



**VALUE FOCUSED THINKING IN DEVELOPING
AEROBATIC AIRCRAFT SELECTION MODEL FOR TURKISH AIR FORCE**

THESIS

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AFIT-OR-MS-ENS-12-02

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THESIS

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Abstract

The mission of an aerobatic team is to enhance government recruiting, and credibly represent an Air Force. For that reason, Turkish Air Force Command plans to replace the current aerobatic aircraft, which have completed their lifetime. Before making this type of decision, Operational Research Directorate in the TurAF Headquarters performs different research to construct an overall decision guide. Although, that department constructed very successful decision-making guides, the analysts need a more systematic approach for these types of complex problems.

The purpose of this research is to lessen the potential human errors by using decision analysis and cost analysis techniques. This research uses Value- Focused Thinking in conjunction with Multi-Objective Decision Analysis and Cost Analysis. It creates a decision-making model that allows decision makers to interact with analysts by specifying his/her objectives, values and preferences. On the other hand, cost analysis process determines cost effective alternatives. Alternatives are scored using 17 evaluation measures that are identified by interviews with the decision maker and stakeholders. Robustness of the model is tested by sensitivity analysis. Results of sensitivity analysis on current weights indicate that this model has robust results. Nevertheless, sensitivity analysis on cost indicates that many issues may influence the robustness of cost estimates and the best cost effective alternative.

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To my Husband, expected Baby, Father and Mother

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List of Terms

AFT	Alternative Focused Thinking
AHP	Analytical Hierarchy Process
BWB	Germany Federal Office for Defense Technology and Procurement Company Center
CBS	Cost Breakdown Structure
DA	Decision Analysis
ELECTRE	Eliminating and Choice Expressing Reality
FMS	Foreign Military Sales
HEIM	Hypothetical Equalities and Inequalities Method
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
MCDA	Multicriteria Decision Analysis
MMH/FH(S)	Mean Man Hour per Flight Hour
MOA	Memorandum of Agreement
MODA	Multiobjective Decision Analysis
MTTR	Mean Time to Repair
NAMSA	NATO Maintenance and Supply Agency
NATO	North Atlantic Treaty Organization
O&S	Operating and Support
R&D	Research and Development

SDVF	Single Dimensional Value Function
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TurAF	Turkish Air Force
USAF	United States Air Force
VFT	Value Focused Thinking
Tender	The price offer with the document and/or information submitted by a tenderer to a contracting entity for the procurement carried out pursuant to the provisions of this Law.
Tenderer	Supplier, service provider or works contractor submitting tender to procurement of goods, services or works.
Contracting Officer	Authorized and liable persons or boards as well as those persons to whom the required authority and liability has been transferred properly in the contracting entity to spend and to carry out procurement proceedings.

VALUE FOCUSED THINKING IN DEVELOPING AEROBATIC AIRCRAFT SELECTION MODEL FOR TURKISH AIR FORCE

I. Introduction

1.1 Background

In early years of aviation history, there were different reasons to use flight maneuvers. One of the most known is aerobatic displays. The first air meet that included the first aerobatic performance was in 1909. By development of aviation, air meets and air shows became very popular during the 1920s. In the time up to World War II international competitions in aerobatics were developed (Hickoksports, 2011). In order to increase the interest of the air force among young people, many countries formed aerobatic demonstration teams. One of the leading countries was Turkey.

Ataturk, the founder of Turkish Republic, recognized the importance of aviation to national security in 1925, saying, “The future is in the sky. Nations who fail to protect their skies can never be sure of their tomorrows”. The Turkish Air Force (TurAF) is one of the oldest air forces and has operated more than 180 different types of aircraft since 1911. TurAF currently ranks second in NATO in terms of fleet size, behind only the USAF. Supported by long-range in-flight refueling capability, the fighter jets of the TurAF participate in international operations and exercises on all continents of the world.

The Air Force Command has the purpose of “Preventing threats and dangers likely to be received via air against Turkish country and Turkish Nation, and facilitating

the way to success of the duties of Land and Naval Forces during a possible war.” Another important duty of the TurAF is promoting itself and Turkish Republic both at home and abroad and endearing aviation by enhancing relationships with the public. For that reason, the first official aerobatics demonstrations started in 1926 within the Air Force School.

