used in this method. The value of this Preference Function must be between 0 and 1.

In PROMETHEE especially in the case of many criteria more than seven, it may be difficult to obtain the clear view of the problem for a decision maker. [14] The dominance relation between two criteria is focused in this method to be able to make value judgments. As mentioned in the former paragraph there is no specific guidelines to weight the criteria in this method but, generalised criteria is needed to be defined for weighting.

"With PROMETHEE, a weight w_j=1 may be chosen for criterion j. For each other criterion, the weight is then measured relative to the jth criterion. These weights can be determined by asking the question:"How much is criterion i more important than criterion j (with respect to the

higher goal)?"

With PROMETHE, we have a single set of weights w_j, j=1,.....,n, with n as the number of criteria, while in the pairwise comparison matrix we have n columns, which would lead to n sets of n weights. If the pairwise comparison matrix is consistent we end up with a matrix of rank 1. Hence, there is a single linear independent row, which, thanks to the reciprocal character of the pairwise comparison matrix, is equivalent to a single linear independent column. This permits to define a single set of weights. In general terms, any column can be taken to determine the PROMETHEE weights, because the choice w_j=1 is arbitrary with respect to the index j, given the relative measure of the weights in PROMETHEE".[14]

Briefly it can be said that a decision maker needs to apply only a limited number of pairwise assessments that are required only for the first row. The rest of the pairwise comparisons are generated automatically after the formal assessment for the first row. The decision maker obviously needs to control the impacts of his or her choices on the entire evaluation matrix.

For the group decision applications, the overall decision can be made after calculating the weighted sum of the individual net flows in PROMETHEE.

II.1.4. The Multiattribute Utility Theory (MAUT)

Multiattribute Utility Theory (MAUT) is a structured methodology or systematic method designed to handle the tradeoffs among multiple alternatives. Early applications of MAUT were about public sector decisions and public policy matters.

"In general, the utility $U(x)=U(x_1,, x_1, x_3.....x_N)$, of any combination of outcomes (x_1, x_1, $x_3.....x_N$) for N attributes can be expressed as either an additive or a multiplicative function of the individual attribute utility function $U_1(x_1)$, $U_2(x_2)$.....U_N, (x_N) provided that each pair of attributes is:

1. Preferentially independent of its complement; that is, the preference order of consequences for any pair of attributes does not depend on levels at which the other attributes are held.

2. Utility independence of its complement; that is, the conditional preference for lotteries (probabilistic trade-offs) involving only changes in the levels for any pair of attributes does not depend on the levels at which the other attributes are held.

To illustrate condition 1, suppose that four attributes for a given project are profitability, time to market, technical risk, and commercial success. Preferential independence means that if we judge technological risk, for example to be more important than profitability this relationship is true regardless of whether the level of profitability is high or low or somewherein

between and also regardless of the value of the other attributes.

The second condition, utility independence, means that if we are deciding on the preference ordering (ranking) for probabilistic trade-offs between for example technological risk and time to market, this can be done regardless of the value of profitability[7]

The following procedure may be used for MAUT as a general guideline. The steps of this general procedure are:

- Determine appropriate view point for the decision
- Identify decision alternatives
- Identify attributes for evaluation
- Identify factors for evaluating the attributes
- Establish a utility scale
- Transform each factor value to its utility scale
- Determine the relative weights for each attribute and factor
- Calculate total utility for each of the decision alternatives
- Determine which decision alternative has the greatest utility score
- Perform sensitivity analysis.[15].

II.1.5. Analytic Hierarchy Process

The Analytical Hierarchy Process (AHP) is a method developed by Thomas Saaty in 1996 for solving multi-attribute decision problems. Actually this idea is a result of some former and successive studies or researches on different areas by Saaty. These are solving a specific problem in contingency planning in 1977, design alternative features for a developing country, Sudan, in 1977, energy allocation in 1979, investment in technologies under uncertainty, dealing with terrorism in 1977 and the other smaller applications such as buying a car, choosing a job and selecting a school. Today various applications of AHP have involved the participation of engineers, lawyers, political social scientists and mathematicians or even ordinary citizens. It is very easy and useful methodology to be able to provide pairwise comparisons in each area of expertise.

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. [4] It uses a hierarchical structure to abstract, decompose, organize and control the complexity of decision involving many attributes, and it uses informed judgment or expert opinion to measure the relative value or contribution of these attributes and synthesize a solution. [5]

According to Saaty, a hierarchy is an abstraction of the structure of a system to study the functional interactions of its components and their impacts on the entire system. From this definition there are two main question on which the AHP lies. These questions are: How the functions of a system are structured and how the impacts of any element in hierarchy are measured.

The strength of the AHP lies in its ability to structure a complex, multi-person, multi-attribute problem hierarchically, and then to investigate each level of the hierarchy separately, combining the results as the analysis progress. [7]

AHP incorporates judgments or personal standards in a logical way. It depends on imagination, experience and knowledge to construct the hierarchy of the main focus and on logic, instinct and experience to provide judgment.

The primary goal of the AHP is to select an alternative that best satisfies a given set of criteria out of a set of alternatives or to determine the weights of criteria in any application. AHP scales the weights of attributes at each level of the hierarchy with respect to a goal using the decision maker's (experts') experience and knowledge in a matrix of pair-wise comparison of attributes. The usual application of AHP is to select the best alternative from a discrete set of alternatives.

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. [7]

The given definition on the previous paragraph is represented in the Figure 1 as a three level hierarchy for a selected problem.

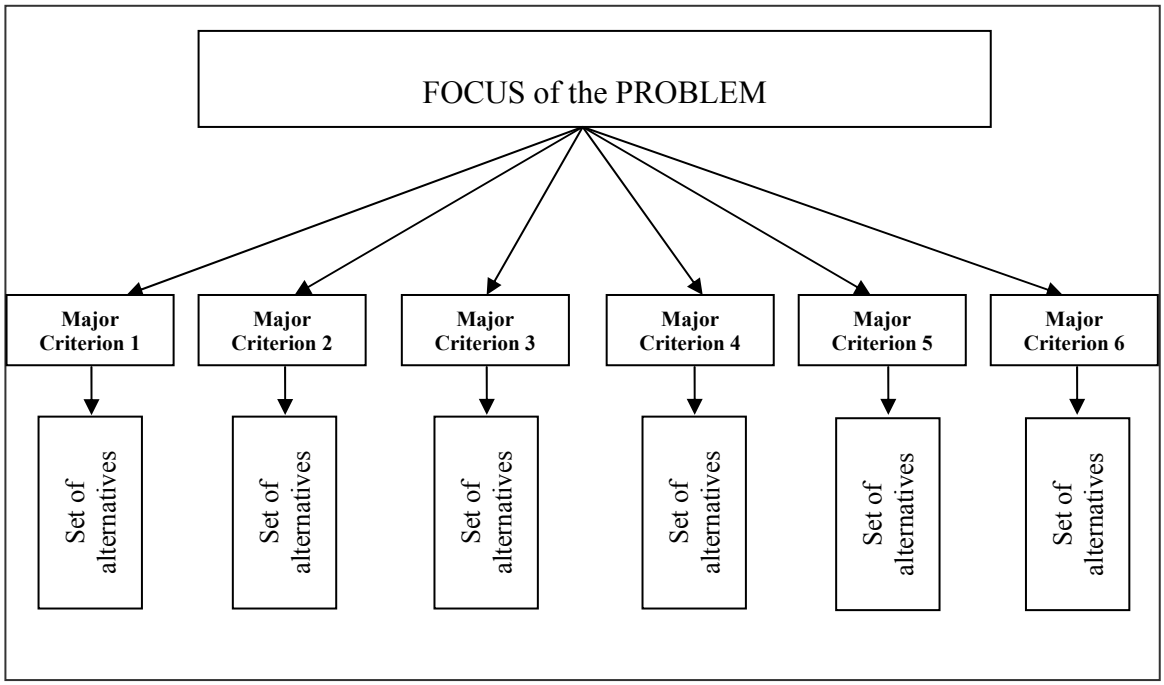

Figure II-II Three Level Hierarchy Illustration

Regarding the various application of AHP, it can be said that, there are many crucial advantages of the AHP in MCDM problems. It is possible to list the advantages of AHP as follows:

