NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

THE USE OF THE ANALYTICAL HIERARCHY PROCESS AS A SOURCE SELECTION METHODOLOGY AND ITS POTENTIAL APPLICATION WITHIN THE HELLENIC AIR FORCE

by

Angelis Tsagdis

June 2008

Thesis Advisor:	Jeffrey Cuskey
Second Reader:	James Airola

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2008	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE The Use of the Analytical Hierarchy Process as a Source Selection Methodology and Its Potential Application within the Hellenic Air Force			**5. FUNDING NUMBERS**
6. AUTHOR: Angelis Tsagdis			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

This thesis assesses the feasibility of using the Analytical Hierarchy Process (AHP) as a dynamic tool for decision-making in defense acquisition. The gradual reductions in defense budgets, the need for efficient allocation of funds among competitive activities, the demand from public opinion for rationality, transparency and efficiency in defense spending, the complicated legislation concerning procurements, all call for changes in the way officials make decisions. The AHP is a multiattribute decision-making technique, developed by Thomas Saaty to support users with complex decision-making by combining their experience, judgment, and intuition with a view to selecting the best course of action from a number of alternatives. Literature suggests that the AHP is suitable for a wide variety of applications in economics, finance, politics, games and sports, conflict resolution, cost/benefit analyses, resource allocation, source selection, and resolution of everyday problems. This study focuses on the potential use of the AHP for combat aircraft source selection by the Hellenic Air Force, analyzing legislative, acquisition and technical issues relating to this procurement. It concludes that AHP is a suitable decision making tool for defense acquisitions and recommends the Hellenic Air Force evaluate its potential usefulness via a series of pilot acquisition programs.

14. SUBJECT TERMS Analytical Hierarchy Process (AHP), Source Selection, Combat Aircraft Source Selection, Hierarchies of Criteria, Multicriteria Decision Making, Key Performance Parameters in Acquisition of Combat Aircraft.			**15. NUMBER OF PAGES** 99
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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THE USE OF THE ANALYTICAL HIERARCHY PROCESS AS A SOURCE SELECTION METHODOLOGY AND ITS POTENTIAL APPLICATION WITHIN THE HELLENIC AIR FORCE

Angelis Tsagdis
Lieutenant, Hellenic Air Force
Military School of Combat Support Officers, 2001
B.A in Economics, Aristotle University of Thessaloniki, 2001
M.Sc. in Statistics, Athens University of Economics and Business, 2006

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
June 2008

Author: Angelis Tsagdis

Approved by: Jeffrey Cuskey,
Thesis Advisor

James Airola,
Second Reader

Robert N. Beck, Dean
Graduate School of Business and Public Policy

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LIST OF ACRONYMS AND ABBREVIATIONS

AHP- Analytical Hierarchy Process

AIAA- American Institute of Aeronautics and Astronautics

ANP- Analytical Network Process

CAIV- Cost As Independent Variable

CR- Cost Reimbursement

DFARS- Defense Acquisition Regulations Supplement

DMs- Decision makers

DoD- Department of Defense

EEC- European Economic Community

EU- European Union

FAR- Federal Acquisition Regulation

FFP- Firm Fixed Price

FRP- Full Rate Production

GAO- General Accountability Office

HAF- Hellenic Air Force

HOTAS- Hands On Throttle And Stick

HUD- Head Up Display

IT- Information Technology

LCC- Life Cycle Cost

LPTA- Lowest Price Technically Acceptable

MCI- Mission Capability Index

MDA- Milestone Decision Authority

MTBF- Mean Time Between Failure

MTTR- Mean Time To Repair

O&S- Operation and Support

PD- Presidential Decree

PI- Performance Index

RCS- Radar Cross Section

RDT&E- Research and Development, Test and Evaluation

RFP- Request for Proposal

SSA- Source Selection Authority

TOC- Total Ownership Cost

UAV- Unmanned Aerial Vehicle

U.S.- United States

USA- United States of America

ACKNOWLEDGMENTS

Dedicated to my parents, Dionisios and Soultana, and to my brothers, Aristeidis, Dimitrios and Sotirios.

I also thank the Hellenic Air Force for giving me the opportunity to study and live in a great country.

I mostly thank God for giving me health and strength to achieve my dreams.

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I. INTRODUCTION

A. GENERAL INFORMATION

> What is our mental image of a decision maker? Is he a brooding man on horseback who suddenly rouses himself from thought and issues an order to a subordinate? Is he a happy-go-lucky fellow, coin poised on his thumbnail, ready to risk his action on the toss? Is he an alert, gray-haired businessman, sitting at the board of directors' table with his associates, caught at the moment of saying "aye" or "nay"? Is he a bespectacled gentleman, bent over a docket of papers, his pen hovering over the line marked (X)?

The above abstract from Herbert Simon (1960, 1), illustrates with eloquence and humor, common perceptions of decision-makers in today's world. Decision-making within the defense environment where decisions influence national doctrine, operational readiness and capabilities, geopolitics and foreign policy can be highly complex and calls for a well-organized framework that enhances interaction and interdependence amongst multiple factors and criteria and simplifies the way of thinking. The Analytical Hierarchy Process (AHP) provides such a framework and deals with convoluted problems in intricate environments.

This thesis introduces the AHP and provides the rationale for its potential implementation by the Hellenic Air Force.

B. OBJECTIVE OF STUDY

The Unified Medium-Term Program for the Development and Streamlining of the Hellenic Armed Forces (Hellenic Republic, Ministry of Defense 2006), designed to meet current operational defense needs and based on constraints imposed by the country's extant fiscal conditions, provides for expenses of 11.39 billion euros for major acquisition programs (aircraft, ships, tanks etc.) for the period 2006-2011. Of this amount, over seventy percent (8.5 billion euros) concerns the quittance of older programs and contractual liabilities engaged by previous Unified programs; thus, the acquisition of several major defense systems has been postponed for the period 2011-2015.

Furthermore, over the next decade the Hellenic government aims to fix the amount appropriated for military programs to 1% of Gross Domestic Product, shifting national priorities to sectors such as Education, Medicare, Social Security and Social Welfare. Consequently, the constrained defense budget requires a more efficient and effective allocation of funds amongst competing activities and necessitates the use of every analytical tool to optimize strategic acquisition.

Simultaneously, the new Acquisition Regulation (President of the Hellenic Republic 2007) that became effective on 1 January 2008 constitutes a substantial shift from the "lowest price" doctrine to "best value" acquisition. The determination of criteria other than price, such as Total Ownership Cost (TOC), warranties, technical performance, maintenance, follow-on-support services, and delivery time as basic evaluation factors for source selection, and the need to weigh them according to each factor's contribution to the final product not only complicates acquisition procedures, but eventually may hinder timely and effective decision-making.

The AHP allows for consideration of all the above parameters and factors in acquisition. This thesis presents the AHP as a methodology compliant with the current Hellenic Acquisition Regulation and as a potential contribution to solving one of the most critical problems for Department of Defense (DoD) decision-makers (DMs) worldwide: how to select combat aircraft. Sufficient response to this problem of major systems acquisition would signal that this process can be used effectively for other similar applications in the defense environment. Furthermore, this thesis advocates the usefulness of the AHP for other applications in defense environment.

C. SCOPE AND LIMITATIONS

After introducing the theoretical and practical framework of the AHP, this study focuses on the source selection of combat aircraft for the Hellenic Air Force. Thus, this thesis has a number of unique characteristics and attributes: a) There is a conspicuous lack of similar applications in literature. b) This study has to combine sufficiently the bureaucratic procedures followed by government agencies (laws, regulations, and orders) with the pure scientific methodology proposed by the AHP. c) It has to determine the basic criteria applicable in source selection of various types of combat aircraft (bombers, interceptors, or multi-role). As such, the research intends to present a single model, which with the proper customization based upon trends and needs (technological, geopolitical, legislative, as well as others), could be embodied in the Hellenic acquisition system. d) The author has to take into account the expertise, experience, concerns and ideas of multi-member committees, usually authorized for such decisions and created to think simultaneously as a flight, engineer, logistics, financial, and support officer. This is against the principles and structure of the AHP, which is based on the active participation of expert panels. However, this obstacle is simply part of the challenge of this thesis. Finally, e) The nature of this research and the limited accessibility to documents related to such procurements (i.e. classified documents or business confidentiality issues), will result in a presentation of unclassified material. Additionally, the thoughts expressed and conclusions herein are solely the author's opinion.

D. RESEARCH QUESTIONS

This research addresses the following questions:

Primary Questions:

1. What is the AHP? Where can it be used?
2. How can the HAF implement AHP in the current Hellenic acquisition system?

Secondary Questions:

1. What are the advantages and disadvantages of this method?
2. What is the relation of AHP with the business world?
3. Is the use of AHP compatible with current Hellenic acquisition regulations?
4. Which criteria should be considered for combat aircraft source selection?

E. METHODOLOGY

This research takes a four-phase approach to answering the aforementioned research questions. The first phase covers the literature review and presents the AHP (theory and examples, advantages and disadvantages). The second phase analyzes the current legislative environment in the Hellenic Acquisition System and discusses the suitability of AHP. Additionally, there is an illustrative comparison with the acquisition system in the U.S. (basic similarities and differences). The third phase focuses on the construction of a model for combat aircraft source selection. The most critical point in this phase is the determination of the basic criteria and their visual depiction in a 'hierarchy tree.' Finally, in the fourth phase there is a summary of the findings, answers to research questions, a report of limitations and weaknesses identified during the construction of the model and a proposal of issues for further research.

F. ORGANIZATION OF THESIS

Chapter I provides the justification of this research and presents basic AHP concepts. Chapter II consists of the literature review and extensively describes the methodology for problem solving. This chapter is designed to ensure the reader is familiar with the AHP theory and its various applications, and the reported strengths and weaknesses. Chapter III introduces the reader to the current acquisition legislation in Hellas, and provides a basis to understand the similarities and differences with the U.S. regulations. Chapter IV discusses a methodology that combines the AHP with the existing legislation, takes into account trends and needs in the defense environment, and incorporates them to the combat aircraft source selection. This thesis concludes with a summary of the findings, conclusions and recommendations, and identifies issues for further research.

II. THE ANALYTICAL HIERARCHY PROCESS (AHP)

A. OVERVIEW

This chapter examines the role of AHP in problem solving. Beginning with Herbert Simon’s theory on management decision, the AHP is then introduced and analyzed. The objective of this chapter is to familiarize readers with both the concepts of problem solving in complex environments and the AHP, which emerged as a powerful multi-criteria method that attacks complexity with simplicity. Finally, the chapter ends by presenting the advantages and disadvantages of the AHP method, as identified by various authors and professionals.

B. LITERATURE REVIEW

According to the Nobel laureate Herbert Simon (1960, 1-2), decision making is synonymous with managing. Simon divides the decision process into three phases: a) The intelligence activity, during which DMs establish understanding of the current conditions that call for corrective measures. b) The design activity, where DMs set the desired future state and conditions, and develop a variety of alternatives to attain them (brainstorming phase). c) The choice activity, where DMs select the one alternative that best meets the specific needs and attains the objective.

Simon’s theories on decision making, along with his research in other areas of the social sciences (public economics, psychology, computer science, public administration, management, etc.), not only resulted in his 1978 Nobel Prize Award in Economics, but also, to the establishment of a new way of thinking and dealing with complex problems relating to decision-making (The Nobel Prize Organization, 1978).

Clearly influenced by Simon’s approach, Thomas Saaty was concerned about the apparent lack of setting priorities and simplifying mental processes in decision-making. Thus, he developed the Analytical Hierarchy Process in the 1970s while he was working on problems regarding contingency planning for the U.S. DoD (Saaty 1980, preface). His objective was to model problems in a way that includes and measures "…all important tangible and intangible, quantitatively measurable, and qualitative factors" (1980, 1-2). The method begins with the identification of the objective (i.e. choose the best policy or effectively and efficiently allocate funds amongst competing activities). Next, DMs structure the hierarchies. This is simply the criteria determination phase (i.e. which factors are important to the decision?). The criteria are broken down into subcriteria in order to divide large amounts of information into manageable elements (analysis phase). After that, DMs determine the possible alternatives and set priorities by pairwise comparison of all elements within the hierarchy both with each other and with the alternatives. In this manner, the importance of each criterion relative to the others and the rank of alternatives are determined. Finally, the whole process is tested for consistency; inconsistency would signal that the process should be repeated with a new approach in judging the relative importance of all elements.

Saaty's bibliography on the AHP and problem solving in general provides readers with abundant information on effective decision-making. First, Saaty and Boone introduce an excellent theoretical framework for creativity and problem solving applicable to all practitioners, professionals and researchers (1980, 127-148). In the applied area of management science, he defines the necessary steps to analyze and structure the hierarchies, providing simultaneously a series of examples from various focus areas (1990, 27-74). In addition, he establishes the use of priorities in every decision introducing an "importance scale" (Saaty 1980, 54; Saaty and Vargas 1982, 23), where criteria and subcriteria are ranked from one to nine according their importance after pairwise comparison.

Moreover, Saaty has offered a variety of AHP applications. He has presented applications used for: a) Economics, finance, politics, games and sports (Saaty and Vargas 1991); b) Conflict resolution (Saaty and Alexander 1989): c) Cost/benefit analysis and resource allocation: d) Group decision-making: and e) Resolution of everyday problems such as the selection of a car or a school for children, career path determination etc. (1990, 47-49; 1994, 149-196). AHP applications enormously multiplied after the development of proper software, which simplified the computations and directed step-by-step DMs to reach the "best" decision. Ernest Forman, who developed the Expert Choice software by integrating AHP concepts with personal computers, states that the official webpage of the company "contains references to over 1000 articles and almost 100 doctoral dissertations" (Forman and Gass 2001, 469-486).

On the other hand, a major portion of the literature concerns articles and studies regarding inconsistencies and weaknesses of the method. It is interesting that scholars have been involved in an informal 'conflict' by exchanging letters, comments and articles and the scientific community was divided into two 'camps:' the Saaty supporters and the opponents.

Holder (1990, 1073-1076; 1991, 914-918) believes that: a) The AHP is not very well validated from the laws of physics as Saaty attempted to illustrate with his "chairs example"[1] (1980, 17-19; 1991, 909-914). b) The 1-9 judgement scale for the pairwise comparisons creates problems of consistency to DMs because of its linearity. Alternately, Holder proposes the use of a multiplicative scale which has the form $1, a, a^2, a^3, ... a^n$, and cites Lootsma (1989, 109-116), who applied this scale for a conflict resolution application. c) The AHP needs to be modified to cure the rank reversal problem. For comprehending this concept, a simple example is provided: suppose that the alternatives A and B are ranked as second and third, respectively. The introduction of a new alternative, let us assume C, may reverse the rank between A and B, and B become more preferable than A. This phenomenon constituted the major argument against the use of AHP and was reported by many scholars. Finally, d) Holder opines that it is more preferable to reinterpret numerical estimates in terms of the judgement scale.

1 In this example, four chairs were disposed in a straight line, away from a light source. The experiment was held at night and a strong beam of light was used. A person standing next to the light source, had to determine the relative brightness for the chairs, by using Saaty's 1-9 Judgement Scale. Thus, he had to compare the brightness of each one chair with all others. The experiment was repeated with the participation of two individuals and the outcomes for the brightness of the chairs were the same. With this optics experiment, Saaty wanted to prove that the theoretical framework of AHP and the mind process while using it, are validated by the laws of physics and logic. His conclusion was that "the eye is able to select the appropriate numbers non-linearly from the 1-9 scale as they bunch together for the distant objects." In a repetition of the experiment, Saaty used also his wife and son to make pairwise comparisons; note that while it was very common for every visitor to Saaty's house to participate in similar experiments (for example the comparison of weights of different size rocks or suitcases) (Forman and Selly 2001, 70-71).

Dyer (1990) states that "…the AHP is flawed as a procedure for ranking alternatives in that the rankings produced by this procedure are arbitrary." Furthermore, he proposes the integration of AHP with the concepts of the traditional multi-attribute utility theory, as it was first introduced by John von Neumann and Oskar Morgenstern (1947). Also, he considers that "…the AHP elicitation questions suffer from even more ambiguity than those of preference questions…." In this manner, he alleges that the efforts of Harker and Vargas (1987, 1383-1403) to present ambiguity as inherent for all preference methods are "misleading." Additionally, he refers the rank reversal problem and the arbitrary rankings resulting from it, providing an example created by himself and Wendell. Finally, he ends his critique by proposing alterations to the method.

Forman (2001) introduces transitivity as a weakness that usually appears when AHP deals with multicriteria problems. He further cites Fishburn's research (1991, 113-134) relating to nontransitivity in decision theory. AHP is structured on the axiom of the transitive preferences. Thus, if choice A is twice as preferable as choice B, and B is twice as preferable as choice C, then, based on this axiom, choice A must be four times as preferable as C. However, Fishburn notes that:

> Transitivity has been the cornerstone of traditional notions about order and rationality in decision theory. Three lines of research during the past few decades have tended to challenge its status. First, a variety of experiments and examples that are most often based on binary comparisons between multiple-factor alternatives suggest that reasonable people sometimes violate transitivity, and may have good reasons for doing this. Second, theoretical results show that transitivity is not essential to the existence of maximally preferred alternatives in many situations. Third, fairly elegant new models that do not presume transitivity have been developed, and sometimes axiomatized, as alternatives to the less flexible traditional models.

According Belton and Gear (1983, 227-230), "…there is a degree of imprecision in the specification of what factors should be taken into account when determining the weights." The authors then present two examples to support their allegation.

Warren's study (2004) for the Australian DoD focuses on the following: a) He criticizes the AHP for its fundamental axioms. According to Warren these axioms do not

"…comprise a necessary and sufficient set of mathematical prerequisites as the foundations of a computational methodology should." b) He believes that the AHP leads to misunderstanding of the rating scale type, due to the ambiguity as to whether "…the input relative importance ratings are on an implicit ratio scale, or whether the derived priorities computed from the comparison matrix are on a derived ratio scale." c) He argues against the use of the right hand principal eigenvalue and eigenvector. d) He reports problems emerged while rating the "relative importance" of the criteria. e) He addresses other anomalies and secondary problems.