After becoming a NATO member, the TurAF modernization period accelerated after 1952. In TurAF history, the first aerobatic display teams, corresponding to technological modern world standards, was formed soon after the introduction of the jets in 1952. By changing its name and type of aircraft, six different aerobatic demonstration teams were established in different years. The sixth of the TurAF aerobatic display teams formed by F-5A (Freedom Fighter) aircraft in 1971. After a period of 20 years, the TurAF decided to re-establish its aerobatics activities. For that purpose, the last aerobatic demonstration teams of the TurAF obtained the call sign of Turkish Stars in 1992 (TuRAF 100th Anniversary, 2011).

The Turkish Stars are the aerobatic demonstration team of the TurAF and the national aerobatics team of Turkey, which is the proof of capabilities of the modern Turkish Air Force. Since, the highest level of skills and knowledge is necessary in order to perform air shows to the audience. Turkish Stars fly with eight Northrop F-5 Freedom Fighters, making them one of the few national aerobatics teams to fly supersonic aircraft, and the only one with formations of eight supersonic jets. Their aim is to “Present the TurAF on a national and international platform, to represent the Turkish Republic, to contribute to the efficiency and discipline of the TurAF, to reinforce the peoples’ trust in

the Air Force, and to increase the interest of the air force among the young people of Turkey (Turkish Stars, 2011).

1.2 Problem Identification

In order to accomplish its goals, maintain flight safety and protect its reputation, the TurAF needs to keep up with the latest aviation technology. For that reason, the Air Force Command plans to replace the F-5 aircraft which has been used since 1971 and which has completed their lifetime. A decision making process will be used by TurAF to procure twenty aircraft in total.

Before making decisions for big projects, the Operational Research Directorate in the TurAF Headquarters performs different research to construct an overall decision guide for decision makers. However, this process is performed by using the experience and knowledge of the analysts. Although, that department constructed very successful decision-making guides, the analysts need a more systematic approach for these types of complex problems and project decisions.

1.3 Research Questions

In order to construct a robust decision-making model, this study asks the following research questions:

- Is it possible to construct a robust, objective and traceable decision-making model, which lessens human errors, reduces the amount of total working time and selects the best alternative among diverse number of alternatives with different attributes?

- Who are the stakeholders of the system that affect the decision process and are affected by that decision?
- What are the desired characteristics of an aerobatic aircraft that will satisfy the decision maker's and stakeholders' demands?
- Is it possible to create a model that will specify the most cost effective alternative?

1.4 Research Approach

The motivation of this research derives from the multiobjective decision problem of the TurAF aerobatic aircraft selection problem. This research presents a decision-making methodology for top-level decision makers who make strategic decisions about military projects and system selection.

Decision-making for this type of decisions is a process characterized by complexity, uncertainty, multiple objectives, and combination of different data types. Most of today's important project management decisions are complex. Without proper analysis, it is hard to make choices among diverse numbers of alternatives. The complexity of decision-making depends on many reasons. Most problems in decision-making involve multiple objectives and uncertainties. The number of alternatives can be significant and make decision making more complex. Multiple stakeholders with different objectives and preferences make that process harder. Hence, it is not easy to see all of the different aspects of a problem. Keeney, 1992 describes that as "In an uncertain world, the responsible decision maker must balance judgments about uncertainties with his or her preferences for possible consequences or outcomes." Decision maker may

make poor decisions without proper approach. In addition, overtime these poor decisions become a burden, especially decisions that are connected to large-scale projects that affect many people and consume a big budget (Virine & Trumper, 2008).