- First off all, any level of details about the main focus can be listed or structured in this method. By this way the overview of the main focus or the problem can be represented very easily.
- The AHP provides a simple and very flexible model for a given problem.
- It has a very wide range of usage like; planning, risk and cost effectiveness, benefit and risk analysis, choosing any kind of material among alternatives.
- The AHP provides a scale for pair-wise comparisons and defining priorities.
- AHP relies on the judgments of experts from different backgrounds; so the main focus or the problem can be evaluated easily from different aspects.

- The AHP takes into consideration the relative priorities of factors or alternatives and represents the best alternative to the people for their aim.

II.1.5.1. The Steps of the AHP:

After checking out the different applications of the AHP in [3] and [4] the steps of the AHP can be listed as three steps. These are;

- Structuring the Hierarchy.
- Pair-wise Comparisons. (Determining the Weights)
- Decision Phase (Selection of the best alternative among the others)

II.1.5.1.1. Structuring the Hierarchy

According to the questions which a decision maker attempt to answer , the hierarchy may be very simple or may expand in complexity. That is why a decision maker should construct the hierarchy very carefully, and select between faithfulness to reality.

Generally there are no strict rules or procedures to structure a hierarchy. Because each problem or case, in which AHP is used, is a unique issue and the functional representation of problem solving may differ from person to person, from time to time. However the following route is used mostly in AHP applications. At the bottom level the alternatives are listed, at the level above the characteristics of these alternatives are given by the applicant. The aim of the whole process or the main focus item is represented at the highest level. The crucial thing in structuring the hierarchies is that all levels should be related to each other in order to provide a valuable process. For example the bottom level may consist of alternate warship types which can be used in any service and the level of characteristics may include cost, fuel consumption, weapon systems, sensor systems, hull type and survability.

II.1.5.1.2. Pair-wise Comparisons (Determining the Weights)

Expert opinions or a questionnaire application is mostly used on this step of the AHP. 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 II-I is used for the pair-wise comparisons in AHP applications.

Table II-I AHP Scale[7]

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 1 are organized in a comparison matrix (A). Let A will be defined as;

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

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

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

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

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.

$$N=\begin{pmatrix} 1/CS_1 & a_{12}/CS_2 & \ldots a_{1n}/CS_n \\ (1/a_{12})/CS_1 & 1/CS_2 & \ldots a_{2n}/CS_n \\ (1/a_{1n})/CS_1 & (1/a_{2n})/CS_2 & \ldots 1/CS_n \end{pmatrix} \begin{matrix} RowAverage = & w_1 & (1st\ CriterionWeight) \\ RowAverage = & w_2 & (2nd\ CriterionWeight) \\ RowAverage = & w_3 & (3rd\ CriterionWeight) \end{matrix}$$

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.

II.1.5.1.3. Decision Phase

The ranking of the alternatives or the major criteria is based on a composite weight is listed in this step and the one which has the highest composite weight is chosen as the best alternative or the most important criteria.

II.1.5.2. Consistency in AHP

Consistency means that the decision maker is exhibiting coherent judgment in specifying the pairwise comparison of the criteria or alternatives. Mathematically, a comparison matrix **A** is consistent if $aij = ajk = aik$, for all i,j, k.

This property requires all the columns (and rows) of **A** to be linearly dependent. The columns of any 2×2 comparison matrix are dependent, and hence a 2×2 matrix is always consistent.

It is unusual for all comparison matrices to be consistent. Given that human judgment is the basis for construction of these matrices, some degree of inconsistency is expected and should be tolerated provided that it is not unreasonable.

To test consistency to determine whether or not it is reasonable, the

consistency ratio (CR) is used. Given **w** is the column vector of the relative weights *wi*, *i*=1,2,…,*n*, **A** is said to be consistent if, and only if; $Aw = nw$**.**

For the case where **A** is not consistent, the relative weight, *wi*, is approximated by the average of the *n* elements of row *i* in the normalized matrix **N**. Letting $\overline{w}$ be the computed estimate, it can be shown that;

$$A\overline{w} = n_{Max}\overline{w}, n_{Max} \geq n$$

The closer $n_{\max}$ to n, the more consistent the comparison matrix A.

The value of n_{Max} is computed from $A\overline{w} = n_{Max}\overline{w}$ by observing the ith equation. This means that the value of n_{Max} can be determined by first computing the column vector $A\overline{w}$ and then summing its elements[6].

The critical parameter to check the consistency is the Consistency Ratio (CR) of A. There are two more parameters to be bale to compute the Consistency Ratio. These are Consistency Index (CI) and Random Consistency Index (RI) of A. If $CR \leq 0.1$, the level of inconsistency is acceptable. Otherwise, the inconsistency in A is high and the decision maker is advised to revise the elements of a_{ij} of A to realize a more consistent matrix. The computation of CR is done according to the formulas below [6].

$$CR = CI / RI$$
$$CI = (n_{Max} - n) / n - 1$$
$$RI = 1.98(n-2) / n$$

II.2. 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.

Moving from the single decision maker to multiple decision makers causes a great deal of complexity into a MCDM problem. When AHP or one of the other MCDM techniques is used in group decision making application, group members structure the problem, provide judgments, debate the judgments, and reach a consensus in a way. In an ideal situation, it is preferred that, the group is small and

attendance is well informed, highly motivated and knowing the aim of the whole study. However, often the participants are not equal according to their experience, perspective, education level and interest at the time of the application.

Generally there are two types of procedures to handle the Group Decision Making issues. These are ;

- Live sessions
- Form of correspondence[7]

In the live sessions application, the group spends a time to structure the problem and defines the issues to be examined. Weighting all factors follows the structuring case. By these two steps, a complex issue is broken down into different levels which are very useful for the group to be able to see the big picture. After disclosing all levels of problem, each participant can present his or her own concerns or definitions in any level. In this way agreement can be reached on both high order and low order aspects of the problem through clustering and ordering of all concerns the participants have already expressed. Afterwards the group agrees on how it will proceed to enter judgments. At the final step pairwise comparisons is done and the group selects the best alternative that satisfies the problem.

In the form of correspondence methodology there is no need for organised meetings as in the live sessions. The Delphi Method is one particular approach for doing correspondence applications recently [7].

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 [15]. 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 [4] taking Geometric Mean is the proper method to be able to obtain weights in a group to decide.