Before proceeding with the presentation of AHP in combat aircraft source selection, it is useful to present some bibliography on this specific topic. Apparently, it is very difficult to track studies and research by official institutes or scholars on applications relative to combat aircraft source selection using AHP. This fact encumbers the author's effort to determine the primal and most important criteria and leaves area for further research by defense institutions and organizations, with the participation of experts from different focus areas.

Mavris proposes that affordability, mission capability, operational readiness, wartime survivability, and peacetime safety constitute the five major attributes in military aircraft selection (Mavris and DeLaurentis 1995). Furthermore, he provides both a theoretical and an analytical framework for aircraft analysis and design, detailing cardinal factors such as affordability, system effectiveness, life-cycle design, and uncertainty (Mavris et al. 1998). In his application for the selection of an Unmanned Combat Air Vehicle (UCAV), Chao Zhang considers as basic criteria: technology, armament, avionics and subsist[2] (Zhang et al. 2006). In research conducted by Nguyen for the Australian DoD (2003), the most important parameters were considered speed, ferry range, maximum payload, cost, reliability and maneuverability. Finally, the same criteria were selected by Forman and Selly (2001, 29) in their own application.

None of the aforementioned authors, with the exception of Mavris, provide rationale as to why they selected their respective criteria, and their applications lack a

2 This criterion refers to the ability of the UCAV to persist under combat situations and is synonymous to survivability.

detailed analysis on the derived thought process. Undoubtedly, they focus on how AHP (or alternative methods) can simplify the decision-making process, after constructing the hierarchy of criteria, directing their analysis on the objective (selection of the best aircraft) rather than on the special acquisition characteristics. Despite that, these studies stand as a valuable approach for current research.

In conclusion, although not without detractors, the AHP, as a decision-making model, is of great value and interest for the scientific community. It attracts the attention of scholars, researchers, practitioners, and organizations. This fact ensures its constant evolution, and facilitates the way to recognition and use more extensively.

C. DESCRIPTION AND USE

Two out of the three ingredients of the 'Analytic Hierarchy Process' have Hellenic roots. Their etymology, according Merriam-Webster Dictionary (2007), is as follows. Hierarchy: (from the Hellenic "ιερά αρχή" = holly principle or authority) a graded or ranked series <a *hierarchy* of values>. Analysis: (from the Hellenic verb "αναλύειν'' = to loosen) separation of a whole into its component parts. Combining etymology with some basic concepts already analyzed, AHP results as a both qualitative (determination of objective, criteria, subcriteria, structuring the hierarchy) and quantitative (pairwise comparison, check for consistency) method that measures and synthesizes constituent elements for complex decisions. According to Saaty (1994, 5), "…it is a framework of logic and problem-solving that spans the spectrum from instant awareness to fully integrated consciousness by organizing perceptions, feelings, judgements and memories into a hierarchy of forces that influence decision results."

1. Basic Theory

For each rational decision, people evaluate a series of factors and/or activities according their relevant importance to the decision. Following Saaty's theoretical approach (Saaty and Vargas 1982, 17-21; Saaty 1994, 45-68), let us assume that n such factors must be considered prior to a decision. Denoting these factors by $A_1, A_2, ..., A_n$, the comparison of the activities A_i, A_j can be depicted by the pair (A_i, A_j) and, thus, with the n-by-n matrix $A = (a_{ij})(i, j = 1, 2, ...n)$. Apparently, this matrix consists of non-zero entries since all elements have positive values and all diagonal elements are equal to unity given that they depict self-comparisons. As AHP grounds its success on the fact that it measures the consistency of people's judgements, matrix A is consistent if and only if $a_{ij}a_{jk} = a_{ik}$. Hence, if car A is twice as preferable as car B, B is five times as preferable as car C, then A is 10 times as preferable as C. Returning to the theory, the use of an absolute scale for the measurement of weights of the n activities allows people to compare them by the use of $w_{1,} w_{2,} ..., w_n$, and the construction of a n-by-n matrix W, "whose rows consist of the ratios of the measurements w_i of each of n activities with respect to all others."

$$W = \begin{pmatrix} \frac{w_1}{w_1} \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \vdots & \ddots & \vdots \\ \frac{w_n}{w_2} \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{pmatrix}$$

If matrix A is consistent, then: a) It has the form $A = (w_i / w_j)$ with $i, j = 1, 2, ..., n$ and b) It is reciprocal; hence for each element a_{ij}, $a_{ij} = \frac{1}{a_{ji}}$ with $i, j = 1, 2, ..., n$. Then we need to solve the equation $Aw = nw \Leftrightarrow (A - nI)w = 0$ for the unknown w. Given that the matrix A has unit rank because every column is a constant multiple of the first one, there is a single eigenvalue λ_i with $i = 1, 2, ...n$, which is different from zero. It is also known that $\sum_{i=1}^{n} \lambda_i = tr(A) \equiv n$, because if we add all diagonal elements of A (1+1+…), their sum equals n. If we denote this non-zero eigenvalue with $\lambda_{\max}$, we have $\lambda_i = 0, \lambda_i \neq \lambda_{\max}$ and $\lambda_{\max} = n$. Whichever column from matrix A we obtain as solution, the difference between all columns/solutions will be a multiplicative constant. But as we need a normalized solution, we normalize the column/solution so that the sum of its components is unity. After obtaining the eigenvector w, we may calculate the eigenvalue $\lambda_{\max}$, from the formula $\lambda_{\max} = \sum_{i=1}^{n} a_{ij} \frac{w_j}{w_i}$. Every result for which $\lambda_{\max} > n$, signals inconsistency, the exact magnitude of which is measured by the Consistency Index (C.I): $C.I = \frac{\lambda_{\max} - n}{n-1}$ and the Consistency Ratio (C.R): $C.R = \frac{C.I}{R.I}$ (where R.I stands for random consistency index).3 The value of C.R should be around 10 per cent or lower so that the whole process is accepted.

2. Hierarchies

Figure 1 describes the necessary steps to construct a hierarchy in a problem (Saaty 1990, 33). The first step is to clearly state the overall goal or objective (What do we want to accomplish?). The overall goal is sometimes composed of subgoals that also need to be determined.

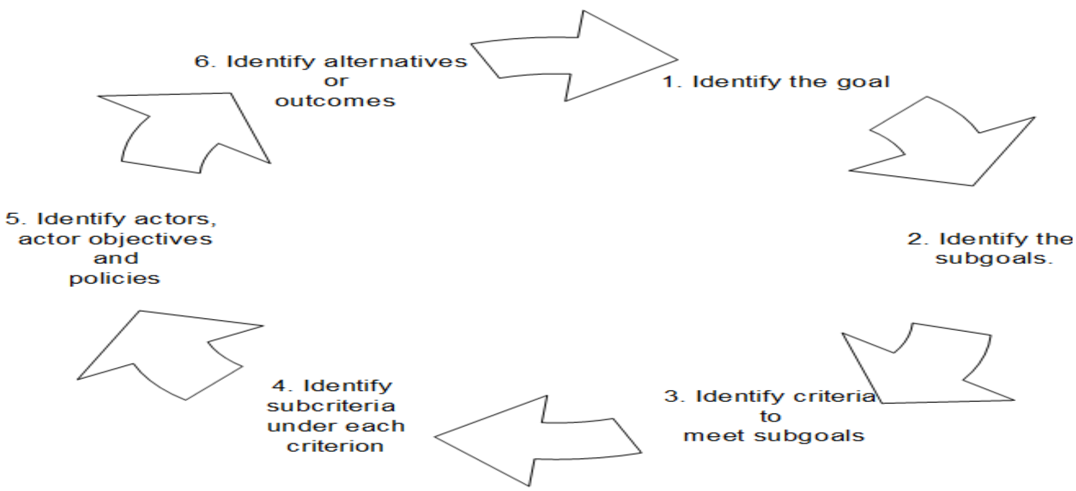

Figure 1. Construct the Hierarchy

Source: Adapted from Saaty, Thomas L. 1990. *Decision Making for Leaders- The Analytic Hierarchy Process for Decisions in a Complex World.* Pittsburgh: RWS Publications, p. 33.

3 Random Index (R.I) was developed at Oak Ridge National Laboratory by researchers that generated R.I for matrices of order 1-15. The sample size was 100 and Saaty with his colleagues repeated the calculations at Wharton School with a sample size of 500. In the table below, R.Is from 1-11, come from the results obtained at Wharton, and from 12-15, from results at Oak Ridge (Saaty 1980, 21).

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The most critical part of this process is step 3 where DMs identify which criteria must be taken into account prior to the decision. Usually during this phase, experts and DM brainstorm to identify the major factors and parameters that influence the outcome or decision. The rule is that when an alternative adequately meets the prespecified criteria, it consequently meets the overall goal. In step 4, these criteria are broken down into their constituent parts (subcriteria). For example, safety for a combat aircraft depends on reliability, maintenance defects, and design defects (Mavris et al. 1998). In the next step, DMs need to identify the stakeholders who are dependent, influenced by, or influence the final decision. Finally, during the last phase, DMs identify the alternatives or the desired outcomes. Obviously, this methodology becomes more complex by adding subobjectives, criteria, subcriteria, and alternatives since all of them will be compared with each other. A visual depiction of a hierarchy is given in Figure 2 below:

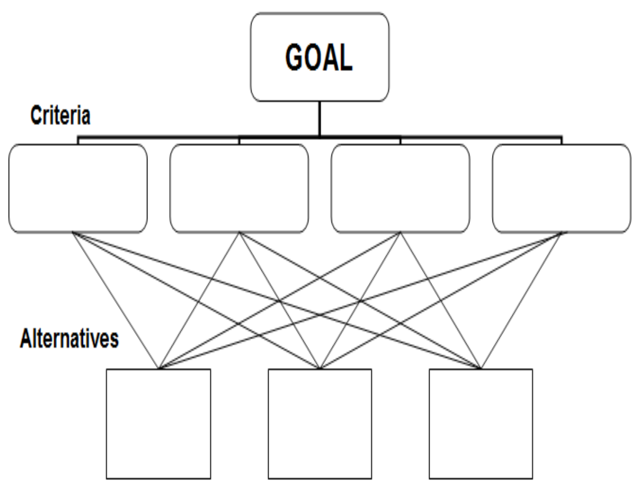

Figure 2. The Hierarchy

Source: Saaty, Thomas L. 1994. *Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process.* Pittsburgh: RWS Publications, p. 95. Figure 4.1.

The decomposition of a goal to its component elements enables the development of practical decisions, while coping with complexity. It is easier dealing with one factor, criterion, actor or alternative at a time, than having to make a decision instantly, assimilating large pieces of information. Additionally, with the use of the proper software, DMs can estimate how a change in prioritization at a certain level of the hierarchy affects priorities in lower levels (sensitivity analysis) and the rank of alternatives, thus giving them the opportunity to reconsider and modify their decisions.

The hierarchy analyzed above is called dominance hierarchy (Saaty 1994, 101) and "…descend[s] like an inverted tree with the boss at the root, followed by successive levels of bossing." These hierarchies can be divided into structural and functional ones. The first ones apply for decision related to structural attributes and identities. For example, a structural hierarchy within U.S. DoD consists of the Secretary of Defense, the Deputy Secretary of Defense, the Chairman of Joint Chief of Staffs, the Unified Combatant Commands, and so on until the last soldier, airman, sailor and civilian. On the other hand, most complex decisions concern functional elements that are usually interrelated. For example, choosing college for children may depend on family's budget, its distance from hometown, its status and prestige, and the potential of a scholarship.

To familiarize readers with the concept of constructing hierarchies, a representation of Forman's application for choosing the best retail site is provided (Forman and Selly 2001, 53-61). Let us assume that we have to determine a location to open a retail store and there are three alternatives: the suburban shopping center area (outside the town), the mall (a complex with many retail stores, restaurants, and coffee-shops) and a main street (downtown). Initially, the criteria selected for this decision are: a) The cost to open this business; b) The customers' visibility (Can this store be located easily by potential customers?); and finally, c) The extant competition in each area (similar/complimentary businesses). This preliminary analysis results in Figure 3:

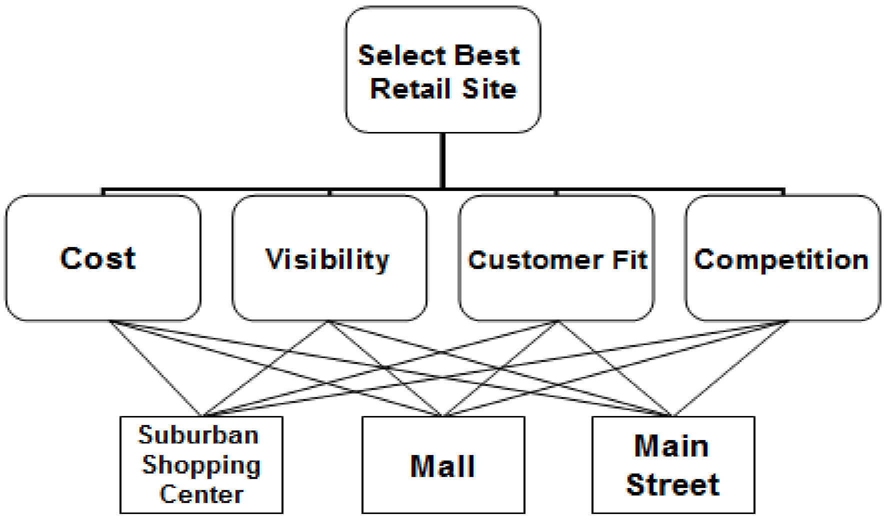

Figure 3. Best Retail Site Selection

Source: Adapted from Forman, Ernest, and Mary Ann Selly. 2001. *Decision by Objectives.* Washington DC: The George Washington University, p.56. Figure 3.

The aforementioned analysis lacks of detail since it does not take into account several other important factors. In order to get more specific, let us divide the criteria into their components. Cost is a variable depending upon the expenses needed to open the business (denoted here as initial cost, which may include investment in equipment, recruit and training of employees, advertisement, uniforms, etc.), the percentage of gross monthly income for the landlord and the monthly lease cost. Furthermore, competition is influenced by both the existence of similar stores in the area and the existence of complimentary stores that may act as magnet for potential customers (for example a store with kids clothing next to an ice-cream store, helps both businesses to increase their turnover). Finally, customer fit is a factor related to the number of people passing by the store and the potential of the store to attract more customers (for example, an ice-cream store in the financial district may attract many employees during summer months and become a popular “hang-out” for the lunch break). Figure 4 incorporates this new information.

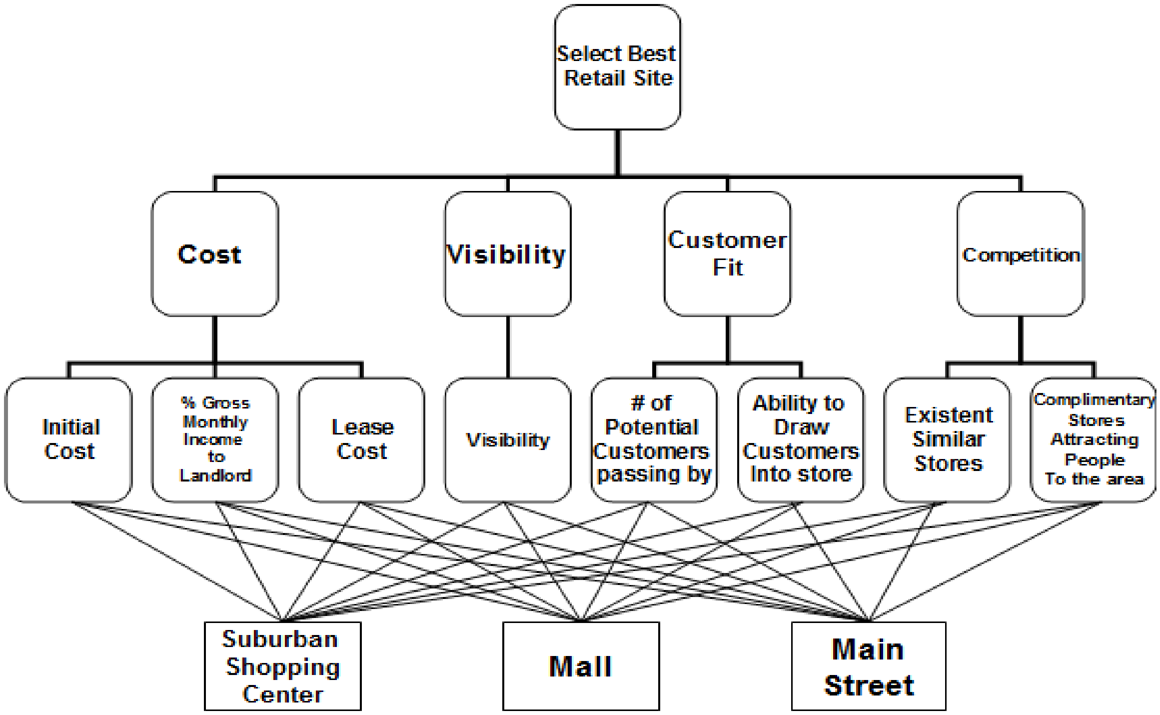

Figure 4. Best Retail Site Selection (Scenario 1)

Source: Adapted from Forman, Ernest, and Mary Ann Selly. 2001. *Decision by Objectives.* Washington DC: The George Washington University, p. 57, Figure 4.

The problem of selecting the best location for a retail site may become even more complicated adding new criteria, subcriteria, or even alternatives. Also, the AHP allows for the intervention of different approaches in decision-making. In Figure 5, the model becomes intricate by adding three scenarios of uncertainty. Evidently, the survivability and the prosperity of a new company depend strongly on the economy's performance. Risk escalates as we move from a booming economy, to status quo, and finally to a gloomy economy. Wages, rent, cost of equipment, consumption versus savings, business activity, and stagnation versus investment, are only some of the variables that differentiate based upon the financial situation. Figure 5 presents the new version of the model.