Strategic decisions are the combination of high-level uncertainty, long-term consequences, interaction between different factors that cause complexity, and necessitation of identifying key stakeholders to evaluate effects of that decision on a system (Zopounidis, 2010). As a result, decision-makers face great distress while they are making strategic decisions. Therefore, strategic decision-making needs to follow a well-organized and well-designed systematic process. Decision Analysis (DA) allows decision-makers to overcome the problems associated with the strategic decisions by using analytical results. Hence, it mostly eliminates the intuition of the decision maker. The decision analysis process entails a logical analysis of a correctly structured problem, identification of creative alternatives based on reliable information, implementation of the selected alternative and an evaluation of the results. According to Keeney, 1992 “DA is a practical framework of methods and tools to promote creativity and help people make better decisions.”

The decision process of selecting an appropriate aerobatic aircraft effects many issues. The most critical one is the fame of Turkish Air Force and Republic of Turkey. Since, Turkish Stars perform many national and international shows all around the world in order to accomplish its goals. Another main issue of any poor decision that has negative consequence is the cost of the project. Because this project includes a minimum 30 year period, present cost can be enormous due to a wrong decision. On the other hand,

many stakeholders have different positions that they face as a result of different aspects of the decision. In addition, they may have different objectives that can affect the final decision. Hence, the problem just by using personal intuitions or expert opinions will be very complex to make a decision. Realizing that poor decision making in large-scale projects can result in high costs and cause harm, governments and private businesses recognize the importance of decision analysis techniques. As a result, decision analysis process is essential in order to make decisions that are more appropriate. From that point of view, the purpose of that research is to lessen the potential human errors that can cause a poor decision by using decision analysis and cost analysis techniques.

Complexity and interactions between different factors constitutes conflicting and multiple objectives. Once a decision maker defines his or her fundamental objectives, a technique called Value Focused Thinking (VFT) is appropriate for decision-making process and evaluation of alternatives. Using VFT for decision-making process enables objective, traceable and robust results (Jackson, Jones, & Lehmkuhl, 1996). Hence, it leads to a systematic approach for decision making which interacts with decision maker and stakeholders by minimizing human related problems.

Different types of aircrafts with different characteristics may be challenging to compare and decide at first glance. For that reason, this research creates a decision-support model that allows decision makers to interact with analysts by specifying his/her objectives, values and preferences. On the other hand, the cost analysis process determines cost effective alternatives. For that reason, this research uses Value- Focused

Thinking (VFT) in conjunction with Multi-Objective Decision Analysis (MODA) and Cost Analysis.

1.5 Research Assumption

This research makes the following assumptions:

- a. Only one type of aircraft will be the final decision among the alternatives.
- b. There is no limitation on suppliers. TurAF may purchase any aircraft from any supplier.
- c. TurAF has a technological background and eligible personnel to support any type of aircraft.
- d. Lifetime of each aircraft is 30 years.
- e. Aircraft features remain the same to the end of the service life.
- f. Evaluation measures give the proper weighting.
- g. Weighting accurately depicts the decision maker's preference.

Section 4 includes sensitivity analysis of proper weighting assumption (f) and weighting accuracy assumption (g). Hence, accuracy of assumptions is tested. Other assumptions are inherent from the problem. Therefore, there is no sensitivity analysis, which tests accuracy of other assumptions.

II. Literature Review

The purpose of this chapter is to provide a brief review of Turkish acquisition rules and regulations and literature, theory and researches related to Decision Analysis, Value-Focused Thinking and Life Cycle Cost Analysis.

2.1 Turkish Procurement Procedure

Procurement is the process of acquiring goods and services from other organizations. Its purpose is to obtain cost, time, quality and performance efficient goods and services. Companies show great deal of interest to obtain the optimal efficiency level. In recent decades, government organizations became a part of that struggle. However, different from companies, governmental rules and organizations control governmental procurement activities. These factors create a great amount of restriction on procurement processes.

Defense procurement is one of the most critical governmental procurement activities. Since, the main purpose of the defense procurement is to maintain modern and combat ready armed forces. Turkish Armed Forces procurement activities have some governmental regulations. Following sections will review the regulations and rules that are used for defense procurements for Turkish Armed Forces to see if there is any legal restriction to apply VFT.