As mentioned before the ideal case is to construct the group with small number of attendees. However, in a large group, it is easy to handle the problem by

dividing into smaller, specialized subgroups each dealing with some specific aspects of the matter. When the groups gathered again for a final justification, the values in each matrix can be debated and revised if necessary.

At this point, the debate can be eliminated and the opinions from each group can be taken by directly or by a questionnaire. The final results are taken by geometric mean of the judgments. The values are multiplied and root equal to the number of individual values. Following formula can describe the geometric mean(v stands for value).

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

Another method for solving conflicts in a group is to vote on proposed values. The final result can also be derived as a range of values that represents the range of judgments.

Addition to the problem of weighting of alternatives or values in a group, there are some other critical or special problems in group decision making process. These are unequal power and different experience; variable preferences; changes in preference; unwillingness of declaring preferences.

- Unequal Power and Difference in Experience: Often groups are formed with decision makers who have different experiences on the problem discussed. It is possible to solve this problem by weighting votes according to the importance or expertise of the attendee. By this way the individuals can be compared with respect to factors such as power, experience, political background, wealth, ability, education level. Consensus on these kinds of matters will result in a set of priorities for weighting the judgments of individuals.
- Variable Preferences: This case occupies when some of the attendees are much more interested in some particular questions than the others. Bargaining on the votes helps to reach the consensus or agreement.
- Changes in Preferences: In a dynamic structure of the group formation when the new information or changes happen from external environment, the people in the group may change their preferences. It is obvious that

these kinds of changes get the problem more complicated and harder to solve.

- Unwillingness the Judgments of Individuals: This problem appears when the people tend to hide their real preferences. If this problem occurs, then the definition of issues will be incomplete and the decision making process will be inadequate [4].

PART III

III. WARSHIP DESIGN AND LITTORAL COMBAT SHIP (LCS)

III.1. WARSHIP DESIGN

Ship design is a complex endeavor requiring the successful coordination of many different disciplines, both technical and non-technical. The first stage in ship design is the preliminary design which seeks to define the basic payloads and ship characteristics. This stage begins with highly experienced decision makers and end users who declare to articulate their desires and tradeoffs about the ship. This process is more art than science as decision makers must select design goals on the final design. Experienced naval architects work through design trades in an informal manner relying on their experience to guide major design parameters by using these goals. At this point engineers and program managers are traditionally pressured to meet performance requirements; budget constraint and adhere to schedule. As understood from these constraints, the critical objective attributes considered are mission effectiveness and cost [5].

Addition to the constraints mentioned in the previous paragraph, 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.

Naval warship design process starts with the analysis of the requirements with

the aims of developing a variety of conceptual solutions. Developing these conceptual solutions requires a deep research on the alternative hull form configurations, the weapon types, the sensor system configurations, the existing design algorithms and the alternative powering and resistance systems. Addition to those research areas, technological risks and the engineering complexity must be kept in mind at the beginning of a design process.

After this analysis about the conceptual solutions the next step is detailing the concepts which have greatest promise for the design including some trade-off studies. It is possible to list in the following way these studies [9]:

- Optimization of the hull form regarding powering, mobility and stability.
- Each weapon system separately and the system configuration of all.
- Susceptibility including ship signature reduction methods.
- Propulsuion system alternatives.
- Number of personnel.

At the end of this trade-off phase a single preferred design configuration will have been defined and selected. This selection contains the major equipments and systems with an acceptable level of risk aspects. By this step a general arrangement drawing of the ship is also reached. Antenna, combat systems locations, weapon fire arcs, main and auxiliary machine locations, command and control compartments, weapon systems and their compartments and the decks position are held in this drawing [9].

The next stage of the design process is to develop a complete engineering definition to answer all requirements and the whole arrangement needs.

At the final stage the tests and trials are planned for the warship design. Since these tests and trials are essential procedures before going into the service for a warship, they must be planned very carefully to be able to check the all specifications, the whole set of requirements and the integrated performance of the all systems. A careful checking is required because a slight deviation from the pre-determined specification for one system may affect the performance of the other systems.

After this brief explanation about warship design process, the warship design

criteria held in this thesis are mentioned more detailed in the next chapter.

III.2. LCS DESIGN

Naval Operations near land are best described as warfare in confined waters. Coastal waters off an enemy's homeland are not only where the enemy will test a navy's control, but also where it has the advantages of congestion and limited battle space. Warships which operate in this complex environment will have their warning and reaction times significantly reduced and their ability to maneuver will be compromised by virtue of shallow water and the always present mine 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 [1].

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. There is a generic illustration of LCS can be seen in Figure III-I.



Figure III-I An Illustration of LCS Model[8]

III.2.1. The Concept of Littoral Navy

Eventhough there is not a standardized definition for littoral waters, it is agreed that in the littoral environment the advantages goes to the defending forces. As a general definition, the sea portions with an average water dept 60-65 meters like Turkish Navy's areas of responsibility, the Aegean Sea, The Sea of Marmara, The Mediterranean Sea and the Black Sea are accepted as littoral waters [1].

A coastal country can be defined as a country that is located along the sea but, is without the ability to establish sea control outside its local waters. This country however controls its local waters quite effectively.

"Some general characteristics are shared by most such navies. First, coastal navies are prepared and trained exclusively for operations within the littoral environment. They understand and are fully acquainted with the geography and conditions of their local waters, which serve well to offer cover and protection to their forces. Second, since these coastal navies intend to operate in and control these waters, their weapon and sensor systems are optimized to operate without degradation in a near-land environment. Third the ships and patrol craft of a coastal navy are relatively small and expendable. The proliferation of advanced missile technology allows the concentration of significant amounts of firepower on small platforms. These ships are designed for local operations and not long distance operations.

The primary functions of these navies of these coastal countries can be broke down into three elements; protection against illegal exploitation of natural resources within exclusive economic zone; a show of sovereignty and control over territorial waters; and deterrence against invasion from the

sea."[1]

In order to support these functions a coastal navy should use a mixture of elements of the coastal defense system against-surface, subsurface, air and mine threats. To be able to perform against these various threats, different mission packages are required for a coastal or littoral warship. These mission packages are held in more detailed in the following paragraph.

III.2.2. The Basic Capabilities of Each Different Mission Packages

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. A Mission Package is a functional grouping of systems that is integrated in LCS to give it the capability to execute a focused mission or inherent mission. The LCS shall have the capability to change out Mission Packages in order to shift missions. [8]

LCS design concept consists of two distinct parts, the ship itself and the mission package which she carries and deploys. For the LCS, the ship is referred to as the "sea-frame" and consists of the hull, command and control system, launch and recovery systems and certain core systems like radar and weapon systems or sensor systems. A core crew will be responsible for the sea-frame's basic functions. The secondary missions such as Intelligence, Surveillance and Reconnaissance (ISR), Homeland Defense/ Maritime Intercept, Special Operation Forces support may be applied while evaluating the basic functions of sea-frame. However Mine Warfare, Anti-Submarine Warfare or Surface Warfare operations, which are the major type of missions, require the exact Mission Packages additional to the basic sea-frame capabilities. Each mission packages consists of special systems including manned and un-manned vehicles and the sub-systems such as additional sensors, sonar systems or weapon systems. Additional crew will be needed to operate these systems. Each mission package is designed as being self-contained and interchangeable and will allow LCS to meet specific threats.