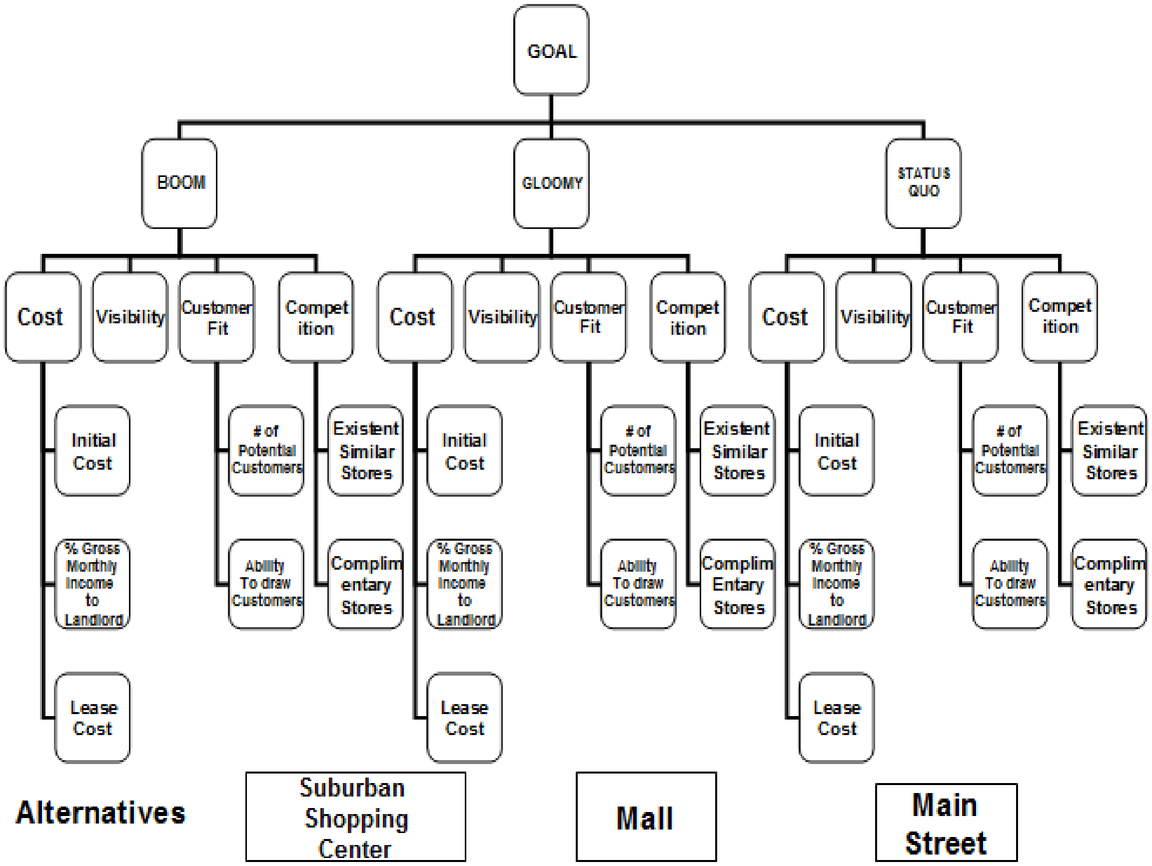

Figure 5. Best Retail Site Selection (Scenario 2)

Source: Adapted from Forman, Ernest, and Mary Ann Selly. 2001. *Decision by Objectives.* Washington DC: The George Washington University, p. 58, Figure 5.

Forman and Selly presented several more versions of this application using Expert Choice software. Without getting into further detail, the evolution of information technology and the development of proper software that incorporates the AHP framework made possible the construction of very complex hierarchies (even with hundreds of nodes) and the instant computation of convoluted math formulas.

3. The Judgement-Scale

Intensity of Importance	Definition	Explanation
1	**Equal Importance**	**Two activities contribute equally to the objective**
2	Weak	
3	**Moderate Importance**	**Experience and judgement slightly favor one activity over another**
4	Moderate Plus	
5	**Strong Importance**	**Experience and judgement strongly favor one activity over another**
6	Strong Plus	
7	**Very Strong or Demonstrated Importance**	**An activity is favored very strongly over another; its dominance demonstrated in practice**
8	Very, very Strong	
9	**Extreme Importance**	**The evidence favoring one activity over another is of the highest possible order of affirmation**

Table 1. The Fundamental Scale

Source: Saaty, Thomas L. 1980. *The Analytic Hierarchy Process*. New York: McGraw-Hill.p.54,Table 3-1.

Table 1 represents Saaty's judgement scale for pairwise comparisons (1980, 54). Numbers 2, 4, 6, and 8 stand for intermediate values between the numbers adjacent to them (for example value 2 does not concern neither equal importance nor moderate one, but a level between them). Moreover, as it was presented earlier in the basic theory section, if element A has relative importance of value 5 compared to element B, then the latter has relative importance of value 1/5, compared with the former one (reciprocal identity). Saaty used this 1-9 scale because he believed (1980, 55) that peoples' "…ability to make qualitative decisions is well represented by five attributes: equal, weak, strong, very strong, and absolute." In addition, people "…can make compromises between adjacent attributes when greater precision is needed." Adding the five main attributes with the four adjacent, we reach Saaty's scale. In practice when we compare two alternatives with respect to an attribute or characteristic, we use these numbers. See the following for an example of use of the scale and the calculations needed to support a decision.

Let us assume that we want to buy a car on the basis of luxury. For simplicity, we have three alternatives: a Rolls-Royce (R), a BMW 528 (B) and a Mercedes E-Class (M). We construct the following matrix (Table 2) with our own personal judgments:

Luxury	M	B	R
M	**1**	*2*	*1/4*
B	1/2	**1**	*1/8*
R	4	8	**1**

Table 2. Selection of the most luxurious car

Commencing, we fill the diagonal elements, which stand for self-comparisons and are equal to unity (bold numbers). Then, we have to ask ourselves how much more luxurious a Mercedes is compared to a BMW or a Rolls-Royce, based on our perceptions, experience, knowledge, or other information. Using the verbal explanations provided by the scale, we consider that a Mercedes is weakly more luxurious than a BMW, but also much less luxurious than a Rolls-Royce. Thus, we enter the value 2 for Mercedes over BMW and $1/4$ for Mercedes over Rolls-Royce. Taking into account the transitivity identity, we enter the value $1/8$ for BMW over Rolls-Royce. Using the formulas, we obtain the following: $a_{ii} = 1, (i = M, B, R) \Rightarrow a_{MM} = 1, a_{BB} = 1, a_{RR} = 1$. Additionally, from the pairwise comparisons we obtain: $a_{MB} = 2, a_{MR} = 1/4$. Since the reciprocals are $a_{BM} = 1/2, a_{RM} = 4,$ using the transitivity formula, we obtain $a_{BM} a_{MR} = a_{BR} \Rightarrow a_{BR} = 1/2 \, 1/4 = 1/8 \Rightarrow a_{RB} = 8.$

In the next phase, we estimate the relative importance of each car with respect to luxury. First, we add the values in each column and we obtain Table 3.

Luxury	M	B	R
M	**1**	*2*	*1/4*
B	½	**1**	*1/8*
R	4	8	**1**
Column Sum	5.5	11	1.375

Table 3. Selection of the most luxurious car (sum of columns)

Next, we divide the value of each column with the respective sum and we obtain the normalized matrix (Table 4).

Luxury	M	B	R
M	0.181818	0.181818	0.181818
B	0.090909	0.090909	0.090909
R	0.727273	0.727273	0.727273

Table 4. Selection of the most luxurious car (Normalized Matrix)

After that, we find the average for each row, which are respectively 0.1818, 0.0909, 0.7272. These numbers give the overall preference for the three alternatives. Hence, Mercedes gets 18.18 percent, BMW 9.1 percent and Rolls-Royce 72.7 percent. Surely, one would argue that this example is very simple and the solution known from the beginning. But what is not known from the beginning is how willing are we to pay for the extra luxury of a Rolls-Royce. Dividing the cost of these models with the percentages obtained above, we conduct an informal cost-benefit analysis (where benefit here is luxury) and we discover the final rank of the alternatives. Thus, if the Rolls-Royce model is 4 times more expensive than the Mercedes one, then we should prefer the latter.

Furthermore, software allows DM to express their judgements not only with Saaty's verbal scale, but also with the use of either graphical or numerical modes. When using numerical judgements, number 1 implies that the elements have equal importance; number 2, that the first one has two times a certain identity over the other; number 9, that it has 9 times a certain identity over the other, and so on. The graphical judgements generally use a chart pie interconnected with two bars. Increasing the length of one bar over the other (thus one element is relatively more important than the other), results in increasing the portion of the pie for the first element, and vice versa. All these approaches are consistent with Saaty's principles and were developed to simplify and popularize the method.

4. Axioms

After introducing some basic elements of the AHP theory (basic concepts, hierarchy, and judgement), it is appropriate to summarize the foundations and axioms of this method. AHP is grounded on three basic principles: "decomposition, comparative judgements and synthesis of priorities" (Saaty 1994, 337-338). Decomposition applies in the deconstruction of an overall goal to objectives, criteria, subcriteria, and so on. Visually, deconstruction is depicted with a tree with the most general concept being at top, and the increasingly specific concepts as leaves. The alternatives lie on the root of the tree. Comparative judgements apply when conducting pairwise comparisons of all nodes within a branch with respect to their parent node. The comparisons begin from the lowest level branches of the tree and gradually, reach to the top. Finally, the synthesis of priorities applies when multiplying the value/priority of a branch with the priority of their parent node. After estimating all priorities until reaching the second-level nodes (which are, most of the time, the criteria or sub-goals/sub-objectives), we add back all priorities to find the final ranking of the alternatives. AHP was originally based on three axioms; the fourth was added later by Saaty (Saaty 1994, 338-346; Forman and Selly 2001, 50-53).

Axiom 1: Reciprocal. Let us assume that we have two elements A and B. If we denote with $P_c(E_A, E_B)$, their paired comparison with respect to their parent element C, then $P_c(E_A, E_B) = 1/P_c(E_B, E_A)$. Simply, if A is considered 3 times heavier than B, then B is one third as heavy as A.

Axiom 2: Homogeneity. The comparison of elements should be limited to similar things that do not differ too much, or have very different attributes. "We cannot compare a grain of sand with an orange according to size" as "the mind tends to make large errors in comparing widely disparate elements" (Saaty 1994, 342).

Axiom 3: Independence of Judgements within the Hierarchy. Without this axiom, the principle of hierarchic composition does not apply because different levels of the hierarchy appear interdependent (outer or inner) and do not form a tree. Simply, when DMs make judgments or estimate priorities for the elements, these actions must not depend on other judgments or prioritizations within the hierarchy. This axiom is often violated in the decision-making process when DMs establish criteria with "overlapping areas or commonalities" (Saaty 1990, 86), and results in a misleading rank of alternatives. For example, if one wants to buy a car and has established the basic criteria for this decision as price, cubic capacity, and luxury, this falls into the trap of interdependence since, as a general rule, the more luxurious a model the higher its price. Saaty (1990, 90-91) distinguishes between two types of interdependence: the additive, where an element contributes some value to others, and the synergistic, where the interaction of all elements in a hierarchy is greater that the sum, which results by adding them separately (overlap). Without entering into detail, as dealing with interdependency constitutes a separate part of this study, the AHP confronts this issue with the construction of supermatrices and superhierarchies (Saaty and Vargas 1982, 28-30; Saaty 1994, 224-292).

Axiom 4: Expectations "Those thoughtful individuals who have reasons for their beliefs should make sure that their ideas are adequately represented for the outcome to match these expectations" (Saaty 1994, 346). Merely, when people deal with a problem, they should try to represent and embody all their ideas and perceptions that are rational for them. Different people may have different approaches and different outcomes may result. This axiom says that while DMs use the AHP, both their personal beliefs or even sometimes their bias and the nature of the problem determine the final rank of alternatives.

5. Example

This example represents the application for the selection of the "best" vacation site (Saaty and Vargas 1982, 34-37), and incorporates all the issues analyzed above and familiarizes readers with the math calculations.

Let us assume that a four-member family has three alternatives for the Christmas break to go to: a Sea Shore Resort (S), a Mountain Resort (M), or Relatives (R). The basic criteria to be taken into account are: distance from hometown (minimal drive time denoted as MDT), adequate facilities for all members of the family (convenient facilities denoted as CF), sightseeing (acquaintance of new places denoted as NA), relaxed environment (RE), activities for children (CA) and cost (C).[4] The hierarchy is depicted in Figure 6.

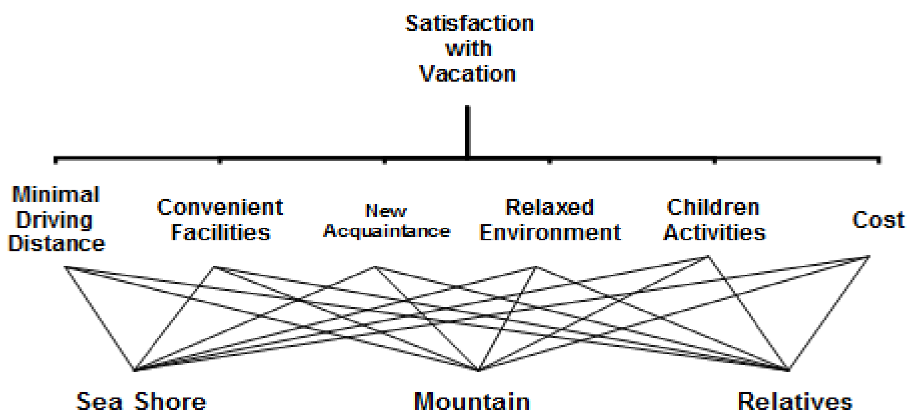

Figure 6. Hierarchy for Vacation Site Selection

Source: Saaty, Thomas L., and Luis G. Vargas. 1982. *The Logic of Priorities.* Massachusetts: Kluwer Nijhoff Publishing, p. 35, Figure 2.1.

Assuming that the judgements have already been made by the family members, we obtain the two tables (actually eight tables) that include the comparisons made among the criteria with respect to the overall goal (Table 5), and the comparisons among the alternatives and the six criteria (Table 6.). Despite that software made possible the computation of the eigenvectors, the eigenvalues, the C.R and C.I, it is advisable that readers comprehend how the values are derived and thus are provided with the following systematic guidance.

4 Readers may change these criteria and alternatives or even add more according their preferences and needs, time schedule etc.

	MDT	CF	NA	RFE	CA	C
MDT	1	1	7	5	3	1/3
CF	1	1	5	3	3	1
NA	1/7	1/5	1	1/3	1/7	1/9
RFE	1/5	1/3	3	1	1/3	1/3
CA	1/3	1	7	3	1	1/5
C	3	1	9	3	5	1

Table 5. Comparison of Characteristics with Respect to the Goal

Source: Saaty, Thomas L., and Luis G. Vargas. 1982. *The Logic of Priorities.* Massachusetts: Kluwer Nijhoff Publishing. p. 35, Table 2.5.

Minimal Drive Time	S	M	R	Convenient facilities	S	M	R
S	1	1/7	1/5	S	1	9	5
M	7	1	5	M	1/9	1	1/9
R	5	1/5	1	R	1/5	9	1
New Acquaintances	S	M	R	Relaxed Environment	S	M	R
S	1	9	7	S	1	1/5	5
M	1/9	1	1/9	M	5	1	9
R	1/7	9	1	R	1/5	1/9	1
Children Activities	S	M	R	Cost	S	M	R
S	1	9	5	S	1	1/7	1/9
M	1/9	1	1/7	M	7	1	1/5
R	1/5	7	1	R	9	5	1

Table 6. Comparison of Sites with Respect to the Criteria

Source: Saaty, Thomas L., and Luis G. Vargas. 1982. *The Logic of Priorities.* Massachusetts: Kluwer Nijhoff Publishing, p. 36, Table 2.6.

Step 1: In the matrix presenting the comparison of criteria with respect to the goal (Table 5), find the sums of all columns. Add the values in each column. Then, normalize the matrix by dividing each element in the column with the respective sum of the column. You obtain Table 7.

	MDT	CF	NA	RFE	CA	C
MDT	0.176174	0.220588	0.21875	0.326087	0.240458	0.11194
CF	0.176174	0.220588	0.15625	0.195652	0.240458	0.335821
NA	0.025168	0.044118	0.03125	0.021739	0.01145	0.037313
RFE	0.035235	0.073529	0.09375	0.065217	0.026718	0.11194
CA	0.058725	0.220588	0.21875	0.195652	0.080153	0.067164
C	0.528523	0.220588	0.28125	0.195652	0.400763	0.335821

Table 7. Normalized Matrix of Criteria

Step 2: In the normalized matrix (Table 7), find the average for each row. This is accomplished by adding all elements in a row and dividing the sum by six (the number of alternatives). After these calculations, you obtain the priority vector (Table 8). Check for numerical mistakes: if you add all values in the priority vector, their sum must equal one. The priority vector depicts the relative importance of each criterion in the decision.

	MDT	CF	NA	RFE	CA	C	Sum	Priority Vector
MDT	0.176174	0.220588	0.21875	0.32608696	0.2863636	0.11194	1.339904	0.22332
CF	0.176174	0.220588	0.15625	0.19565217	0.0954545	0.335821	1.17994	0.19666
NA	0.025168	0.044118	0.03125	0.02173913	0.0136364	0.037313	0.173224	0.02887
RFE	0.035235	0.073529	0.09375	0.06521739	0.0318182	0.11194	0.41149	0.06858
CA	0.058725	0.220588	0.21875	0.19565217	0.0954545	0.067164	0.856334	0.14272
C	0.528523	0.220588	0.28125	0.19565217	0.4772727	0.335821	2.039108	0.33985

Table 8. The Priority Vector

Step 3: To estimate the eigenvalue $\lambda_{\max}$, C.I and C.R, multiply the rows of the initial matrix (Table 5) with the principal vector: you obtain a new vector. Divide the values of this new vector with the respective values of the principal vector: you obtain a third vector. If you then find the sum of all values in it, and divide the sum by the number of criteria (six), you obtain $\lambda_{\max}$. Then, using the equation $C.I = \frac{\lambda_{\max} - n}{n-1}$, for $n = 6$, and $C.R = \frac{C.I}{R.I}$, for $R.I = 1.24$,[5] you estimate the consistency ratios (Table 9.).