2.1.1 Turkish Public Procurement Law

The purpose of Turkish Public Procurement Law is to establish principles and procedures that apply in any governmental procurement. According to the Law, the

definition of procurement is “ the proceedings which involve the award of a goods, services or works contract to the tenderer selected in accordance with the procedures and conditions laid down in this Law, and which is completed by signing of the contract following the approval of the contracting officer”. Energy, water, transportation and telecommunication sectors are out of the scope of the Law. Also, the law has some exceptions which are defined in article 3b of the Public Procurement Law. According to article 3b “Goods, services and works procurement which are decided by the relevant ministry that these are related to the defense, security or intelligence or that these require to be treated confidentially, or procurements requiring special security measures during the performance of the contract pursuant to related legislation or those concerning the cases in which the basic interests of the state’s security needs to be protected.”. Depending on that article, Turkish Armed Forces use 2009/14973 enact to procure goods, services or works.

2.1.2 2009/14973 Enact

2009/14973 enact establishes the principles and procedures to be applied on procurement related to Turkish Armed Forces modernization, preservation and development. Activities related to procurement begin with Turkish Armed Forces demand to Defense Industry Counselor. Prior to the procurement proceedings of goods, services or works, the entity shall conduct all necessary price research and shall determine an estimated cost by using cost analysis. It is not desired to exceed that calculated estimated cost. Estimated cost is not being stated in tender or pre-qualification advertisements. Cost Estimation Calculation Statement describes all of the details for estimating cost.

Other step is preparing specifications list. Preparation of administrative and technical specifications specifying all characteristics of the goods, services and works that constitute the subject matter of the procurement by the contracting entities is essential and mandatory. Procured subject must satisfy these specifications. If candidate procurement subject does not have all of the specifications, negotiations are allowed to rearrange the subject and the price. Three kinds of documents are prepared to determine the specifications. Administrative Specifications Document specifies procurement objectives, tender participations requirement, evaluation criteria, contracting processes, quality requirement and quality assurance issues. Pre-qualification Document is used for restricted method of contracting. It specifies information for pre-qualification application and evaluation factors. Technical Specification Document specifies all of the technical information. That includes sampling issues, acceptance issues, handling and packing requirements and warranty issues (Turkish Public Procurement Law, 2002).

In procurement of goods, services and works by contracting entities, open procurement procedure or restricted procurement procedure may apply. Defense Industry Counsellorship decides procurement procedure. Open procedure is a procedure where all tenderers may submit their tenders. If all specifications are satisfied, the agreement is made following the price negotiation. The lowest bidder who meets technical and financial specifications wins the tender. Restricted procedure is a procedure in which tenders who are invited following pre-qualification by the contracting entity, can submit their tenders. Procurement of goods, services or works may be conducted by restricted procedure where open procedure is not applicable as the nature of the subject necessitates speciality and/or

high technology and in procurement of works. This evaluation is based on the Pre-qualification Document. If all specifications are satisfied, the agreement is made following the price negotiation.

Material and service support is made by direct procurement. The method of direct procurement may be applied in international agreements like MOA (Memorandum of Agreement). Another way is agreements with foreign military defence ministries like FMS (Foreign Military Sales) which is made with United States Military Defence Ministry. Agreements with military organizations like NAMSA (NATO Maintenance and Supply Agency) are a different procedure to supply material and service support. Agreements can be made with foreign military material sales organizations that are under government control such that BWB (Germany Federal Office for Defense Technology and Procurement Company Center) (2009/14973 Enact). For domestic defence procurement, enact is used.

2.1.3 Applicability of VFT

Due to Turkish Procurement Law and 2009/14973 enact, there is no restriction to apply VFT for the aerobatic aircraft procurement procedure. In fact, Turkish procurement procedures utilize Alternative Focused Thinking (AFT). It is obvious that direct procurement and open procurement types specify the alternatives first and then construct all analysis depending on those alternatives. Restricted procurement type is better than other two types of procurement, but it needs further systematic approach. The following section describes differences between AFT and VFT.