If an LCS is equipped for Mine Warfare (MIW), then this mission

package will perform:

- Detect, classify and identify moored or bottom mines to achieve an effective coordination between the units of MIW command and control platforms.
- Perform bottom mapping in an area including bottom mines and the other non-mine underwater objects.
- Execute mine sweeping operations by using off-board systems and deploy, control and recover off-board systems and control data flow between these systems and ship itself.
- Do mine neutralization.

If an LCS is equipped for Anti-Submarine Warfare (ASW), then this mission package will perform:

- Multi-sensor ASW detection, classification, localization, tracking and engagement of submarines throughout the littoral waters at day and night times.
- Carry out offensive ASW operations in a designated search or surveillance area.
- Carry out defensive ASW operations in littoral waters.
- Perform acoustic range prediction and ASW search planning.
- Kill or get damaged the enemy submarines by using hard kill weapon systems.
- Provide work for signature management and soft kill systems to counteract and disrupt the threat's detect to engage sequence in the littoral environments.

If an LCS is equipped for Anti-Surface Warfare, then this mission packages will perform:

- Multi-sensor Anti Surface Warfare detection, classification, localization, tracking and engagement of ships throughout the littoral waters at day and

night times.

- Conduct integrated surface surveillance using on board and off-board sensors.
- Discriminate and identify friendly and neutral surface vessels from surface enemy threats in high density shipping environments.
- Deploy, control, and recover off-board systems and process data from off-board systems.
- Perform surface engagements to the surface threats independently.
- Use agility and speed, signature management, and soft-kill measures to disrupt the threat's detect to engage sequence and conduct offensive operations against surface threats

PART IV

IV. APPLICATION

IV.1. AIM OF THE APPLICATION

This thesis study is held to determine LCS design criteria's weights via Analytic Hierarchy Process (AHP) by using the author's classification of criteria. The reason of why the LCS is chosen, as the warship type whose criteria's weights are examined in this thesis, is that LCS is considered crucial in implementing of new operational concepts, and being developed for joint force operations to maintain consistent in littoral waters by defeating the threats of mines, submarines and surface forces such as terrorist attack boats.

By regarding the new concept of naval operations in littoral waters and the sea borders of TURKEY connected to mostly littoral waters [2]; this thesis may be accepted that it will be an initial research for analysing or prioritizing the importance of the LCS criteria. Because the focus of the naval operations has moved away from the cold war blue water fleet actions towards low and medium intensity operations in the littoral regions within a joint integrated battlespace as has been demonstrated in recent conflicts.

IV.2. SCOPE OF THE APPLICATION

The scope of the thesis consists of only determining the weights of criteria in LCS design. The general examples of AHP in the literature include comparisons of

alternatives based on objectives. In this thesis 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. This situation gets the thesis study more harder to handle and to release regarding the secrecy. By this thesis it is possible to determine the weights of criteria of LCS which opens a new concept of joint application on the littoral seas with the evaluations of experts from different engineering disciplines and operators from ships.

IV.3. METHODOLOGY FOLLOWED

In this thesis study, a Group Decision Making application, which contains AHP method, is taken as a procedure to determine the weights of design criteria of LCS type warship.

It has been already mentioned in Part II that, the group decision making application can be either in live sessions or in the form of correspondence. As a general route, when AHP is used in a group session, the group participants structure the problem, provide the judgments, debate the judgments and make a case for their values or weights until consensus is reached.

The methodology in this thesis has a significant difference than the general route of the group decision making application with AHP due to the aim and the scope of the thesis. As mentioned in previous section, the scope of the thesis consists of only determining the weights of criteria of LCS design.

The flow chart used in the application phase can be illustrated in the Figure IV.I. After clearing that the AHP will be used in this study, the proper steps are planned and carried out for the rest of the thesis. The definition of each step and the work done in each step is more detailed at the following explanations.

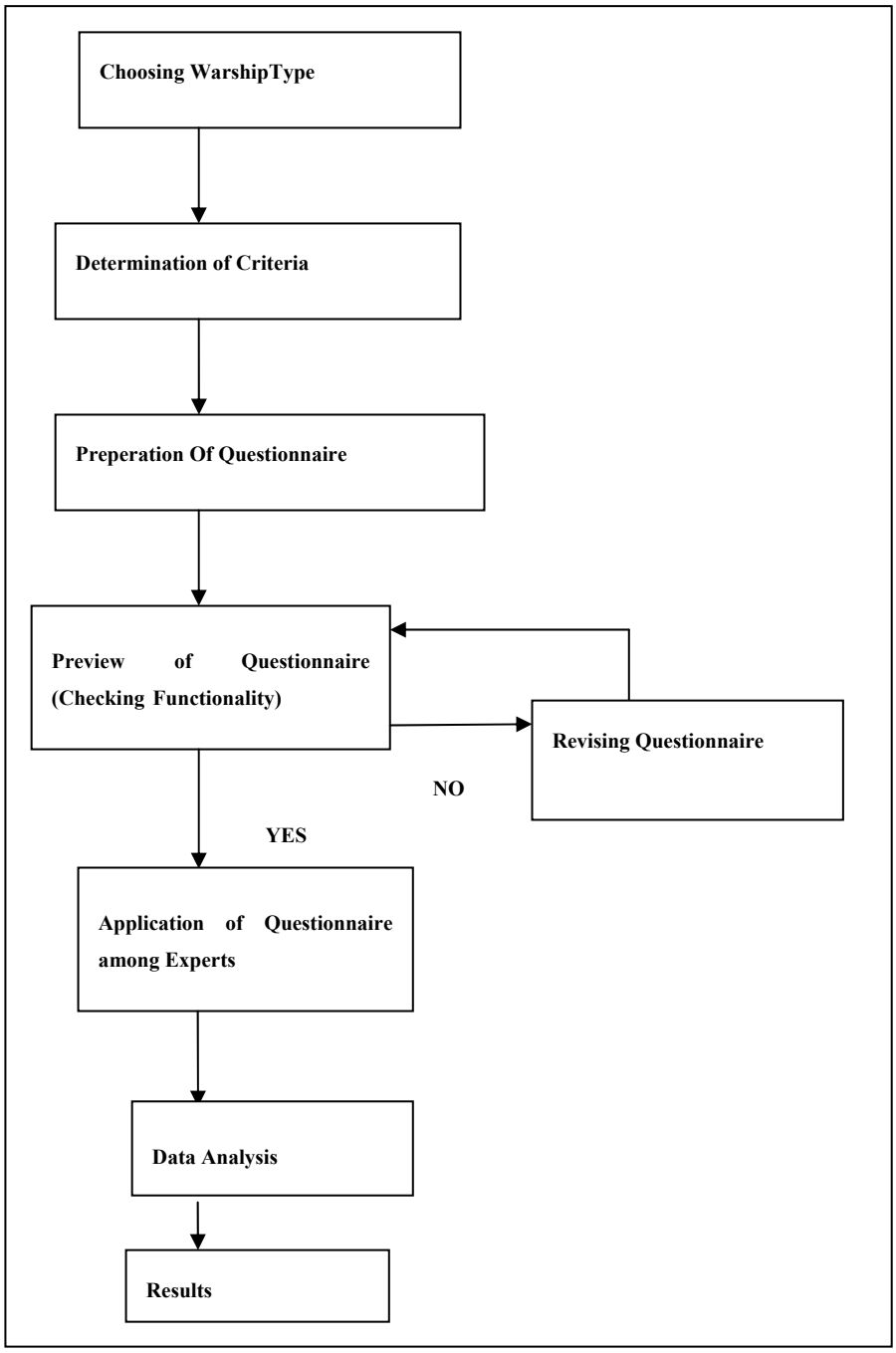

Figure IV-I Flow Chart of The Thesis Methodology

IV.3.1. Choosing the Warship Type

As mentioned in the section IV.1, the reason of why the LCS is chosen as the warship type examined for its criteria in this thesis, is that LCS is considered crucial in implementing of new operational concepts, and being

developed for joint force operations to maintain consistent in littoral waters by defeating the threats of mines, submarines and surface forces such as terrorist attack boats.