5 For matrix of order four (n=4), R.I=1.24.

	MDT	CF	NA	RFE	CA	C	Priority Vector	2nd Vector	3^{rd} Vector
MDT	1	1	7	5	3	1/3	0.22332	1.506428	6.745687
CF	1	1	5	3	3	1	0.19666	1.538091	7.821197
NA	1/7	1/5	1	1/3	1/7	1/9	0.02887	0.181115	6.273318
RFE	1/5	1/3	3	1	1/3	1/3	0.06858	0.426267	6.215469
CA	1/3	1	7	3	1	1/5	0.14272	0.889629	6.233282
C	3	1	9	3	5	1	0.33985	2.385653	7.019698
								Sum:	40.30865
C.I=	0.143622		C.R=	0.115824		R.I=1.24		**λ max:**	6.718109

Table 9. Finding λ_{max} , C.I, C.R for the Criteria

Step 4: Compare all alternatives amongst each other and with respect to the criteria. You obtain six different matrices merged into Table 10. The rationale for this step is to determine the relative importance of the alternatives for each criterion.

Minimal Drive Time	S	M	R	Convenient facilities	S	M	R
S	0.076923	0.106383	0.032258		0.7627119	0.473684	0.818182
M	0.538462	0.744681	0.806452		0.0847458	0.052632	0.018182
R	0.384615	0.148936	0.16129		0.1525424	0.473684	0.163636
New Acquaintances	S	M	R	Relaxed Environment	S	M	R
S	0.797468	0.473684	0.863014		0.1612903	0.152542	0.333333
M	0.088608	0.052632	0.013699		0.8064516	0.762712	0.6
R	0.113924	0.473684	0.123288		0.0322581	0.084746	0.066667
Children Activities	S	M	R	Cost	S	M	R
S	0.762712	0.529412	0.813953		0.058824	0.023256	0.084746
M	0.084746	0.058824	0.023256		0.411765	0.162791	0.152542
R	0.152542	0.411765	0.162791		0.529412	0.813953	0.762712

Table 10. Normalized Matrix of Alternatives

Step 5: Repeat steps 1-3 for the matrix, which describes the comparisons of alternatives with respect to the six criteria (Table 10). You obtain the priority vectors for each alternative with respect to each criterion, depicted in Table 11.

	Minimal Drive Time	Convenient Facilities	New Acquaintances	Relaxed Environment	Children's Activities	Cost
Sea	0.0719	0.6849	0.7114	0.2157	0.702	0.0556
Mountain	0.6965	0.0519	0.0516	0.7231	0.0556	0.2424
Relatives	0.2316	0.2633	0.237	0.0612	0.2424	0.702
Λ	3.273	2.988	2.959	3.196	2.982	3.318

Table 11. The Eigenvectors and the Eigenvalues

Step 6: Multiply the eigenvectors of Table 11 with the Priority Vector (Table 8.) to find the final rank of the alternatives (Table 12.).

Alternatives	Weights	Rank
Sea Resort	0.305154	Third
Mountain Resort	0.307129	Second
Relatives	0.387716	First

Table 12. Final Rank/Results

The results indicate that the family's needs are best met by choosing the visit to their relatives. Another approach to this problem would be if we treated cost separately and then we divided it with the final value of the alternatives. The lowest ratio (cost/benefit) would determine the "best" solution. Practitioners and other DM understand that the comparisons among the elements of the hierarchy presented in this example express unique beliefs, perceptions, evaluations, and needs. Had they been in the position to decide for their families' vacation, the results would be different.

D. ADVANTAGES AND DISADVANTAGES

1. Advantages

In this section, there is an analysis of the main advantages (and later on, disadvantages) of AHP. When applying the method in different circumstances, different strengths and weaknesses appear, however the purpose here is to present an overall picture of advantages and disadvantages without customizing them for each application.

The complexity in today's world is an undoubted fact that is usually characterized by uncertainty, difficulty in predictability and planning, and constant evolution. Strategic decision-making is a prerequisite for sustainability and survivability not only in the business world, but also within the government environment where the stakes are high and decisions influence many stakeholders.

The AHP was developed to incorporate all these factors along with experience and intuition into a simplistic approach and has become a widespread tool for various types of organizations. Today AHP is used by corporations listed in Fortune 500,[6] branches of government such as defense, transportation, healthcare, and public administration, universities (where the AHP technique is often taught as a course or constitutes a subject for researches and theses), and other institutions.

By this point in the thesis, it is likely that readers may have already identified some of the obvious merits of this method. First, the hierarchical structure allows DM to organize large pieces of information into manageable amounts, facilitating understanding and comprehension. AHP is structured as a well-designed thought process that can be easily followed even without specific mathematics knowledge or experience and expertise in decision making. Its foundation is the use of rationale and logic in a step-by-step process. Moreover, the development of software expanded the user base and eliminated many of the associated difficulties of applying it. Amazingly, there are not many decision making problems that cannot be formulated and solved utilizing the AHP; likewise, the published number of applications constantly increases.

Figure 7 represents the advantages of AHP as they were addressed by Saaty (1990, 22-26).

6 The Fortune 500 ranking consists of the top American public corporations which are evaluated on the basis of gross revenues. The listing is published annually by the magazine "Fortune."

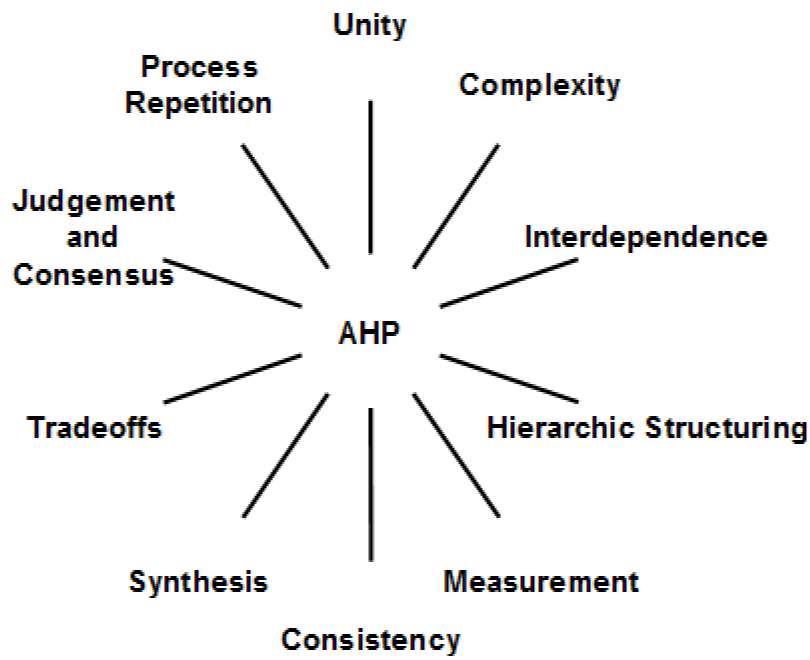

Figure 7. Advantages of the AHP

Source: Saaty, Thomas L. 1990. *Decision Making for Leaders- The Analytic Hierarchy Process for Decisions in a Complex World*. Pittsburgh: RWS Publications, p. 22, Figure 2-2.

The attribute of unity concerns the simplicity of the method, its wide variety of applications, and the fact that it is based on three principles of analytic thinking: structuring hierarchies, setting priorities, and being logically consistent (Saaty 1990, 17-18). This method was developed by Saaty specifically to address complexity in decision making.

One other advantage of the method is interdependence. According to Saaty, “the AHP can deal with the interdependence of elements in a system and does not insist on linear thinking.” Despite that statement, there are many critiques regarding the interdependence of factors and alternatives, and questions relating to how AHP can effectively deal with an attribute almost intrinsic in human nature. When people brainstorm to record all the factors related to an outcome, they usually include criteria or alternatives that influence one another. This leads to either double counting, or to the distortion of the relative importance of each element in the hierarchy. Interdependence and the ways to deal with it is sufficiently defined in the disadvantages portion of this study.

Hierarchical structuring and measurement reflect the mental process of humans to sort elements in a more convenient way that facilitates prudent decision making, and to rank them based on their knowledge, experience, preference, and rationale. In fact, the AHP imitates the logical process of the human mind. Additionally, it is flexible as it affords the DMs an opportunity to check their assessments for consistency (with the use of indexes, as previously discussed) and revise them as necessary.

The final four attributes concern the way AHP is applied. The participation of people from different areas of expertise, along with their personal beliefs, experiences, ideas, or even imagination, assures that the final decision is a 'win-win' selection. The AHP substantially changes the role of DMs from a "one-man show" to active cross-functional team members. It enhances the participation of various experts and the cooperation among them, allows the synthesis of various angles of view, introduces tradeoffs in the determination of relative importance as a way to obtain the best solution, and ensures consensus for the final decision. The latter attribute also establishes co-accountability for strategic decisions and transparency, as all ideas are 'represented' in the final product; and there is adequate clarification as to why an alternative has been chosen.

Finally, this method is very adaptive as it can be supplemented by other decision making tools. For example, the use of an Ishikawa diagram (also known as "fishbone" diagram) may determine the roots of a problem or the component parts of an element in the hierarchy. Furthermore, studies have shown that with the proper modification AHP can be compatible with the Delphi method (Zhang et al. 2006), despite Saaty's opposition and concerns for it (1980, 69-70).

2. Disadvantages

Obviously, the perfect decision making model does not exist and there is little chance for it to ever be developed. In this section, there is a representation of the three primary critiques against the use of the AHP. Of course, there are many more debates as far as the use of the AHP (functionality, axioms, and theoretical framework), the analysis of which is far removed from the objective of this thesis.

a. Rank Reversal

The introduction of a new alternative in the existing set of alternatives may lead to the rank reversal phenomenon. This simply means that, if in the beginning alternative A was more preferable than alternative B, the introduction of alternative C may reverse the rank between A and B; thus, B becomes more preferable than A. Several authors (Belton and Gear 1983; Holder 1990; Dyer 1990) studied the weakness of AHP to assimilate new information and proposed modifications to obtain consistency.

Saaty and Vargas (1984) noted that "it is not inconsistency that affects rank order, but the judgement magnitudes for the new alternatives and the subsequent composition of priorities that do." According to their study, rank reversal is not likely to appear when the new alternative is less preferable than the least preferred initial alternative or more preferable than the most preferred initial alternative. All the same, if this new alternative falls in the ranking of relative importance between the existing ones, then it is probable to reverse the rank. Moreover, the authors believe that rank reversal is sometimes legitimate and acceptable, against the traditional multi-attribute utility theory notions. Their rationale is based on the basic economic principle that a good in scarcity is more valuable that a good in abundance.

Forman (1987) provides an excellent example as to why rank reversal is justifiable or even desired in some cases. Furthermore, he explains why sometimes AHP leads to counterintuitive results, which, paradoxically, are substantially accurate and consistent with economic fundamentals. In his example, three basketball players (A, B, and C) are evaluated according to two equally weighted criteria: offense and defense. While player A is excellent in offense and with acceptable skills in defense, player B is excellent in defense with acceptable skills in offense, player C appears to have above average skills in both defense and offense (but not being excellent in either of these areas). The judgements are as follows: a) A is twice as preferable as C and four times as preferable as B, with respect to offense; and b) B is twice as preferable as C and four times as preferable as A, with respect to offense. Tables 13 and 14 show the pairwise comparisons (absolute consistency is assumed).

	A	B	C
A	1	4	2
B	¼	1	1/2
C	½	2	1

Table 13 Comparison with respect to Offense

	A	B	C
A	1	¼	½
B	4	1	2
C	2	½	1

Table 14 Comparison with respect to Defense

Source: Forman, Ernest H. 1987. Relative Vs Absolute Worth. Mathematical Modelling 9, no. 3-5: 195-202 (figure 2).

The 'paradox' in this example is that most people intuitively believe that these three players are of equal importance. Their rationale is that since player C is twice as preferable as player A, as far as defense, and $\frac{1}{2}$ as preferable as far as offense, consequently, A and C are of equal importance. The same rationale justifies the equal importance of B and C. But intuition is not always right. Player C gets a double "slice" from A in the their combined share of the defense "pie" and player A gets a double "slice" from C in the their combined share of the offense "pie." However, these two combined shares are not equal since player A dominates the offense "pie" and the defense "pie" by player B.

Additionally, Forman continues his example by adding five more excellent offensive players. Judging the new set of alternatives on the basis of relative importance, player B becomes more valuable than A. This new rank (and the appearance of rank reversal) is justified by the fact that player B is scarce and thus, has higher relative importance than the offensive players have. Had we judged these alternatives in absolute terms (isolating every single player and evaluating him separately), players A and B would still be of equal value: in clear violation of fundamental economics.

Conclusively, the comparison of relative importance of an element in the hierarchy may lead to rank reversal, a phenomenon consistent with the AHP principles and cardinal economics.

b. Transitivity and Consistency

Another area where authors and practitioners focus their critique against the AHP is the transitivity axiom, a principal attribute in traditional multi-attribute utility theory. The violation of this axiom leads to inconsistency; and, furthermore, to the distortion of the final rank of the alternatives. If A is twice as preferable as B, and three times as preferable as C, then A must be six times as preferable as C. At first sight, it may appear easy to preserve consistency within the hierarchy, but this is attainable only while making comparison under no more than two criteria. When the structure of alternatives and criteria get complicated, it is almost impossible for DM to obtain the perfect consistency for the matrices.

Forman and Selly (2001, 47-49) set out six factors that cause inconsistency: a) Clerical errors when entering the values of comparison into the matrices; b) Lack of information when making the judgements. Sometimes, it is probable that DMs do not take into account all factors that influence the importance of an element; therefore, their judgements are biased; c) Lack of concentration when making the comparisons. DMs base their judgements on assumptions already made and often do so unintentionally; d) Real-world situations modeled by AHP are not perfectly consistent. No one questions that there is no perfect information, perfect competition, perfect knowledge, unmistakable judgements, accidental issues, and other parameters that cannot be measured in a consistent way; e) The structure of the constructed model, which sometimes may not capture the most significant parameters of a problem; and f) Setting a goal to be perfectly consistent sometimes leads to inconsistency. The goal for DMs should be to be consistent with their intuition, experience, and knowledge -- not with the model itself.

The previous analysis resulted in the acknowledgement that inconsistency is almost inherent in the AHP models. Nevertheless, Saaty determined (1980, 21) that if the Consistency Ratio (C.R) is less than ten percent, the model should be considered acceptable or tolerable. He further opines (1994, 84-85) that inconsistency is very important for the adjustment and improvement of a model and its constant evolution for better results. Also, he advises DM (1994, 85-86) to restrict their comparison to no more than seven elements. He states that the smaller the number of elements to be compared, the greater their relative importance and the less impact of inconsistency within the model. Of course, this does not mean that DMs should leave elements out of their judgements only to confine the structure to less than seven elements.

c. Interdependence

Intuitively, when DMs brainstorm to determine which elements influence the final decision, they sometimes fail to notice their interdependence; thus violating the third axiom of AHP.

Interdependence comprises 'outer dependence' and 'inner dependence.' The first occurs when the relative importance of an alternative depends (among others) on an element already processed by the alternative and vice versa (when an element depends on the alternative). For example, choosing a car is a case where people have to take into account, among other factors, the style of each alternative. Given that each alternative (car) has its own style, outer dependence appears because style is both an element for the decision and a basic element of the alternative.

Inner dependence characterizes the bi-directional relationship amongst alternatives. For example, software companies depend heavily on information technology (IT) for their existence and development. Without the use of personal computers, there would not be software and other applications. On the other hand, IT as both a science and reality is strongly affected by software. We cannot have IT breakthroughs without analogous software evolution and development. To determine dependence in the decision tree, we need to consider simple questions: a) What affects what?; b) To what extent?; and c) How can we isolate these relationships and measure their relative importance in the final decision?

Saaty (1994, 253-276) provides a series of examples to help DMs understand the notion of interdependence and the way to effectively deal with it. DMs first have to determine which criteria affect each other. Then, DMs have to construct a super-matrix of criteria, putting zeros to all self-comparisons and the comparisons made with respect to the independent criteria (i.e. the criteria that do not affect other ones or are affected by others), and, finally, judge the relative importance of each dependent criterion to the other dependent criteria. From this super-matrix the final relative importance of each criterion is derived and the method is continued as described. Furthermore, Saaty developed the Analytic Network Process (ANP), a holistic approach that facilitates decision making when the construction of a hierarchy is impossible due to the interdependence of criteria and alternatives. Saaty and Vargas (2006) set out a variety of applications where ANP is more suitable than the AHP, with the use of networks that "…spread out in all directions and involve cycles between clusters and loops within the same cluster" (2006, 7). ANP is based on the AHP axioms and framework but also allows for feedback, a factor that enhances qualitative decision-making.

E. SUMMARY

This chapter introduced the AHP as a decision-making tool. It began by presenting the existing literature concerning the use of this method, its applications, and reported strengths and weaknesses. Briefly, the AHP is currently used in a variety of problems ranging from economics, finance, politics, resource allocation, cost/benefit analyses, and conflict resolution. The main strengths of AHP include the simplicity for use, and its ability to incorporate and synthesize large amounts of information by structuring all the critical elements for a decision into hierarchies. Some of the weaknesses comprise the rank reversal phenomenon, transitivity and consistency issues, and the interdependence of the elements within the hierarchy.

Later on this chapter, there was an analytical presentation of AHP's theoretical framework. This section familiarized readers with axioms and formulas and provided Saaty's step-by-step methodology when dealing with problems. Additionally, the author applied the AHP for the selection of the best retail site, the most luxurious car, and he represented Saaty and Vargas' example for the selection of the best vacation site for a family.

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III. THE AHP IN THE CURRENT HELLENIC ACQUISITION LEGISLATION

A. OVERVIEW

This chapter introduces readers to the current Hellenic procurement legislation and explains why the AHP can have a substantial role in source selection. In addition to presenting the compatibility of the AHP with the acquisition environment in Hellas, this chapter also focuses on important similarities and differences between Hellenic and U.S. acquisition regulations and practices.

B. HISTORICAL INFORMATION ON ACQUISITION REGULATION IN EUROPE

World War II left Europe with great losses in human resources, a financial slump, abandoned countryside and agriculture, and 'open wounds' in almost every area of human interest. The vision of a united Europe where countries would determine effective solutions for the quick re-development of the nations while avoiding new conflicts resulted in the Treaty of Rome, in 1957. As indicated in the official website of the European Union, the Treaty of Rome established the European Economic Community (EEC), as a league of democratic nations that would enhance peace, stability, democracy, cultural exchange and financial development. In the preamble of the Treaty (accessed from the Hellenic Resources Network website), the six founding countries (Belgium, West Germany, France, Italy, Luxembourg, and Netherlands):

> Resolved to ensure the economic and social progress of [their] countries by common action to eliminate the barriers which divide Europe,
>
> Affirming as the essential objective of [their] efforts the constant improvement of the living and working conditions of [their] people,
>
> Recognizing that the removal of existing obstacles calls for concerted action in order to guarantee steady expansion, balanced trade and fair competition,

> Anxious to strengthen the unity of [their] economies and to ensure the harmonious development by reducing the differences existing [in] the various regions and the backwardness of the less favored regions,
>
> Desiring to contribute, by means of common commercial policy, to the progressive abolition of restrictions on international trade,
>
> Intending to confirm the solidarity which binds Europe and the overseas countries and desiring to ensure the development of [their] prosperity, in accordance with the principles of the Charter of the United Nations,
>
> Resolved by thus pooling [their] resources to preserve and strengthen peace and liberty, and calling upon the other people of Europe who share their ideals to join in [their] efforts,
>
> Have decided to create a European Economic Community….

The EEC promised peace and prosperity for all nations in Europe and cooperation and coherence on cardinal issues of public policy, national security, economy, and culture. Nevertheless, the road to success was slowed down by a series of obstacles such as ethnocentrism, national interests above the interests of the EEC, cultural diversity among nations, and reactions in the interior of countries. Additionally, citizens concerned about a Europe of "two speeds:" those counties that could easily progress with the march of events and those ones that would need radical transformations.

It was not until February 7, 1992, when things started changing dramatically. In the city of Maastricht, the namesake Treaty was signed; a treaty that substantially sped up the processes for political and economic unification, enforced a detailed course of action by all members, and established the identity of European citizenship. The latter allowed people from the member counties (and thus businesses) to move and reside freely within the territory of the European Union (EU) (European Union 1992).

Directive 2004/18/EC for public procurements is based in the aforementioned framework (European Union 2004). Its objective is founded upon:

> …the principle of freedom of movement of goods, the principle of freedom of establishment and the principle of freedom to provide services and to the principles deriving there from, such as the principle of equal

treatment, the principle of non-discrimination, the principle of mutual recognition, the principle of proportionality and the principle of transparency.

Furthermore, in Article 53-Contract Award Criteria, legislators established two categories of acquisition: a) the "lowest price" acquisition where price is the only criterion to be taken into account, and b) the "best value" acquisition, where "…quality, price, technical merit, aesthetic and functional characteristics, environmental characteristics, running costs, cost-effectiveness, after-sales service and technical assistance, delivery date and delivery period or period of completion…" are taken into account prior to a contract award.

The Directive dictated that all member-nations of the EU reform their acquisition legislation in order to comply with it. Also, the establishment of a common legislation allows businesses from all over Europe to compete for awards in numerous countries, thus improving competitiveness, innovation, and development. Because of these legislative transformations, the Hellenic government put in place Presidential Decrees no. 60 and 118 (President of the Hellenic Republic 2007), effective 1/1/2008.

C. AHP AND THE HELLENIC ACQUISITION REGULATION

Presidential Decree (PD) no. 60 is, in fact, the official translation of Directive 2004/18/EC. The real 'innovation' in the acquisition regulation established by PD no. 118, is that its clauses apply to all government agencies and organizations where the government constitutes the main shareholder.

In Article 20, there is a distinction between awards to offerors based upon "lowest price technically acceptable" and awards to offerors based upon the "most advantageous offer from an economic standpoint." In this section, we study how the AHP can be implemented in the latter category of bids, as combat aircraft source selection is conducted in a similar manner.

For "best value" acquisitions, source selection authorities should take into account the following criteria (President of the Hellenic Republic 2007, Article 20): a) price; b) costs of installation, function, and maintenance (as they are described in the issued solicitation); c) the fulfillment of technical specifications and requirements; d) warranties and guarantees; e) after sales support and service; f) the schedule of deliveries; and g) every other criterion and requirement related with the nature of the product or service embodied in the solicitation. Figure 8 illustrates these concepts in the AHP framework.

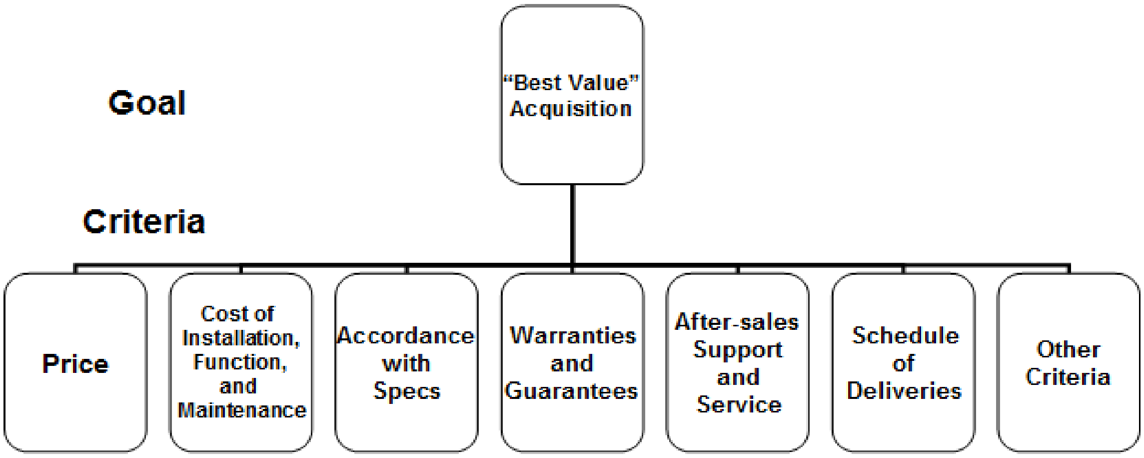

Figure 8. The AHP in the Hellenic Acquisition Regulation

Furthermore, the PD establishes the process for the evaluation of the offers. It distinguishes the source selection criteria into two broad categories: a) the economic criteria, which include price and costs of installation, function, and maintenance (which can categorized as price related factors); and b) the rest of criteria, described above (service, support, warranties and deliveries). The latter category is further divided into two subcategories: a) criteria related to technical requirements, quality and performance, which include the ones that ensure the responsiveness of the offeror to the technical requirements of the solicitation; and b) criteria related to technical support and service. The visualization of all criteria is depicted in Figure 9.

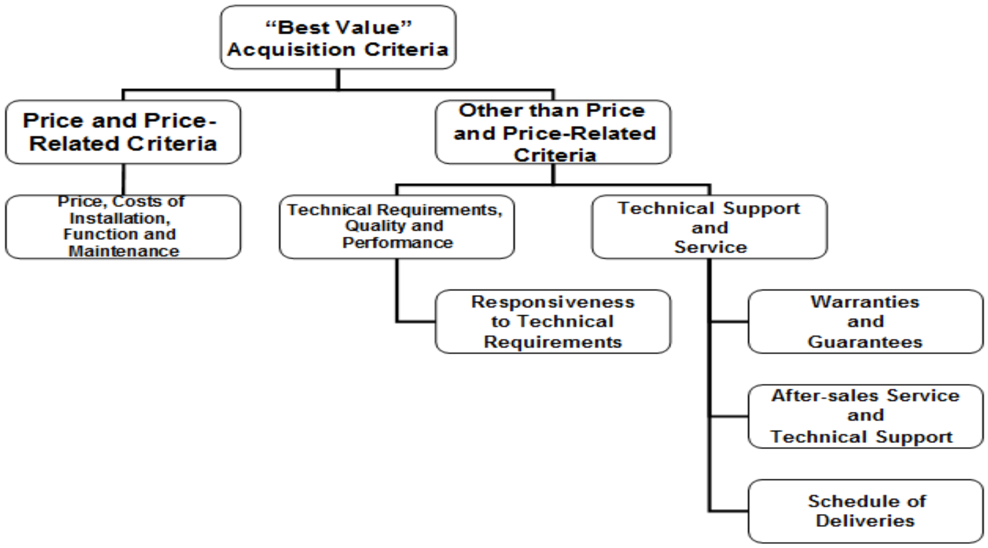

Figure 9. The "Best Value" Acquisition Criteria

The "Technical Requirements, Quality, and Performance" criteria may score up to 80 percent, whereas the "Technical Support and Service" criteria, up to 30 percent; but the sum of these two categories must always equal 100 percent. Each element of the "other than price and price-related" criteria may score up to 100 percent, with the exception of 'outperformance,' that allows scores up to 110 percent. The relative importance of an element is accrued by multiplying its grade with the relative weight of the 'pool' to which it belongs. For example, if an offer is graded with 90 percent with respect to its responsiveness to the technical requirements, and the weight for the "Technical Requirements, Quality, and Performance" category is 80 percent; then the relative importance of this specific element is $90\% \times 80\% = 72\%$.

After determining the final rank of all "Other than price and price-related factors," the source selection authority (SSA) has to divide "price and price related factors" with the score obtained by all other criteria. The smallest fraction among the compared criteria constitutes the "best value" offer.

The AHP is compatible with the current Hellenic regulation (and consequently, the European regulations). The AHP helps DMs to establish criteria, assign weights for every 'pool' (category) and prioritize the relative importance of each element. Moreover, DMs can use the AHP to compare offers amongst other offers and with respect to the degree of satisfying the stated requirements. As well, the use of appropriate software allows the conduct of sensitivity analysis; thus DMs have the opportunity to understand how a different evaluation and score assignment preserves or distorts the results. The whole source selection process represents the decomposition of a hierarchy of values to manageable elements; and, therefore, includes every useful bit of information for DMs.

In conclusion, the AHP appears to be a dynamic tool for management, evaluation, and decision-making in procurements where a large number of factors need to be determined and taken into account,.

D. THE U.S. ACQUISITION SYSTEM AND AHP

The U.S. Acquisition System is based on a variety of laws, regulations and guides. The fundamental institutional document that covers all government procurements is the Federal Acquisition Regulation (FAR). Additionally, DoD and its agencies have established the Defense Acquisition Regulations Supplement (DFARS) and DoD 5000 directives that, respectively, supplement the FAR and relate to program management issues (from the early stage of refining a requirement until the delivery of products and services to the end-customer). Furthermore, each service (Navy, Army and Air Force) has internally established a variety of guides, according their overall mission, specific needs, and organizational structure. This section covers basic materials regarding source selection procedures and describes the basic differences and similarities between the Hellenic and the U.S. systems of public procurements.

The most critical connection between these two systems is the identical separation of procurements into two large categories: a) "lowest price technically acceptable" (LPTA) acquisitions; and b) "best value" acquisitions. On the other hand, the major difference emerges from the contract types: in the European system, there are only Firm Fixed Price (FFP) contracts, whereas in the U.S. there are also Cost Reimbursement (CR) contracts.

In FFP contracts, contractors are paid after the delivery and acceptance of the product or service. The risk is totally borne by the contractors since they are obliged to deliver their product or service according to the requirements established in the solicitation in order to be paid. Alternately, in CR contracts, the contractor is gradually reimbursed for all reasonable, allocable, and allowable costs incurred during production. The contractor, in this case, provides his "best effort" and the final result may be outside the government requirements.

According to the FAR, Part 2.101, best value "…means the expected outcome of an acquisition that, in the Government's estimation, provides the greatest overall benefit in response to the requirement." The source selection process is described and analyzed in FAR Part 15.3 and the relevant guides of the Services. A proposal evaluation includes the following: a) cost or price evaluation; b) past performance evaluation, as an "indicator of an offeror's ability to perform the contract successfully;" c) technical evaluation, which reveals the extend of offeror's understanding the requirements and his technical proposal; d) cost information such as data and estimates for labor, equipment, wages, overheads, administrative expenses, etc; and e) subcontracting evaluation and many other factors and criteria, unique to each solicitation.

The aforementioned evaluation criteria are part of "Section M: Evaluation factors for award," in any solicitation; whereas in "Section L: Instructions, conditions, and notices to offerors or respondents," there is an analytic guidance for offerors on how to prepare their proposals. Finally, according to the FAR Part 15.304:

> The solicitation shall also state, at a minimum, whether all evaluation factors other than cost or price, when combined, are:
> (1) Significantly more important than cost or price;
> (2) Approximately equal to cost or price; or
> (3) Significantly less important than cost or price.

In general, the buying organization's rating method of evaluation involves narrative descriptions and it is usually an adjectival descriptor, color coding, or numerical scale.

In the first method, adjectives are used to indicate offerors' understanding of the requirements with respect to each criterion. The most commonly used adjectives describing 'performance' are: "outstanding," "good," "satisfactory," and "marginal." For risk assessment, evaluators use expressions such as "high," "moderate," and "low." Finally, for past performance evaluation, phrases like "high confidence," "significant confidence," "unknown confidence," "little confidence," and "no confidence" are typically used. In color coding, blue represents exceptional performance, green is acceptable, yellow is marginal, and red is for unacceptable performance. Lastly, in numerical rating methods there are usually scales, from zero to ten or from zero to one hundred, for the evaluation of the proposals.

The selection of the rating method varies based on the acquisition type (complexity, number of criteria, product/service, risk, etc), the knowledge and experience of the source selection team members, and other significant factors. In recent years there has been an increasing use of color rating by the Services.

The AHP is based on ratio scales and an author's opinions, and excels in virtues from the other methods utilized. In 1998 Experts Choice and Battelle Memorial Institute, reviewed all currently used evaluation methods and presented a series of problems and inconsistencies that they face.

In numerical rating, the evaluation incurs either ordinal or interval scales. The use of ordinal scales indicates only order and fails to depict the magnitude of differences between the offers with respect to a certain criterion. For example if offers A, B, C, and D are respectively ranked first, second, third, and forth with respect to the criterion "speed," evaluators cannot conclude how much better proposal A is compared to B, regarding this specific criterion, as well as B from C, and so on. Moreover, if evaluators multiply these numbers by the weight of the criterion, they come up with meaningless results. Also, the evaluation process becomes very imprecise as the number of criteria increases and the proposals succeed one another in the various ranks.

When evaluators choose to use interval scales, they *a priori* agree on the meaning of the numbers. For example, if they use a 1-10 scale to grade the alternatives, one must consider, does number "8" necessarily mean that the proposal with this number is twice as preferable as the proposal with number "4"? Thus, consistency is applied with great difficulty. Additionally, interval scales fail to depict certain attributes. For example, can

100º Fahrenheit be considered as twice as hot as 50º F? And if intuitively the reply is positive, readers should consider the conversion of these temperatures into another scale (Celsius), does not maintain this "twice as hot" attribute.

As mentioned, the Services have embraced the adjective and color rating methods for source selection. Slate (2004), in his articles published in the *Defense Acquisition, Technology, and Logistics* (AT&L) Magazine, opines that for the majority of acquisitions these non-quantitative systems are better that traditional (quantitative) systems because they provide:

> … the evaluation team and SSA with greater flexibility in assessing the various benefits and impacts of different approaches taken by offerors to the requirement. The narrative justifications of each strength, weakness, inadequacy, and/or deficiency provide clear detail and rationale for the decision, with the result that there's less second guessing.

The author's opinion, along with the findings of the review from Expert Choice and the Battelle Institute, advocate against the use of color and adjectival rating methods. Firstly, the colors or adjectives cannot describe the difference between two proposals that are very similar in content. For example, if there is a "weight" requirement not to exceed one ton and exceptional performance implies weight less than half a ton, then two different offers with weight ranging from one gram up to four hundred ninety nine kilograms, get the same color. Furthermore, two offerors, A and B, may obtain exactly the same colors in the majority of the criteria, and finally B will lose the award because of a slight shortcoming and different color in only one category. Additionally, how much better is the "blue" color over the "green" or the "exceptional" over the "outstanding?" Using colors or adjectives does not allow evaluators to establish relative importance over criteria and proposals. Besides, bidders that do not get the award cannot extract useful conclusions on the shortfalls of their proposals since the results are not in a quantitative format. Moreover, numerous questions emerge during the debriefing of non-awardees and it is difficult to determine how losing bidders differentiate their proposal from other awardees' proposals.

This analysis indicates that the AHP not only captures the various legislative acquisitions framework, but also resolves problems related to subjectivity, relative importance of factors/sub-factors, comparison of proposals with each other, incorporation of large pieces of information, and consistency in evaluation and source selection. The use of ratio scales is advisable because it allows officials to break down their objectives into manageable sub-objectives (the branches of the hierarchical tree), determine the importance of all critical factors, revise the hierarchy with the use of proper software, and finally, simply compare one element at a time with respect to the criteria. Surely, for acquisition of major systems (weapons, aircraft, ships, etc.), this process becomes time consuming and perhaps frustrating with the number of comparisons involved; but this process ensures consistency, application of rationale, and contributes to the elimination of complaints and protests.