IV.3.2. Determination of Criteria

After reviewing the literature about warship design procedures, the criteria list are finalised as in the Table IV.I.

Table IV-I Warship Design Parameters Used in This Thesis Research

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 the study Mobility, Independent Capability, Weapon Systems, Sensor Capability, Susceptibility and Cost are chosen as the Main Criteria of the AHP structure. Later the sub-criteria of those main criteria are defined for weighting or pairwise comparisons under each main criterion.

The definitions of all criteria are given in the following paragraphs.

- Mobility: The capability of operating at sea with a high level of flexibility.
    a. Sustained Speed: It is a function of ship design including primarily the hull form and power installed.
    b. Stability: The property of being stable under all kinds of weather and sea conditions.
- Independent Capability: It defines the ability of operating at the sea without any interruption under battle condition..
    a. Missile Capacity: The maximum number of missile which a warship can have on it.
    b. Gun and Ammunition Capacity: The number of guns and related ammunitions which a warship can have on it.
    c. Endurance Range: The range for a ship with the ability to continue to sail without any problem to interrupt the operation.
- Weapon Systems: This criterion includes all weapons of a warship used for both defense itself or friendly forces and attack to enemy forces. In this thesis three configurations of weapon systems are focused. These are;
    a. Configuration 1: The first configuration has Surface to Surface Missile (SSM) for surface targets, Closing Weapon System (CIWS) against anti-ship missiles, Land Attack Gun for shore batteries or land forces, Torpedo for submarines, Vertical Launching Surface to Air Missiles against enemy aircrafts and Radio Frequency (RF) and Infrared (IR) decoys against all kind of guided missiles. The key concept of this configuration might be considered as Hardkill capability .
    b. Configuration 2: In this configuration addition to SSM, CIWS,

Land Attack Gun, Torpedo and RF/ IR Decoys; there are more complicated Softkill systems such as Trainable Automatic Decoy Launching System, Active Off-Board Decoys, Floating Decoys, Electronic Attack (EA) System.

c. Configuration 3: In the last configuration, weapon system consists of mostly surface warfare units without SAM systems.

- Sensor Capability: Sensors and ESM systems are the equipments used mostly for detection, classification and identification of any vessel at the sea or on the air. In addition to these specific purposes some sensors provide to sail or navigate safely for a ship. These sensors are Radar Systems, IR Search and Track (IRST) Systems, Electro Optic Imaging Systems and Electronic Support Measures (ESM) Systems.
    a. Configuration 1: In the first configuration there are a Navigation Radar, Multi function Radar, ESM System, IRST System, EO Director and Sonar.
    b. Configuration 2: In the second one there are Navigation Radar, Multi Function Radar, ESM System, IRST System, EO Director.
    c. Configuration 3: In the last configuration there are Low Probability Intercept (LPI) Radar, Fire Control Radar, 3 Dimensions Search Radar, ESM System, Sonar and EO Director.
- Susceptibility: It includes the different type of signature of ship. These are:
    a. Infrared (IR) Signature: The view of a target in the infrared region of the electromagnetic spectrum due to the thermal radiation sources on it. The infrared region lies between 0.75 and 1000 micrometer. In the absence of the external factors IR signature of a ship is a function of its temperature, the paint on the ship, warm areas from conductive heating in the engine room, heated missile launchers, heated stacks from the engine exhaust and exposed exhaust gases.
    b. Radar Cross Section (RCS): It is a measure of strength of a radar signal backscattered from a target for a given incident

power. It depends on ship size, reflectivity of ship's surface or surface covering material and directivity of the radar reflection.

c. Acoustic Signature: The strength of a sonar signal backscattered from a hull's underwater portion.
d. Electromagnetic Signature: The signature of the ship comes from type of the constructed material of the hull.

- Cost: The budget needed for the different stages of a ship from design table to the end of use time.
    a. Follow Ship Acquisition Cost: It is the production cost of the same class ships after the first one for a predetermined time span.
    b. Life Cycle Fuel Cost: It is the cost of the whole fuel amount for a ship which the ship will use.
    c. Maintenance Cost: The amount of budget that will be used for maintenance of the ship during the service time.
    d. Construction Cost: The budget which is required for the build a ship at the beginning of the project.

IV.3.3. Preparation of Questionnaire

The questionnaire used in this thesis is held to obtain the pair-wise comparisons done by the experts from different engineering disciplines on Naval applications like total ship engineering, electrical engineering focused on sensors and weapon systems, acoustic engineering, software engineering and on-board personnel. The complete set of the questionnaire can be found in Appendix A.

At the beginning of the questionnaire the aim of the study is declared. Secondly, a brief information about LCS and the missions of LCS are given. Finally, a small explanation about AHP and the scale used in the pairwise comparisons of AHP are given.

After these explanations related to the key concepts in the thesis, the pairwise comparison matrixes of main criteria and sub-criteria are given for the determination of the criteria's weights or constants.

IV.3.4. Preview of the Questionnaire

A preview session is planned to be able to check out the functionality of the questionnaire. For this session a small group of experts consisting from 3 people is chosen. Two of those experts are from total ship engineering discipline and the third one is from both electrical engineering and engineering management discipline by his two master degrees in these areas.

An application of the questionnaire is done among the selected experts and their feedbacks are taken to revise the questionnaire formation. After revising the questionnaire a final check is done by these selected experts and the author. After this finalisation process the questionnaire is ready to apply among all the experts.

IV.3.5. Application of the Questionnaire

After preview and revising of the questionnaire, the next step is the application of the questionnaire. The questionnaire was applied among 20 experts; 5 of them are total ship design engineers, 9 of them are electrical engineers mostly expertise on sensors and weapon systems, 2 of them are computer engineers, 2 of them are acoustic engineers and 2 of them are officers from ships.

There are two methods used in the application of the questionnaire. The first one is making an appointment or time scheduling for a group of two or three experts according to their daily program and explaining the details about the questionnaire and get it back after they finished. The second method is visiting the experts in their offices and explaining the questionnaire individually and get it back when it is done.

All copies of questionnaire are prepared as hard copies and all experts are requested to fill out the forms by hand. The crucial issue about filling out the forms is that getting clear how to make pairwise comparisons according to AHP scale given in Part II (Table II.I). After this key factor is explained by the author to a group of experts or individual expert, all experts are left alone to make the judgments according to their expertise, knowledge and aspects. The proper plenty of times are

given to all experts to handle the questionnaire.