E. CONCLUSIONS

The European Union's objective has always been federalization based on the model of the USA. There is much to be done for this to happen, since the challenges are multiple and complex: many languages, cultural issues, petty politics, nationalism and ethnocentrism, historical hatred, and conflicts. Nevertheless, in recent years there has been a great effort to enhance the role of EU through legislative reformation and debates on a common constitution. This reformation started with the economic unification of the nation-members, and has experienced the continuous expansion of the community to other non-member countries. In this sphere, we can integrate the effort for a common acquisition system and regulations that aims to improve the development of European trade and the creation of a Europe-centered industrial base. At this point in time, we should not forget that the U.S has put in place, since 1933, the "Buy American Act" (41 U.S.C. § 10a–10d); legislation that "…mandates preference for the purchase of domestically produced goods over foreign goods in U.S. government procurement" to protect the national industrial base and workforce (U.S. Department of State).

The dimensions of acquisition regulations in both the EU and U.S. are not comparable: the EU is just beginning its effort for federalization, whereas the U.S. FAR -

the cardinal document for public procurement - has been in place for decades and is often updated to remain contemporary and effective. Additionally, acquisition and public policy is ranked among the most studied and researched topics in prestigious universities and business schools of the "New World;" but these subjects do not get the same level of attention from universities in Europe. However, EU officials have acted cleverly: they "imported" the concepts of federalism from U.S. (via legislation, doctrine, and policy), and continually strive to integrate them with the current political environment.

The purpose of this chapter was to present some basics on acquisition legislation and to demonstrate that the AHP is a dynamic tool, very easily adaptive to incorporate legal restrictions and frameworks from wherever they come. After familiarizing readers with these concepts and discussing how they are embodied by mathematical modeling, we will now examine how this methodology can be applied in a complex acquisition: the procurement of combat aircraft.

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IV. AHP IN COMBAT AIRCRAFT SOURCE SELECTION

A. OVERVIEW

This chapter provides an overview of the implementation of the AHP in the current Hellenic acquisition system for the source selection of combat aircraft. It begins with a brief analysis of the "best value" source selection process and describes trends in U.S. and Hellenic public policy and the business world relating to major weapon systems acquisition. It then proceeds with the structure of a model, based upon a combination of the overall objective, several criteria, and other significant factors. All parameters considered for this complex procurement are analyzed to the extent that they contribute and affect the outcome. Additionally, the author explains possible customizations of the model.

B. BEST VALUE SOURCE SELECTION

The acquisition lifecycle begins with concept refinement (Figure 10). In the U.S., for major weapon systems, the Milestone Decision Authority (MDA) approves the preferred solution for acquisition, after analyzing existing alternatives and by balancing technology capabilities, funding, schedule and performance characteristics. MDA's objective is to develop a strategy for the acquisition of weapon systems that best meet the national security doctrine and public policy. The process is slightly different in Hellas, since the Government Council of National Affairs and Defence hold the role of the MDA. The composition of this council includes the prime minister and ministers of the Hellenic Government, whereas the Chairman of the Joint Chiefs of Staff with advisory and recommendatory role represents the military. The council examines all alternatives and approves the preferred solution based upon the aforementioned factors.

Current literature in acquisition aiming to reform the U.S. DoD acquisition system by applying commercial practices necessitates solid business cases and a knowledge-based approach. A "solid business case" (GAO[7] 05-304, 06-257T and 07-943T) essentially means that during concept refinement, the end-user and other experts have to match needs with existing capabilities and resources while applying realism in cost estimations, schedule deadlines, and desired level of performance; while concurrently assessing technology maturity and risk. This also presupposes that needs are expressed timely and proactively, to allow authorities to explore opportunities and information, and plan properly. Thus, proactive acquisition increases the probability of meeting cost, schedule, and performance metrics, and it decreases risk associated with delays, over-budgeting, and poor results. On the other hand, the knowledge-based approach comprises a systematic process where the results of a phase determine whether to continue to the next stage: prior to achieving the predetermined objectives of each phase, authorities cannot proceed to the next one. According to this approach, officials establish milestones related to cost, time, and monetary aspects, and review the program periodically. Consequently, there is visibility and continuous control over the program in an effort to reduce risk and uncertainty.

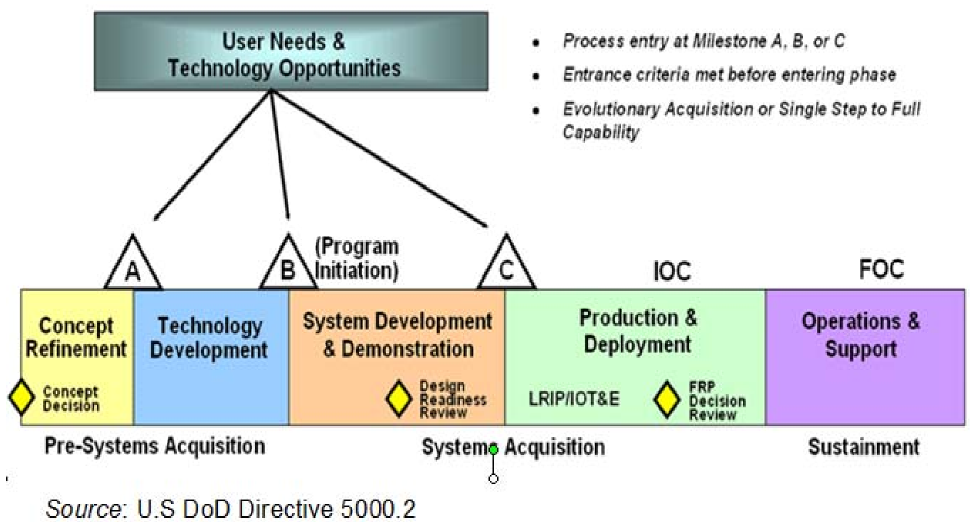

Figure 10. The Acquisition Lifecycle

7 GAO stands for General Accountability Office, an independent, nonpartisan agency that works for the U.S. Congress. It is often referred to as the "investigative arm" and "watchdog" of Congress and its mission is to investigate, audit, and study Government agencies' functions with regard to spending, with the objective of increasing efficiency and effectiveness in the allocation of funds. Official website: http://www.gao.gov/index.html.

The involvement of the AHP in the acquisition cycle begins with the determination of suitable evaluation criteria. Officials have to agree on the desired criteria that contractors have to meet in order to deliver a product/service according to the requirements. This phase usually involves brainstorming by all participants and results in the building of an evaluation model. Then, the experts conduct pairwise comparisons to prioritize the importance of each criterion and check the structured model for consistency. If the level of consistency is less than ten percent (in accordance with the methodology presented in Chapter II), the authorities proceed with the issuance of the Request for Proposal (RFP). Figure 11 graphically represents the aforementioned process.

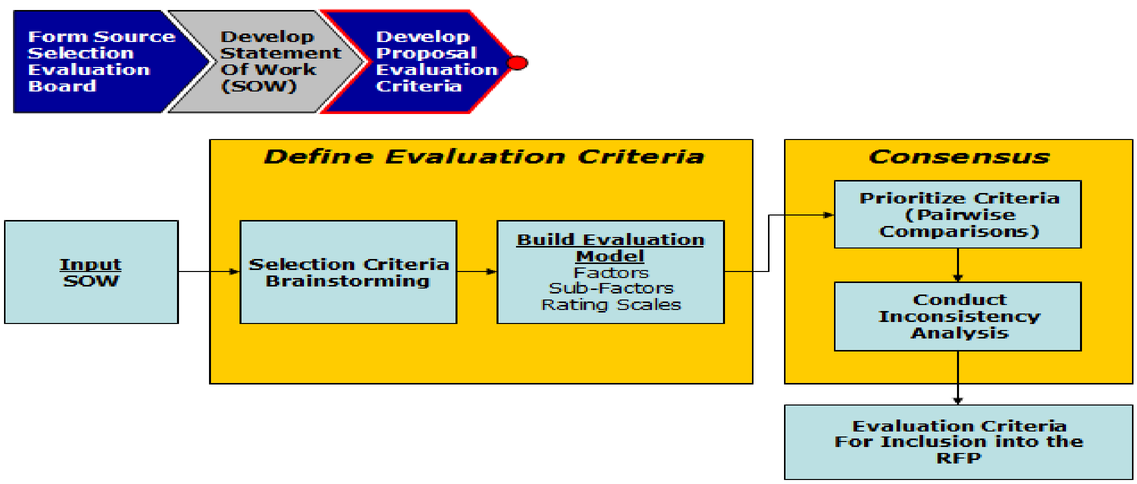

Figure 11. AHP Involvement in the Requirements Refinement Phase[8]

After receiving the proposals, evaluators have the difficult task of processing and comparing the offers, with the ultimate purpose being to award the contract to the offeror who best meets the established objectives. AHP allows for comparisons among the offers with respect to the established criteria, which results in a single final score for each offer. Again, the process is assessed for its consistency and reconsidered if necessary.

The most critical issue that emerges during the evaluation of proposals is objectivity: it is unlikely that all evaluators share exactly the same opinion and

8 This figure consists of part of a presentation on "Best-Value Selection Process" and was sent to the author by Daniel Saaty, son of Thomas Saaty and Vice-President of Decision Lens, Inc., a company that provides consultants and software support to decision makers in budgeting and major acquisitions.

judgement. Nevertheless, dialogue and discussion facilitate more accurate ranking of the proposals, and in exceptional cases of disagreement, the use of DELPHI[9] is recommended.

C. COMBAT AIRCRAFT ACQUISITION USING THE AHP

1. Historical Background and Current Issues

As previously mentioned in Chapter I, the HAF plans to acquire the next generation combat aircraft by the year 2015 utilizing a process that will probably start in 2011 with the issuance of the RFP. Currently, the HAF fighter aircraft arsenal includes the American F-16 (Blocks 30, 50, and 52+), the F-4 Phantom II, the A-7H/E Corsair, and the French Mirage 2000E/BGM and 2000-5 (Hellenic Air Force 2008). Historically, the Hellenic Government has shown a clear preference toward the acquisition of mature fighters that have succeeded in a variety of theatres of war (Vietnam, Libya, Grenada, Gulf War, etc.), or have traditionally been used by its allies. Nevertheless, the competition among defense suppliers has intensified dramatically in recent years with the ambitious arrival of the "Eurofighter" (a multi-role strike fighter constructed by a consortium of three European companies), the increasing interest worldwide for the Russian Sukhoi and the American Joint Strike Fighter, and the French Rafale (constructed by the same corporation that constructs the Mirage). Aside from acquisition issues, it is comprehensible that the final source selection also involves less tangible dimensions such as politics, diplomacy, national interest, strategic doctrine, and alliances.

9 The Delphi method was founded by Helmer and Dakley at the beginning of Cold War (1945) and was developed over a period of time at RAND (Research & Development) Corporation. Their objective was to create a forecasting method that could incorporate knowledge from different areas of expertise and attain consensus among various decision makers. The name of this method goes back to Ancient Greece and the Oracle of Delphi, where Pythia prophesized the future. This method comprises the use of questionnaires where experts express their thoughts and opinions anonymously. After the collection of the first round of responses from the experts, the results are recorded and the process is repeated until all the members of the panel come to an agreement.

2. The Proposed Model

The source selection of a multi-role combat aircraft depends on both monetary and operational effectiveness parameters. Thus, DMs attempt to accomplish the maximum possible operational effectiveness at the minimum cost. Unfortunately, these parameters move in opposite directions and, therefore, the whole process involves various trade-offs. Given that the current Hellenic legislation dictates the treatment of cost as an independent variable (CAIV) in "best value" acquisitions, the proposed model does not include cost as a criterion for the decision. DMs have to compare the various alternatives (aircraft) regarding their operational characteristics, come to a single value for each aircraft, and then divide this value with the cost for obtaining it. The whole process introduces the concept of affordability, which is merely the ratio:

$$Affordability = \frac{OperationalEffectiveness}{CostofAchievingOperationalEffectiveness}$$

(Mavris et al. 1998). To summarize, the proposed model uses the AHP solely to determine aircraft effectiveness.

Operational effectiveness depends on the aircraft's mission capabilities, survivability, readiness, and subsystems. Visually, Figure 12 depicts the basic criteria of the model. Other authors and practitioners may apply a different approach; however, the author's objective is not to question or describe various models for the source selection of a combat aircraft, but to demonstrate that the AHP can be effectively integrated in such decision-making.

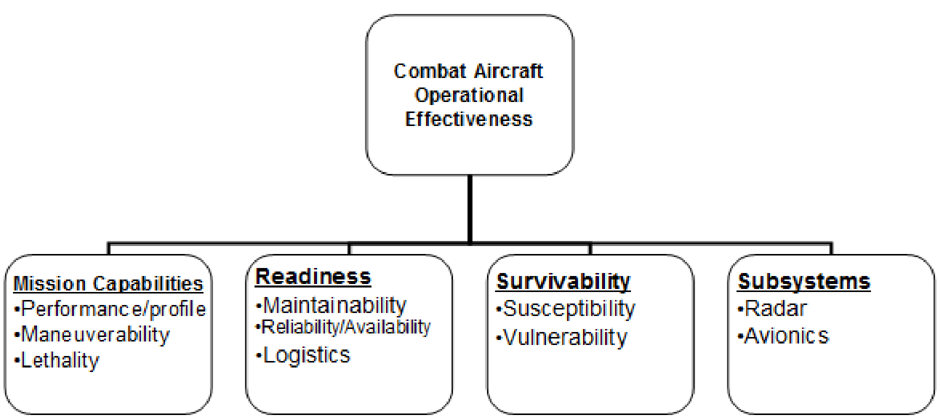

Figure 12. Combat Aircraft Operational Effectiveness

a. Mission Capabilities

(1.) Performance. The mission profile of a combat aircraft substantially determines its performance in various war theatres and scenarios. A multirole combat aircraft can be used for both air-to-air and air-to-ground missions. Nonetheless, the characterization of “multirole” is sometimes deceiving as there are different design and performance requirements (speed, weight, air-dynamics, etc.) that affect the primary role of an aircraft. DMs have to examine parameters such as range fueled/unfueled and range with payload (carrying weapons), then rank the alternatives based on realistic scenarios such as the competence of performing Lo-Lo-Lo or Hi-Lo-Hi missions.[10]

(2) Maneuverability. The maneuverability of an aircraft depends on various factors. First, the design of the aircraft (tail, wings, etc.) facilitates or encumbers its ability to maneuver. However, this ability is mainly influenced by the acceleration loads (positive and negative g’s) that aircraft can sustain, their acceleration to supersonic speed with or without the use of the afterburning system, and the instantaneous/sustained turn rates. Briefly, the acceleration loads represent the ability of acceleration (with its consequent pressures of gravity) due to the rapid change of direction of flight path. The aircraft that withstands bigger acceleration loads offers the aviator more capabilities during operations. Instantaneous turn rate describes the ability of the aircraft to turn quickly for a short period of time, an attribute extremely important during air-to-air (reconnaissance) operations, and in order to escape from hostile environments. The sustained turn rate refers to the ability to sustain turns for long periods without losing altitude and decreasing speed and degrees of turn. This characteristic increases combat capability and lethality since the aviator has more time at his disposal to strike the target without the aircraft giving-up performance. Finally, the afterburning system temporarily augments the thrust of the aircraft by burning additional fuel; again a characteristic with tremendous significance during operations.

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10 A Hi-Lo-Hi mission is one during which the aircraft begins at high altitude, performs its mission at low altitude and returns to the operational base, again flying at high altitude. Analogously, someone can interpret the Lo-Lo-Hi mission or any combination of Lo and Hi.

(3) Lethality. Simulation scenarios have been developed to measure lethality in various types of operations. Additionally, there are supplementary criteria that DMs have to consider during the source selection process; for example, the weapons that the aircraft can carry affect its capability to meet the specific operational requirements either during air-to-air or air-to-ground operations. Besides, the experts should favor proposed aircraft that can also carry weapons (mainly missiles) from the current weaponry of the Hellenic Air Force. In this way, the Government can achieve efficiencies and avoid additional procurement expenses.

Another critical feature is operational endurance, namely the time an aircraft stays in the area of interest at a specified altitude while consuming fuel in an efficient manner. Clearly, endurance and lethality have positive correlation. Finally, all U.S. and European aircraft embrace the HOTAS (hands on throttle and stick) style in the cockpit which allows the aviator to have all the critical switches on the stick and thus focus on the head-up display (HUD) or the horizon in order to avoid making unnecessary movements during maneuvering, targeting, striking, interception or reconnaissance. Providing further detail in all these characteristics is beyond the scope of this thesis.

Mavris and DeLaurentis (1995) propose a single Mission Capability Index (MCI) to measure performance under various configurations, requirements, and assumptions. They assert that the performance of a multirole aircraft depends on how well it performs during air-to-air and air-to-ground missions. The performance during the air-to-ground mission is measured by the Performance Index (PI) $PI = \frac{PayloadXRange}{W_{Fuel} + W_{Empty}}$. Payload is the amount of weapons the aircraft can deliver to a target. Range is the maximum distance that an aircraft can fly given certain parameters such as altitude, weight, and speed. The symbol *W* stands for weight when the aircraft is fueled or empty. For the air-to-air capability, the authors use the Specific Excess Power (P_s) ratio which is a function of thrust (T), drag (D),[11] flight speed (V), and weight (W).

11 Thrust and drag are two opposite forces that are respectively responsible for the propulsion and the slow-down of the aircraft.

The formula is represented by the equation $P_S = \frac{(T-D)V_\infty}{W}$. P_s measures the aircraft's available energy to perform maneuvers and, therefore, determines performance during air-to-ground operations. MCI is a combination of the formulas described above:

$MCI = k\frac{PI}{PI_{BL}} + (1-k)\frac{P_s}{P_{s_{BL}}}$, where k is a factor that ranges between zero and one. For $k = 1$, the aircraft is a pure air-to-ground platform, whereas for $k = 0$ it is a pure air-to-air fighter. For all other values of k, the aircraft's performance during its multiple role depends if $k > (1-k)$ then the aircraft is mainly an air-to-ground vehicle, or if $k < (1-k)$ the aircraft is mainly an air-to-air platform .

b. Readiness

Readiness is also known as 'operational availability' and stands for the number of times (as a percentage) that the aircraft is capable of performing the mission for which it was designed. Low levels of readiness entail reduced capabilities for the warfighter and unproductive use of resources. An aircraft grounded because of a failure constitutes not only a useless asset, but also inefficiently detains monetary and labor resources.

(1) Maintainability. Maintainability refers to the ease of repair and maintenance to keep the weapon system operationally capable. Special features of the aircraft's design facilitate inspection, maintenance, and repair of failures. Wilbur Arnold and the Defense Systems Management College (Arnold 1991, 26) identify a variety of the features that DM have to consider while comparing the alternatives with respect to maintainability. Figure 13 presents some of the main characteristics.

Failure diagnosis, identification and replacement are facilitated by:

- Using modular design techniques
- Use of special built-in circuits for fault detection, error warming lights, etc
- Designing for replacements in higher levels
- Using increased level technicians
- Increasing depth of penetration of localization features
- Utilizing test indicators which are less time consuming and/or less difficult to interpret
- Designing for minimum diagnostic strategies
- Making accessible and obvious both the purpose of the test points and their relationship to the item tested
- Improving quality of technical manuals or maintenance aids
- Designing access for ease of entry
- Minimize or eliminate use of fasteners
- Reducing number of access barriers
- Reducing need for isolation access by bringing test point, controls and displays out to accessible locations
- Reducing number of interconnections per replaceable item
- Using plug-in elements
- Reducing requirements for special tooling

Source: Arnold, V. Wilbur. 1991. Designing Quality into Defense Systems: Design, Manufacturing, Support. Fort Belvoir, Virginia: Defense Systems Management College. p. 26 (Figure 31).

Figure 13. Ease of Maintenance Guidelines

(2) Availability/Reliability. The formula used to measure availability/reliability is: $A_o = \frac{MTBF}{MTBF + MTTR}$, where A_o represents readiness, MTBF is the mean time between failures, and MTTR is the mean time to repair. It is understandable that operational availability increases with MTTR and inversely to MTBF. The MTTR includes the time that engineers spend for maintenance (inspection, preventive or scheduled maintenance, repairs, etc.) and also includes the administrative and logistic downtime (i.e. time for spares to arrive, time obtaining official approvals, staffing and guidance, etc). The downtime for administration and logistics negatively affects the MTTR index and may create a deceiving level of readiness. Many experts and authors use the term ‘inherent availability’ as “a measure of the degree to which an item is in the operable and committal state at the start of the mission when the mission is called for, at an unknown time” (Mavris and DeLaurentis 1995). This definition

precludes preventive maintenance and inspection, and time consumed for administration and logistics. This index appears to be more appropriate for the DMs to evaluate the proposed level of readiness.

(3) Logistics. Logistics cover all the resources needed (personnel, spare parts, materials, tools, etc.) to ensure minimum aircraft downtime and the maximum readiness. DMs have to evaluate the competitors' proposals relating to their ability to expeditiously provide critical materials, tools, and spare parts at low cost. Additionally, they should favor those proposals that guarantee efficient use of human resources to support the aircraft's mission from both the main and the forward operating bases.[12] Other critical factors for consideration and assessment are the proposed plans for maintenance support and supply chain management. Offerors have to submit price catalogs listing critical parts, necessary tooling, and inventories along with estimates for needs in various time intervals (weekly, monthly, annually, etc.). Finally, the solicitation for an aircraft acquisition should contain all the basic clauses for the follow-on-support contract[13] with the awardee. This allows for strategic cooperation, sharing of information and data between the two parties, sets metrics for failures of materials and tools, and determines the obligations to develop new parts or tools or maintenance processes to minimize downtime.

c. Survivability

Robert Ball and the American Institute of Aeronautics and Astronautics (AIAA) define survivability as "the capability of an aircraft to avoid or withstand a hostile environment" (Ball 2005). This environment includes natural conditions of earth, sea, air and space (i.e. lightning, winds, rain, etc) and unfriendly circumstances caused by an enemy such as interceptions or anti-aircraft battery. Survivability, in a purely military environment, comprises susceptibility and vulnerability. Susceptibility is the probability

12 Forward operating bases are positions closer to the enemy/target from where the aircraft conduct their operations. Usually these bases are temporary and, compared to main operating bases, provide rudimentary structure and basic facilities.

13 After awarding the initial contract for the acquisition of an aircraft, authorities award a series of contracts that cover issues such as follow-on-support, maintenance, engineering, software, etc.

of being detected and being hit if detected. Vulnerability is the probability of being killed if hit. Briefly, the following formula elaborates these concepts (Arnold 1991, 39): $P_s = 1-(P_{susc} x P_v) \Leftrightarrow P_s = 1-[(P_D x P_{H/D}) x P_{K/H}]$, with

P_s : the probability of survival,

P_{susc} : the susceptibility,

P_v : the vulnerability,

P_D : the probability to of being detected,

$P_{H/D}$: the probability hit if detected and

$P_{K/H}$: the probability of being killed if hit.

Ball (2003) in *The Fundamentals of Aircraft Combat Survivability and Design* incorporates multivariable analysis of missions and threats in the above formula a (Figure 14.).

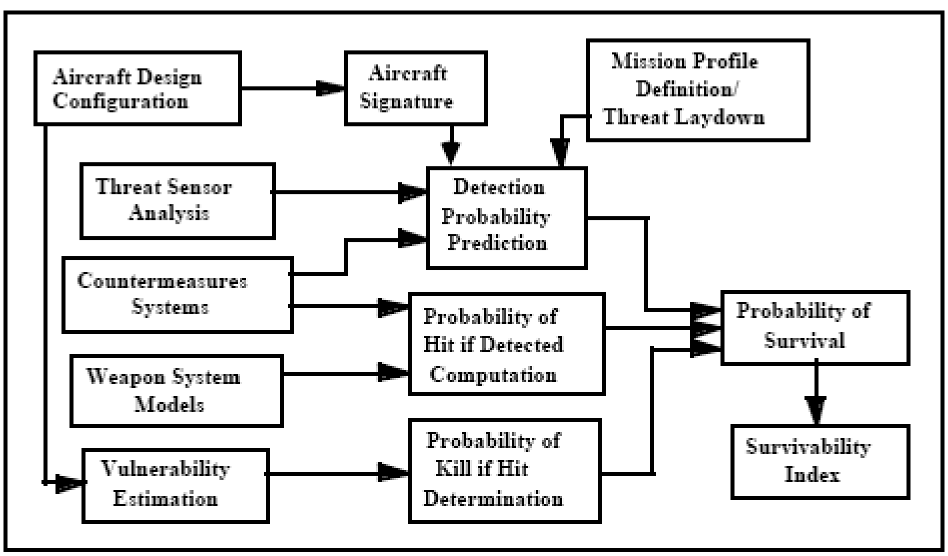

Figure 14. Flow Chart for Survivability Analysis

Furthermore, Hall (2003) introduces the concept of 'kill chain,' which he defines as a series of factors that threaten the survivability of a weapon system. Additionally, he proposes a checklist on how to evaluate air weapon systems with respect to survivability (Figure 15).

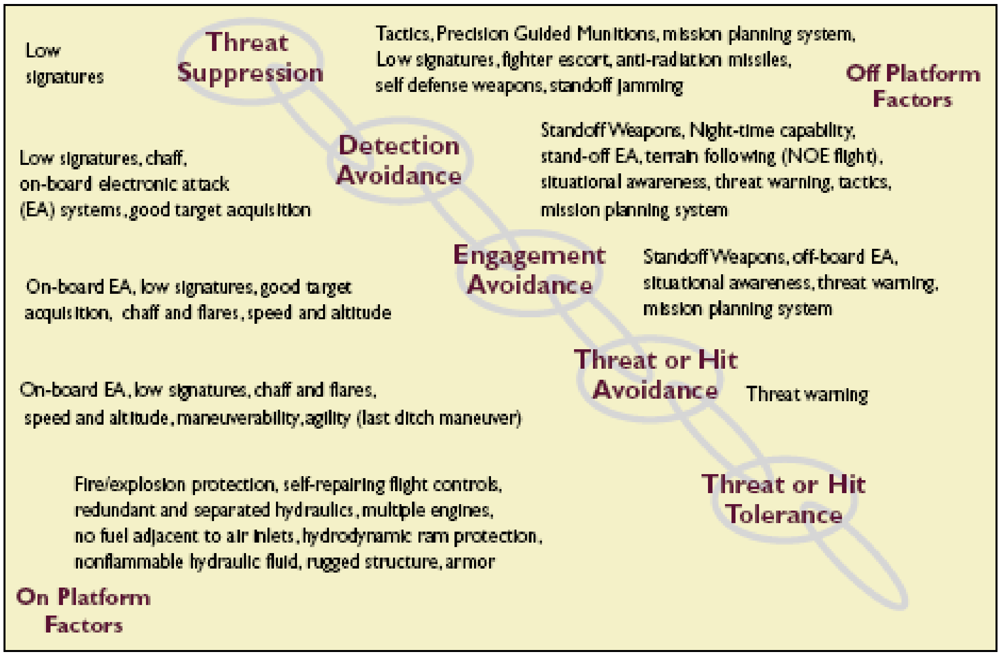

Figure 15. Threat "Kill Chain"

Conclusively, the evaluation of survivability is a very complicated task, since it can actually be assessed '*a posteriori*.'[14] Nevertheless, the experts may have a rough estimate of the proposed survivability with the development of realistic scenarios and the use of simulation.

d. Subsystems

This category is flexible and various systems not previously covered may be covered under 'subsystems:' examples include radar and avionics systems.

Regarding the radar, some easily recognizable features include: i) the scan range, with clear preference to wide range; ii) the multimode capabilities which increase

[14] 'A posteriori' means afterwards. In this case it means "after the contract is awarded."

the aircraft's probabilities of not being detected by enemies on air, ground, and sea, and also allow for the detection of the enemy in the various terrains; iii) the anti-jam capabilities against enemy's electronic warfare; iv) the number of targets tracked simultaneously; v) the 'track while scan' capability; and vi) the radar cross section capability (RCS), as well as significant others.

Avionics comprise all the electronic systems of an aircraft (communications, radar, navigation, flight control systems, weather systems, sonar, etc) and the way the aviator manages them (the various displays within the main console of the aircraft and his 'Head's Up Display'). Clearly, there is a preference for ergonomic designs that facilitate aviators' multi-role under extreme conditions (speed, g's, threats, etc.).

Again, an in-depth analysis of every one of these features for radar and avionics is beyond of the scope of this thesis.

3. Various Configurations of the Model

Mavris and DeLaurentis (1995) propose a different model for the evaluation of a major weapon system, incorporating safety as a cardinal factor for consideration (Figure 16). Nevertheless, they acknowledge that safety "is one of the most difficult [factors] to evaluate" since "by nature, any study of safety is reduced to an exercise in the investigation and analysis of historical data".

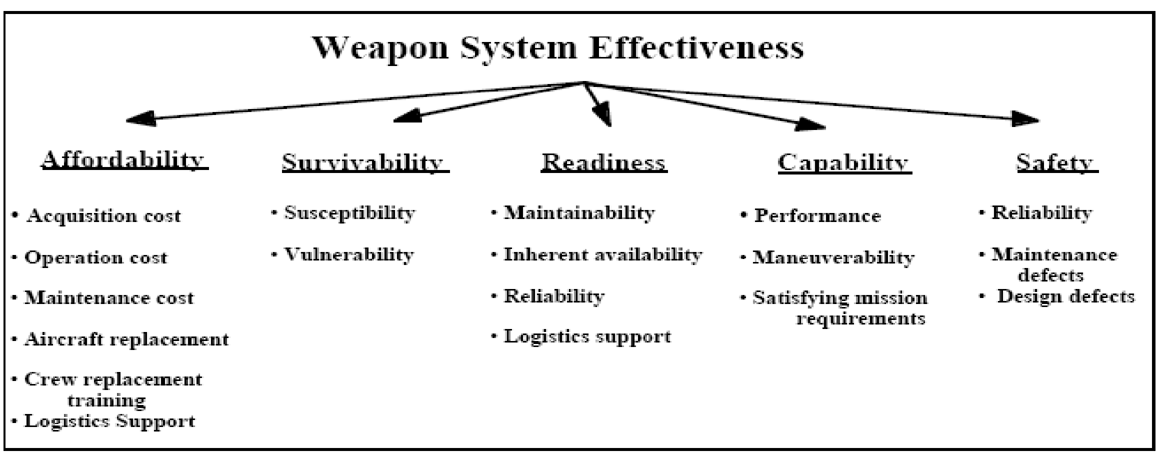

Figure 16. Weapons Systems Effectiveness Chart

Another possible and realistic configuration includes issues related to national interest as evaluation factors, such as the employment of Hellenic companies as subcontractors, the mobilization of industrial base, technology transfer, the active participation in the construction, politics/diplomacy, assessment of strategic alliances, geostrategic issues etc. (Figure 17).

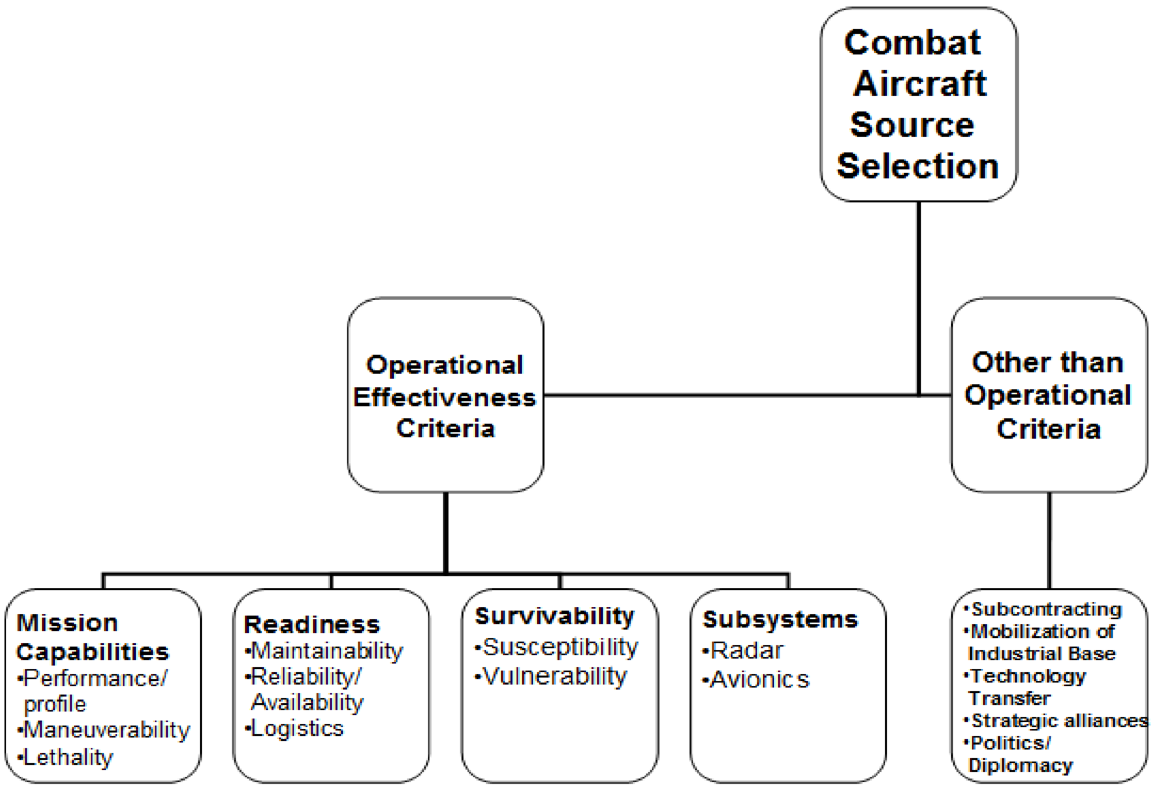

Figure 17. Combat Aircraft Source Selection

Finally, it is advisable to present the evaluation criteria and their relative weights for the concurrent acquisition of the new U.S. Air Force Aerial Refueling Tanker Aircraft. Surely, tanker aircraft have different missions and capabilities from combat aircraft; however, the evaluation process has more similarities than differences. Figure 18 presents the evaluation criteria as recorded in the respective solicitation.[15]

[15] Solicitation No. FA8625-07-R-6470 issued by USAF/AFMC, Aeronautical Systems Center (ASC), Wright – Patterson AFB OH, for the Acquisition of the new USAF Aerial Refueling Tanker Aircraft (KC-X).

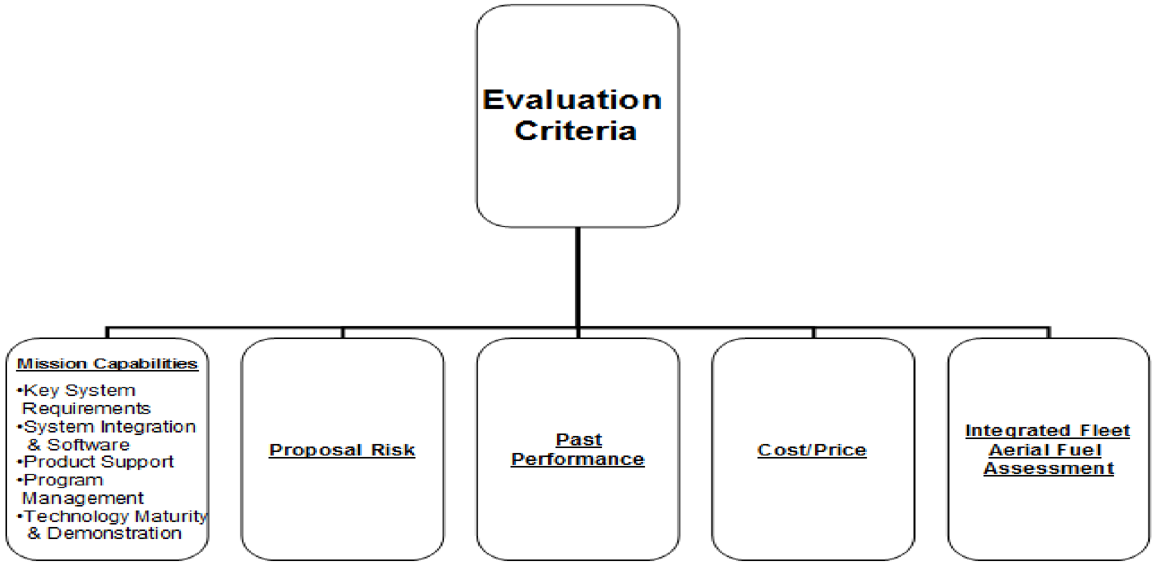

Figure 18. U.S Air Force Aerial Refueling Tanker Aircraft Evaluation Criteria

In section M of the solicitation, there is a narrative description of the weights for each criterion:

> The Mission Capability, Proposal Risk, and Past Performance evaluation factors are of equal importance and individually more important than either Cost/Price or IFARA evaluation factors individually. The IFARA is equal in importance to Cost/Price. Within the Mission Capability factor, the five (5) subfactors are listed in descending order of relative importance from 1 to 5. In accordance with FAR 15.304(e), the Mission Capability, Proposal Risk, Past Performance, and IFARA evaluation factors, when combined, are significantly more important than Cost/Price; however, Cost/Price will contribute substantially to the selection decision.