IV.3.6. Data Analysis

The most important part of the thesis is considered as Data Analysis. The whole data gathered through the questionnaire is switched into the soft data by using special tables prepared for this thesis study and finally analysed to be able to determine the criteria weights.

At the beginning of data analysis all weights are calculated according to the theory of AHP as mentioned in Part II (Section II.1.5.1.2) 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. The first method is computing Geometric Mean used in most group decision making applications to provide a final weight for any criterion from whole set of weights of that criterion. The second method is computing Trimmean by excluding the first two and last two weights for each criterion. The third method is computing Geometric Mean of Groups' Weights. In the last method, all experts are separated into four groups according to their expertise and their concentration on ship design issue. The details of these three methods are mentioned in the following paragraphs.

IV.3.6.1. Geometric Mean Method

According to Saaty [4] 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

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

IV.3.6.2. Trimmean Method

This method is contemplated by the author and tried in this thesis differently than the usual method of Geometric Mean for group decision making applications 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 regrading the total number of data. In this thesis the number of data being excepted is taken four. In another words two highest and the two least weights are not taken into the account while computing the Trimmean.

The whole weights of all criteria are sorted from highest to smallest at the beginning of computing the Trimmean. Afterwards the the two highest and the two least weights are being 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.

IV.3.6.3. Geometric Mean of Groups' Weights

Computation of Geometric Mean of Groups' Weights is the other new method which is tried in this thesis. 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 by the author. 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, 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, 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.

Table IV-II Groups Percentage Shares

Group Number	Percentage Share 1	Percentage Share 2	Percentage Share 3
Group 1 (Electrical and Ship Design Engineers)	**% 80**	**% 10**	**% 60**
Group 2 (Acoustic Engineers)	**% 15**	**% 10**	**% 20**
Group 3 (Computer Engineers)	**% 3**	**% 10**	**% 10**
Group 4 (Officers on Board)	**% 2**	**% 70**	**% 10**

After this group formation, weights coming from each expert are listed in each separate group and geometric mean of these weights are computed according to the formula given before. 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.

PART V

V. RESULTS

The results which have been reached through this thesis study will be handled separately for each method mentioned in previous chapter and afterwards a comparison and a summary of all methods is given finally. The whole set of computations and the list of weights are given in the CD in Appendix B.

As an example, the computation of Weapon System's weight is given below by using the AHP computation steps for an expert's matrix about main criteria.

$$A = \begin{array}{c} \\ \textit{Mobility} \\ \textit{Ind.Cap.} \\ \textit{Wea.Sys.} \\ \textit{Sen.Cap.} \\ \textit{Suscep.} \\ \textit{Cost} \end{array} \begin{bmatrix} 1 & 0.33 & 0.14 & 0.14 & 0.5 & 1 \\ 3 & 1 & 0.2 & 0.2 & 1 & 2 \\ 7 & 5 & 1 & 1 & 5 & 7 \\ 7 & 5 & 1 & 1 & 5 & 7 \\ 2 & 1 & 0.2 & 0.2 & 1 & 3 \\ 1 & 0.5 & 0.14 & 0.14 & 0.33 & 1 \end{bmatrix}$$

Column Sum(CS): 21 12.83 2.68 2.68 12.83 21

$$\text{N}= \begin{pmatrix} 1/CS_1 & a_{12}/CS_2 & \ldots a_{1n}/CS_n \\ (1/a_{12})/CS_1 & 1/CS_2 & \ldots a_{2n}/CS_n \\ (1/a_{1n})/CS_1 & (1/a_{2n})/CS_2 & \ldots 1/CS_n \end{pmatrix}$$

$$N=\begin{bmatrix} 0.05 & 0.03 & 0.05 & 0.05 & 0.04 & 0.05 \\ 0.14 & 0.08 & 0.07 & 0.07 & 0.08 & 0.1 \\ 0.33 & 0.39 & 0.37 & 0.37 & 0.39 & 0.33 \\ 0.33 & 0.39 & 0.37 & 0.37 & 0.39 & 0.33 \\ 0.1 & 0.08 & 0.07 & 0.07 & 0.08 & 0.14 \\ 0.05 & 0.04 & 0.05 & 0.05 & 0.03 & 0.05 \end{bmatrix} \begin{matrix} RowAverage = Weight = 0.04 \\ RowAverage = Weight = 0.09 \\ RowAverage = Weight = 0.37 \\ RowAverage = Weight = 0.37 \\ RowAverage = Weight = 0.09 \\ RowAverage = Weight == .04 \end{matrix}$$

According to the weights given at the sample computation, the weight of Weapon Systems is 0.37 (the third row). The computation is repeated 20 times for each expert and finally there are 20 weights for the Weapon System. These twenty weights are listed as follows: 0.43, 0.2, 0.28, 0.33, 0.11, 0.37, 0.23, 0.20, 0.49, 0.26, 0.27,0.11, 0.16, 0.31, 0.08, 0.27, 0.36, 0.12, 0.38, 0.40.

In the Geometric Mean Method by using the formula of;

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

the weight of the Weapon System is computed as 0.2398 with these twenty weights. The results taken by Geometric Mean Method can be seen in the Table V.I. According to these results of geometric mean, the main criterion which has the highest weight is Weapon System with the weight of 0.2398 and the sub-criterion which has the highest weight is Missile Capacity with the weight of 0.4657. The Table V.I has also the average values and standard deviations of all criteria's weights.

Table V-I Geometric Means of All Criteria

CRITERIA	GEO.MEAN	Average	St.Deviation
Mobility	0.1069	0.1485	0.1181
Independent Capability.	0.0904	0.1105	0.0718
Weapon System	0.2398	0.2680	0.1169
Sensor Capability	0.2085	0.2295	0.0855
Susceptibility	0.1012	0.1215	0.0940
Cost	0.0759	0.125	0.1435
Sustained Sped	0.4485	0.5365	0.2756
Stability	0.3849	0.464	0.2764
Missile Capacity	0.4657	0.5120	0.1872
Gun and Ammunition	0.2507	0.2885	0.1514
Endurance Range	0.1466	0.1995	0.1988
Configuration 1	0.2698	0.321	0.1884
Configuration 2	0.3881	0.4280	0.1856
Configuration 3	0.1974	0.2495	0.1788
Configuration 1	0.2965	0.3535	0.2103
Configuration 2	0.1689	0.203	0.1416
Configuration 3	0.3498	0.4430	0.2540
IR Signature	0.2117	0.2605	0.1607
RCS	0.3248	0.365	0.1671
Acoustic Signature	0.1649	0.2025	0.1462
EM Signature	0.1364	0.171	0.1118
Construction Cost	0.2138	0.2825	0.1923
Life Cycle Cost	0.1373	0.1745	0.1304
Maintenance Cost	0.3154	0.3485	0.1473
Follow Ship Cost	0.1646	0.196	0.1380

In the Trimmean Method; the twenty weights are sorted from highest to smallest at the beginning of computation. Afterwards the two highest and the two least weights are being excepted and the Trimmean is calculated. The sample weight via this method for the Weapon System is calculated as 0.2656. The results taken by Trimmean Method are shown in the Table V.II. When these results are checked, it can be said that the criterion of Weapon System has the highest weight with the value of 0.2656 out of six main criteria and the Sustained Speed has the highest weight

with the value of 0.5481 among the sub criteria.