What is common in all the above figures is the need for constructing hierarchies to integrate crucial factors and sub-factors that affect decision-making relating to combat aircraft source selection. There is not a perfect model or a sole approach but each one of them has its merits and weaknesses and depicts the rationale, experience and intuition of the people that created it.

4. Cost/Price

The preference for mature technology and time-honored solutions for combat aircraft takes away an additional riddle for DMs: the determination of what "cost/price" encompasses. Risk and uncertainty are high for programs that are currently under development. Consequently, DMs have to estimate the Life Cycle Cost (LCC), a variable that embodies research and development, test and evaluation (RDT&E), procurement, and operation and support costs (O&S). Mavris and DeLaurentis (1995) provide the following formula: $LCC = RDT\,\&\,E + \mathrm{Pr}ocurement + O\,\&\,S$. It appears that this formula is quite simple; however, each one of these elements includes other various components, as a result the number of factors for consideration increases to an extent not easily manageable. Figure 19 (Mavris and DeLaurentis 1995) confirms the concerns addressed above with the use of the Ishikawa diagram (also known as "Fishbone" diagram).

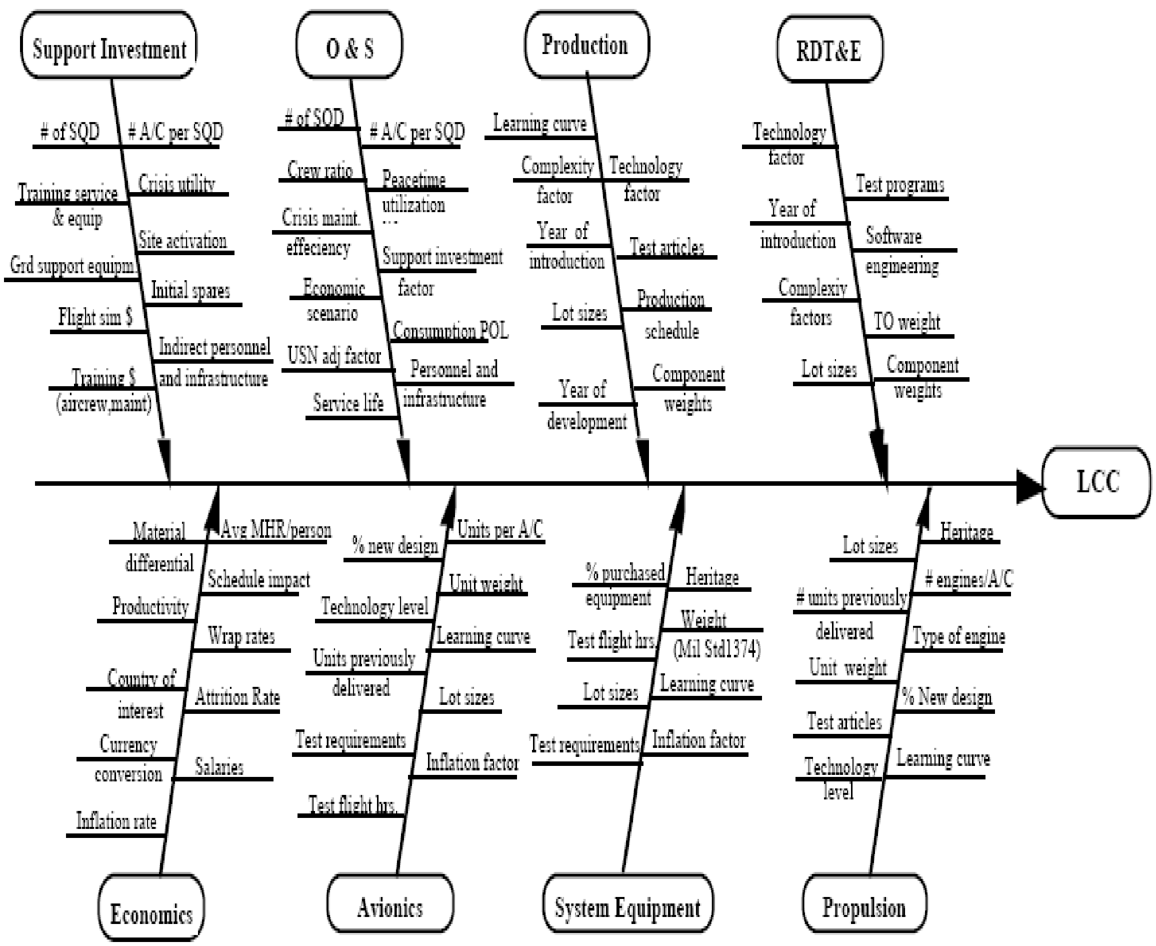

Figure 19. Ishikawa Diagram for Life Cycle Cost

Since the HAF is oriented to acquire an aircraft that will be in full rate production (FRP) during the period of negotiations (see Figure 4.1 The Acquisition Lifecycle), DMs have to price two significant factors: a) the offerors' proposed cost for an aircraft that meets all specified requirements; and b) the operation and support costs that derive from the operational effectiveness of the aircraft.

Estimating the cost of the latter category (O&S) still remains a very complicated task since all the operational characteristics, as described above, have a significant contribution to the O&S costs: therefore, DMs have to assess their monetary value. A comforting feature in this case is the existence of relevant data since the aircraft is already operational and will likely already have been acquired by other buyers. Consequently, the preference for developed aircraft results in fewer problems and a less complex acquisition process. However, it may be difficult to obtain O&S cost data concerning the acquisition of the same or similar weapon systems from other countries (proprietary information, 'top secret' classification, contracts not publicized, etc.).

D. SUMMARY

This chapter focused on the implementation of the AHP in combat aircraft source selection, taking into account a series of considerations for the HAF and the Hellenic government in general. The proposed model, the backbone of this thesis, described the most significant and commonly accepted evaluating factors and provided a brief analysis of operational characteristics. The author intentionally avoided conducting a more thorough analysis of technical features in order to maintain the objective of this study. This thesis attempts to determine if the AHP, from a managerial point of view, is adaptable and flexible enough to facilitate decision-making that entails constrained budgets, calls for integrity and protection of taxpayers' interests, extensive technical requirements, legislative and bureaucratic restraints, factors which are in line with national policy and interests. Through the course of this analysis, it has become evident that there is no single model that serves as a panacea to cure all inconsistencies created by the magnitude of the information involved, the interdependence of evaluation factors (technical capabilities and cost), the "best value" approach dictated by the Hellenic laws and responsible business practices, and the subjectivity which arises in all decision-making. For these reasons, there was also a presentation of different approaches provided by researchers and practitioners, and potential configurations of the proposed model.

The last chapter of this thesis, Chapter V, summarizes the author's findings, concerns, and conclusions regarding the effort to integrate AHP in the very demanding and convoluted defense environment.

V. CONCLUSIONS AND RECOMMENDATIONS

A. INTRODUCTION

This chapter provides a synopsis of the findings and conclusions of the previous chapters by replying to the research question addressed in Chapter I. Furthermore, it furnishes an evaluation of the proposed AHP model for combat aircraft source selection and addresses areas for further research.

B. CONCLUSIONS

1. What is the AHP? Where can it be used?

The AHP is a method designed to support its users with complex decision-making by combining their experience, judgment, and intuition with a view to selecting the best course of action from a number of alternatives based on pre-established and well-defined criteria. Literature suggests that the AHP is suitable for decision-making in economics, finance, politics, games and sports, conflict resolution, cost/benefit analyses, resource allocation, source selection, and resolution of everyday problems.

2. How can the HAF implement it in the current Hellenic acquisition system?

Thomas Saaty developed the AHP while he was working in the U.S. DoD. This fact demonstrates that the method is adaptable to a convoluted defense environment, where complicated legislation and organizational issues may encumber decision-making. The HAF can implement this technique for the source selection of products and services, since the AHP provides a systemic method that allows DMs to compare alternatives in order to select the best option. Additionally, the method is quite dynamic and can incorporate the existing acquisition regulations along with worldwide business practices in acquisition. Furthermore, the HAF can use the AHP for allocation of funds among competing activities, the evaluation of threats, the evaluation of personnel, career development (planning for a career path that provides incentives and satisfaction to employees), cost/benefit projects (determining where to build a base, or whether to close one), and for almost any decision that comprises criteria and alternatives.

3. What are the advantages and disadvantages of this method?

Chapter II provided an in-depth analysis on strengths and weakness of AHP. Nevertheless, it is useful to summarize them briefly in this section.

From the conception of AHP until now, many scholars, researchers and practitioners questioned its appropriateness for use as a multiattribute decision-making technique. Their objections mainly focus on its theoretical foundation and mathematical prerequisites. They insist the issues of rank reversal, nontransitivity of preferences, and the ambiguity and objectivity when DMs assess the alternatives and the importance of criteria. Furthermore, they assert that the interdependence of some elements that affect a decision is inherent and cannot be overcome.

On the other hand, Saaty and his 'supporters', have provided extensive argumentation in favor of AHP by enforcing its theoretical and mathematical framework, accounting for weaknesses apparent in every decision-making model and developing a variety of applications along with guidelines, to prove its usefulness. Moreover, Saaty introduced the Analytical Network Process (ANP), which is grounded on the same principles with AHP, as a means to 'cure' the problem of interdependence and facilitate even more complicated decision-making.

The most important merits of AHP are synopsized as follows: i) simplicity of use by comparing only two elements at a time, ii) ability to manage large amounts of information, iii) ability to tackle interdependence with the construction of "superhierarchies", iv) adaptability to different environments and flexibility to incorporate various inputs (new information, regulations, current practices, etc.), and iv) 'checks and balances' that help DMs confirm whether they use it appropriately (inconsistencies and revision, if necessary). Surely, the development of compatible software provides users with many more capabilities (automatic computations, sensitivity analysis, graphs, etc.). Thus today, DMs do not mind as much about the method's theoretical justification as for its applicability.

In conclusion, as every decision-making model, the AHP has both strengths and weaknesses. Its extensive use by large organizations and institutions (banking, insurance, pharmaceuticals, telecommunications, manufacturing, IT, energy, utility, Government/Government Contracting, international, education) vindicates its success and suitability for various applications and environments.

4. What is the relation of AHP with the business world?

The AHP was 'born' within the defense environment, but shortly thereafter it was embraced by the private sector where it is used broadly.

5. Is the use of AHP compatible with current Hellenic acquisition regulations?

The incorporation in the Hellenic acquisition legislation of "best value", as a concept that allows DMs to trade-off between reasonable cost and quality, literally necessitates the use of multiattribute techniques to award contracts. The separation of criteria into two main categories, the price related and the quality related factors, actually leads to a prioritization of them according to their relative importance on the decision. This is exactly what AHP was designed to accomplish: determine the best alternative in comparison to the existing ones and pre-established criteria. Chapter III analyzed extensively the compliance of AHP with current regulations (both U.S. and Hellenic) and its adaptability to business and global acquisition practices.

6. Which criteria should be considered for combat aircraft source selection?

Based on the methodology required by the Hellenic regulations for source selection and the ability of AHP to comply with it, the author separated the evaluation criteria into "price and price related" factors and "operational effectiveness" factors. Consequently, DMs evaluate separately the monetary value for the acquisition of combat aircraft. As far as operational effectiveness, the proposed model is receptive to changes and customization, and comprises criteria, which are also included in studies from respectable authors and institutions. It can incorporate criteria such as mission capabilities, readiness, survivability, subsystems, and their components to facilitate decision-making.

C. EVALUATION OF THE PROPOSED MODEL - CHALLENGES

The author faced a series of challenges while studying AHP as a method of decision-making and determining a way that the HAF can embrace it in the source selection of combat aircraft. One of the primary concerns was how “a team of one” (the author) could replace experts from various specialities and construct a model. This concern was mitigated by the realization that the objective was not to embody as many criteria as possible and provide a justification for them, but to present the AHP from a managerial point of view. Understandably, there can be no expectation that a single researcher could have the experience, expertise, and knowledge to identify and evaluate all critical factors for the acquisition of a major weapons system. Notably, a number of institutions and organizations (i.e., Australian Defence Force, AIAA, Georgia Tech Institute, George Washington University, etc.) have conducted similar studies with extensive participation from researchers and scientists. One of the objectives of this study is to present a model that is flexible enough to adapt to the complex defense environment and incorporate various inputs (criteria, new information, and legislative issues).

Another concern was that, despite the use of the term “decision makers,” the HAF officials are only responsible to propose the best alternative (i.e., aircraft) to their political leaders in the Ministry of Defense. The Government cabinet, presided over by the prime minister, has the final word over the source selection; a process authorized by statute. Moreover, this decision often involves criteria other than operational performance and cost/price: politics, geo-strategic issues, strategic alliances, and diplomacy are all fundamental factors that may distort the ranking of the alternatives obtained by the AHP. Nevertheless, the proposed model can be customized to incorporate all these factors and provide a sensitivity analysis; thus, determining the extent that other than operational and cost criteria affect the decision. Additionally, the author’s objective was to introduce to his military counterparts a dynamic tool for the determination of the combat aircraft that, from an operational standpoint, represents the “best value” for the Hellenic Government. The presentation of various other models and potential customization demonstrate, again, the merits of this method and its ability to be both flexible and adaptive.

For all the merits of the AHP, it is also prudent to share some thoughts on weaknesses of the method. The capability of the AHP to break down large pieces of information into manageable elements creates a series of problems. First, the main criteria are interrelated and interdependent. For example, the radar system, apart from being a separate criterion for evaluation, has a significant contribution to the survivability of the aircraft. This is also valid for mission capabilities since the more powerful the engines of the aircraft are (speed, thrust, instantaneous/sustained rates, etc.), the more capable the aircraft is to escape from a hostile environment. Taking into account that each one of these criteria (mission capabilities, readiness, survivability, and subsystems) can be further broken down to tens or even hundreds of sub-criteria, it is very difficult for DMs to isolate the impact of each criteria/sub-criteria on the decision. It is apparent that there is a great possibility for a critical element to be undervalued due to the overwhelming number of factors and sub-factors; therefore, leading DMs to make poor decisions.

One way to overcome this weakness is by separating the criteria into two categories: the required ones (i.e., the lack of them leads to disqualification) and the desired ones (i.e., the lack of them is graded negatively but does not lead to disqualification). By setting the highest possible standards of performance, DMs eliminate the extent of interdependence between the criteria and, at the same time, enhance competition on higher standards. For example, if DMs mandate maximum speed with full payload at 2.2 mach and desired speed at 2.5 mach, then the comparison focuses mainly on the proposed speeds and less on how these differences affect other factors (operational costs, survivability, etc.). Additionally, the developer of the AHP, Thomas Saaty, realized that for very complex decisions it is advisable to use the Analytical Network Process (ANP)[16] instead of the AHP.

[16] Briefly, the ANP is a development of the AHP that structures problems using networks instead of hierarchies. This allows for both interaction and feedback within clusters of criteria and between clusters of criteria, and thus confronts more conveniently the weaknesses of inner dependence and outer dependence, which are inherent in the AHP. Saaty and Vargas (2006) provide comprehensive analysis over the theoretical framework of ANP and its potential implementation for a variety of applications.

Finally, other challenges concern objectivity and consensus among experts with different backgrounds, knowledge, and personal judgements. To counter these problems, the author recommends the gradual implementation of AHP in the HAF; first for much simpler procurements. After becoming familiar with its merits and apparent weaknesses, the HAF could use it to facilitate decision-making on more complicated procurements.

D. RECOMMENDATIONS

The author recommends that HAF examine the possibility of embracing the AHP for a variety of applications. Its potential use in a number of pilot programs would provide an opportunity for full and fair evaluation in a real world environment. The method does not entail as a prerequisite the participation of users with certain scientific background; rather, it is open to all experts in a field area, who are able to apply rationale and sound judgement during decision-making.

Nevertheless, the familiarization with both the concepts of AHP and the respective software (even it is user-friendly), requires time for training and practice on a variety of applications. Another reason for the pivotal use is that users have to get used to a more dynamic decision-making scenario, which deviates from strict hierarchies of rank and "senior-subordinate" relationships. In AHP, all participants provide equally their inputs (ideas, judgements, review, etc.) and consensus is reached solely on the basis of arguments and dialogue; a process somewhat innovative for the defense environment.

Finally, as far as the forthcoming acquisition of combat aircraft, the officials should begin to chart in detail the Government requirements, define the evaluation criteria and determine their relative importance for the contract award, whether they apply the AHP or not. It is inevitable that they would result in a hierarchical structure. It is also inevitable that they would unconsciously use concepts of the AHP to evaluate the alternatives. Apparently, the question is why not use this method.

E. AREAS FOR FURTHER RESEARCH

1. Evaluate the feasibility of using the Analytical Network Process (ANP) for combat aircraft source selection.

2. Conduct a comparative analysis of the ANP and AHP in a source selection scenario.

3. Determine notional criteria (required and desired) for combat aircraft source selection.

4. Analyze and quantify non-tangible factors in decision-making.

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