Table V-II Trimmeans of All Criteria

CRITERIA	TRIMMEAN	Average	St.Deviation
Mobility	0.1350	0.1485	0.1181
Independent Capability.	0.1025	0.1105	0.0718
Weapon System	0.2656	0.2680	0.1169
Sensor Capability	0.2325	0.2295	0.0855
Susceptibility	0.1056	0.1215	0.0940
Cost	0.0981	0.1250	0.1435
Sustained Sped	0.5481	0.5365	0.2756
Stability	0.4519	0.4640	0.2764
Missile Capacity	0.5300	0.5120	0.1872
Gun and Ammunition	0.2769	0.2885	0.1514
Endurance Range	0.1488	0.1995	0.1988
Configuration 1	0.3056	0.3210	0.1884
Configuration 2	0.4213	0.4280	0.1856
Configuration 3	0.2213	0.2495	0.1788
Configuration 1	0.3413	0.3535	0.2103
Configuration 2	0.1788	0.2030	0.1416
Configuration 3	0.4481	0.4430	0.2540
IR Signature	0.2425	0.2605	0.1607
RCS	0.3631	0.3650	0.1671
Acoustic Signature	0.1738	0.2025	0.1462
EM Signature	0.1575	0.1710	0.1118
Construction Cost	0.2706	0.2825	0.1923
Life Cycle Cost	0.1538	0.1745	0.1304
Maintenance Cost	0.3488	0.3485	0.1473
Follow Ship Cost	0.1669	0.1960	0.1380

For the Geometric Means of Groups' Weights method the experts are seperated into four different groups. The first group consists of the electrical engineers working on sensor/ weapon systems and ship design engineers. As an exaple, the weights of Weapon System coming from these experts are 0.2, 0.11, 0.23, 0.2, 0.27, 0.11, 0.16, 0.08, 0.27, 0.12, 0.38, 0.4 and Geometric Mean of these 12 weights is computed as 0.16. The second group is formed by the acoustic engineers

and electrical engineers worked on system design and the weights of weapon system coming from this group is 0.28, 0.33, 0.37, 0.36 and the geometric mean of these four weight is 0.33. The third group has the computer engineers and the weights of weapon system from these experts are 0.49 and 0.26 and the geometric mean of these weights is 0.35. The last group has two officers and the weights of these experts for weapon system are 0.43, 0.31 and the geometric mean of these weights is 0.36.

For the GeoSum(1) application the percentage shares of the groups are 0.8, 0.15, 0.03 and 0.02 on the same order with the group numbers. The multiplication of computed geometric means and percentage shares are 12.98 for group 1, 0.05 for group 2, 0.01 for group 3 and 0.007 for group 4. The final GeoSum(1) is computed by adding these four values and it is 0.1968 for Weapon Systems.

Finally the results of the other method called Geometric Means of Groups' Weights are shown in the Table V-III. It can be seen very easily that, the highest weights of main criteria are coming from weapon systems. 0.1968 from first descripted shares, 0.3407 from the second descripted shares and 0.2355 from the third descripted shares. The highest weights of sub-criteria are the missile capacity in the first descripted shares with the value of 0.4560; sensor configuration 3 with the value of 0.5807 in the second descripted shares and missile capacity with value of 0.4565 in the last descripted shares.

Table V-III Geometric Means of Groups' Weights

CRITERIA	GeoSum(1)	GeoSum(2)	GeoSum(3)
Mobility	0.1048	0.0792	0.0979
Independent Capability.	0.0788	0.1109	0.0812
Weapon System	0.1968	0.3407	0.2355
Sensor Capability	0.1794	0.2328	0.1988
Susceptibility	0.0832	0.1303	0.0913
Cost	0.0729	0.0422	0.0686
Sustained Sped	0.4317	0.3883	0.4363
Stability	0.3539	0.4299	0.3666
Missile Capacity	0.4560	0.3358	0.4565
Gun and Ammunition	0.2286	0.2214	0.2337
Endurance Range	0.1257	0.2194	0.1363
Configuration 1	0.2322	0.3094	0.2556
Configuration 2	0.3878	0.3183	0.3749
Configuration 3	0.1808	0.1977	0.1900
Configuration 1	0.2787	0.2529	0.2797
Configuration 2	0.1599	0.1155	0.1594
Configuration 3	0.3051	0.5807	0.3584
IR Signature	0.1847	0.1945	0.1994
RCS	0.2955	0.3754	0.3070
Acoustic Signature	0.1549	0.1144	0.1538
EM Signature	0.1178	0.1277	0.1250
Construction Cost	0.2148	0.1204	0.2095
Life Cycle Cost	0.1083	0.2785	0.1343
Maintenance Cost	0.2789	0.3600	0.2981
Follow Ship Cost	0.1484	0.1462	0.1504

Table V-IV is given for a final comparison of all weights coming from the three different methods. It is a crucial summary for the whole thesis 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 takes the highest weights in all methods as the subcriterion of Susceptibility. The Maintanence Cost takes the highest weights in all methods as the subcriterion of Cost.

Table V-IV 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

PART VI

VI. CONCLUSION

Since the focus of the naval operations has moved away from the cold war blue water fleet actions towards low and medium intensity operations in the littoral regions within a joint integrated battlespace as has been demonstrated in recent conflicts; this thesis study is held to determine Littoral Combat Ship (LCS) design criteria's weights via Analytic Hierarchy Process (AHP) by using the author's classification of criteria

As mentioned in the previous paragraph, the scope of the thesis consists of only determining the weights of criteria in LCS design. The general examples of AHP in the literature include comparisons of alternatives based on objectives. In this thesis 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. By this thesis it is possible to determine the weights of criteria of LCS which opens a new concept of joint application on the littoral seas with the evaluations of experts from different engineering disciplines and operators from ships.

In the literature review part a wide research is carried on to be able to define Multi Criteria Decision Making (MCDM) Techniques, Group Decision Making, Warship Design Process and more specifically Littoral Combat Ship (LCS) Design

Process.

The next part is the definition how to this thesis study is applied. In this part the methodology followed includes preparing a questionnaire, application of the questionnaire and analysis of the results by three different method used in group decision making applications.

Consequently, with this thesis study an initial research for analysing or prioritizing the importance of the LCS design criteria is applied by using the criteria classified by the author of the thesis. Regarding the new concept of naval operations in littoral waters and the sea borders of TURKEY connected to mostly littoral waters; this thesis 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 will use these weights or the constants of the criteria of LCS in the new LCS design projects in TURKEY or in any country.

The other contribution of this thesis 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.

Mobility, Independent Capability, Weapon System, Sensor Capability, Susceptibility and Cost are chosen as the main criteria of warship design by the author. The criterion of Weapon Systems has the greatest weights in all methods within the six main criteria. The criterion of Sustained Speed has the greatest weights in all methods except the GeoSum (2) application as the subcriterion of Mobility. In that application Stability has the greatest weight due to the high percentage share of Group 4 with Experts who have backgrounds different than engineering. Missile capacity has the highest weights in all methods as the subcriterion of Independent Capability. Configuration 2 has the highest weights as the subcriterion of Weapon System in all methods. For the main criterion of Sensor System, Configuration 3 has the highest weights in all methods. The subcriteria of RCS takes the highest weights in all methods as the subcriterion of Susceptibility. The Maintanence Cost takes the highest weights in all methods as the subcriterion of Cost. The consistency of Geometric Mean, Trimmean and Geometric Means of the Group's Weights. methods have been shown by those previous results.

For the future evaluation of this thesis 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.

REFERENCES

[1]. Kertmen, A.: "Evaluation of the Littoral Combat Ship (LCS) Potential for the Turkish Navy", Master Thesis, Naval Post Graduate School, Monterey, USA,**(2006)**.

[2]. www.dzkk.tsk.mil.tr/turkce/platformlar .(Cited March **2007**).

[3]. Saaty, T. L.:, "The Analytic Hierarchy Process", RWS Publication, Pittsburgh, PA, USA **(1996).**

[4]. Saaty, T. L.: " The Analytic Hierarchy Process for Decision in a Complex World", RWS Publication, Pittsburgh, PA, USA **(1995).**

[5]. Brown, A.; Salcedo, J.: "Multiple-Objective Optimization in Naval Ship Design", Naval Engineers Journal, **(2003)**, Vol.115, pp.49-61.

[6]. Taha, H. A.: "Operations Research: An Introduction (Sixth Edition)", Prentice Hall Inc., NJ **(1997)**.

[7]. Shtub, A.; Bard, J.F.; Globerson, S.: "Project Management, Engineering Technology and Implementation", Prentice Hall Inc., NJ, USA **(1994).**

[8]. www.globalsecurity.org/military/systems/ship/lcs.htm. (Cited February **2007**)

[9]. www.globalsecurity.org/military/systems/ship/design.htm. (Cited February **2007**)

[10]. Brugha, CM,: "Structure of Multi Criteria Decision Making", Journal of the Operational Research Society, Volume 55, pp. 1156-1168, **(2004)**.

[11]. Mongin, P,: "Expected Utility Theory", Handbook of Economic Methodology, pp 342-350 **(1997)**.

[12]. Cox, C. J.; Sadiraj, V.: "Risk Aversion and Expected Utility Theory", **(2002)**.

[13]. Karni, E.: "Savage's Subjective Expected Utility Model", John Hopkins University **(2005)**

[14]. Macharis C.; Springael J.; Brucker D. K.; Verbeke A.: "PROMETHEE and AHP : The Design of Operational Synergies in Multicriteria Ananlysis", Europan Journal of Operational Research **(2003)**.

[15]. www.columbia.edu/projects/TheoProject1.pdf (Cited July **2007**)

[16]. Han CH; Ahn BS.: "Interactive Group Decision Making Procedure Using Weak Strength of Preference", Journal of Operational Research Society 56, Pages:1204-1212, **(2005)**.

APPENDIX

APPENDIX A :	THE COMPLETE SET OF THE QUESTIONNAIRE USED IN THE THESIS
APPENDIX B :	CD (AHP WEIGHT COMPUTATIONS)

APPENDIX A : THE COMPLETE SET OF THE QUESTIONNAIRE USED IN THE THESIS

INTRODUCTION for the QUESTIONNAIRE

The aim of this thesis study is to determine the Constants of Criterias' Weights of Warship Design by using AHP (Analytic Hierarchy Process), one of the Multiple Criteria Decision Making Techniques. The ship type was chosen as LCS (Littoral Combat Ship).

LCS will be a Modular Ship. The platform will support mine warfare, anti-submarine warfare and anti-surface boat modules. 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 movement of personnel and supplies. The LCS concept is presently being defined and is envisioned to be an advanced hull form employing open systems architecture modules to undertake a number of missions and to reconfigure in response to changes in mission, threat, and technology.

The primary goal of the AHP is to select an alternative that best satisfies a given set of criteria out of a set of alternatives. AHP scales the weights of attributes at each level of the hierarchy with respect to a goal using the decision maker's (experts') experience and knowledge in a matrix of pair-wise comparison of attributes. The usual application of AHP is to select the best alternative from a discrete set of alternatives.

This questionnaire will be held to obtain the pair-wise comparisons done by the experts from different engineering disciplines on the Naval issues like, total ship engineering, electrical engineering focused on sensors and weapon systems, acoustic engineering and on-board personnel.

The following scale will be used while answering the questions on the questionnaire to be able to make correct pair-wise comparisons.

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

Table 1: Scale Used for Pair-wise Comparisons

APPLICATION OF THE QUESTIONNAIRE

1. Aim: DESIGNING LCS

	Mobility	Independent Capability	Weapon Systems	Sensor Capability	Susceptibility	Cost
Mobility						
Independent Capability						
Weapon Systems						
Sensor Capability						
Susceptibility						
Cost						

2. Criteria and Sub-criteria Matrix

   a. The First Criteria: **MOBILITY**

      Sub-criteria Matrix:

	Sustained Speed	Stability
Sustained Speed		
Stability		

b. The Second Criteria: **INDEPENDENT CAPABILITY**

Sub-criteria Matrix:

	Missile Capacity	Gun and Ammunition Capacity	Endurance Range
Missile Capacity			
Gun and Ammunition Capacity			
Endurance Range			

c. The third Criteria: **WEAPON SYSTEM**

Sub-Criteria Matrix:

	Confi 1	Conf 2	Confi 3
Conf 1			
Conf 2			
Conf 3			

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)

d. The Fourth Criteria: **SENSOR CAPABILITY**

Sub-Criteria Matrix:

	Conf 1	Conf 2	Conf 3
Conf 1			
Conf 2			
Conf 3			

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 + 3D Search Radar + ESM+ Sonar+ EO Director

e. The Fifth Criteria: **SUSCEPTIBILITY**

Sub-Criteria Matrix:

	IR Signature	RCS	Acoustic Signature	EM Signature
IR Signature				
RCS				
Acoustic Signature				
EM Signature				

f. The Sixth Criteria: **COST**

Sub-Criteria Matrix:

	Construction Cost	Life Cycle Fuel Cost	Maintenance Cost	Follow Ship Acquisition Cost
Construction Cost				
Life Cycle Fuel Cost				
Maintenance Cost				
Follow Ship Acquisition Cost				

ACRONYMS

SSM: Surface to Surface Missile

PDMS: Point Defense Missile System

VLS SAM: Vertical Launching System Surface to Air Missile

RF: Radio Frequency

IR: Infrared

EA: Electronic Attack

ESM: Electronic Support Measures

IRST: Infrared Search and Track

3D: 3 Dimensions

EO: Electro Optic

RCS: Radar Cross Section

EM: Electro Magnetic

CURRICULUM VITAE

PERSONAL INFORMATION

Date of Birth : March 06, 1975

Place of Birth : Konya

Languages : Excellent command of both written and spoken English

EDUCATION

- Naval Post Graduate School, CA, USA. December 2001-December 2003
  Master of Science in Combat Systems (in Applied Physics Track)
- Turkish Naval Academy; 1993-1997. Graduation with Electrical Engineering Degree
- Naval High School; 1989-1993.

PROFESSIONAL EXPERIENCES

- Turkish Navy War ship TCG YARHISAR Weapon Officer 1997-1999.
- Turkish Cost Guard 61 Execute Officer 1999-2000.
- Turkish Navy Shore Battery Unit Command 2000-2001.
- Turkish Navy Research Center EW Dept. Project Engineer 2004- Continue

PUBLICATION

Wireless IR Imaging Systems for Robottics; SAVTEK CONFERENCE 2004, ANKARA