2.2 Decision Analysis

As well as the individual decision makers, business executives and governmental decision makers deal with hard decision problems. Decision problems are hard; since, they have inherent complexity and uncertainty in addition to multiple and conflicting objectives. Also because of the different perspectives, a decision can end up with diverse numbers of conclusions and consequences. Decision analysis can help to deal with complexity by providing effective methods for organizing the problem. It also helps to identify the source of uncertainty and represent in a systematic and useful way. Decision analysis provides useful tools to represent and deal with multiple and conflicting objectives. It helps to sort and resolve different perspectives regardless of the number of decision makers and stakeholders (Clemen & Reilly, 2001).

The main purpose of decision analysis is to help decision maker to make decision about specific topics by combining the problem heritage with his or her preferences and beliefs. Instead of struggling with the big problem, decision analysis decomposes the problem into smaller pieces that are easy to understand and solve. Decision analysis is a guideline for systematic thinking; but it does not give the exact solution or best result for decision problems. It is as a tool that gives insights about trade-offs and reveals a recommended course of action (Clemen & Reilly, 2001).

The first step and the most essential step of decision-making is to identify decision problem and decision maker's objectives. Without clear identification of objectives, it is hard to obtain recommended decision. However, in many cases decision maker specify multiple objectives. Multiobjective decision analysis (MODA) provides

insight to decision makers faced with multiple and probably conflicting objectives and significant uncertainties. Multiple conflicting objectives reveal tradeoffs between these objectives. Since, it is very hard to satisfy all of the objectives at the same time. Figure 1 shows overall process used by MODA.

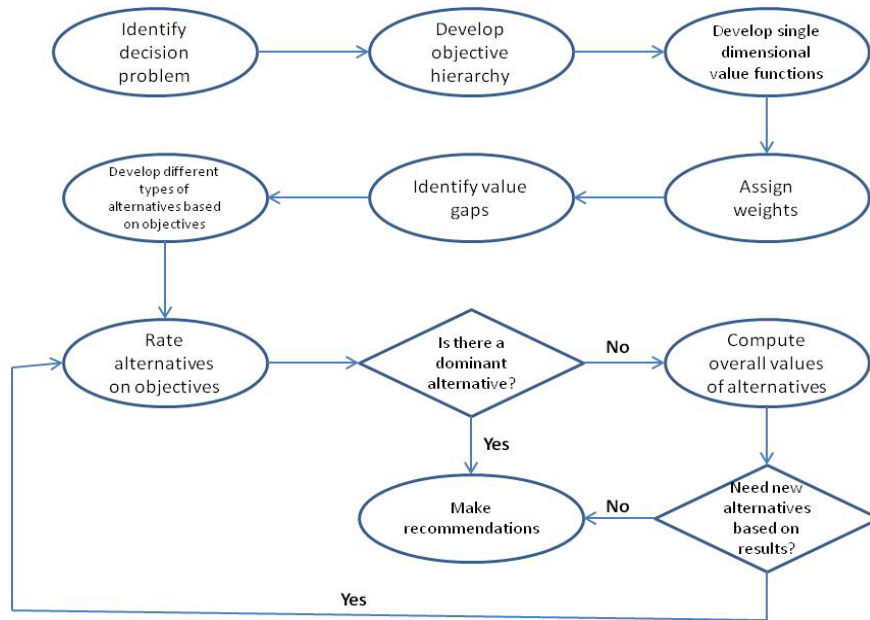


Figure 1 MODA Process (Feng & Keller, 2006)

There are several types of approaches as an alternative to MODA. Depending on the type of the decision problem, different types of methods may be applied. Multicriteria Decision Analysis (MCDA) is one of the most widely used approaches. According to Kirkwood, 1997, “The phrase MCDA refers to a set of related approaches for analyzing multiobjective decisions using mathematical programming (optimization) methods.” There are many MCDA methods in literature. According to Chen & Hwnag, 1991, classification of MCDA methods depends on the type of information and the salient

features of the information. Figure 2 represents that classification. According to (Triantaphyllou, 2000) the most commonly used methods are Weighted Sum Model (WSM), Analytic Hierarchy Process (AHP), Weighted Product Model (WPM), ELECTRE, and TOPSIS. Yoon & Hwang, 1991 contains detailed overview of these techniques.

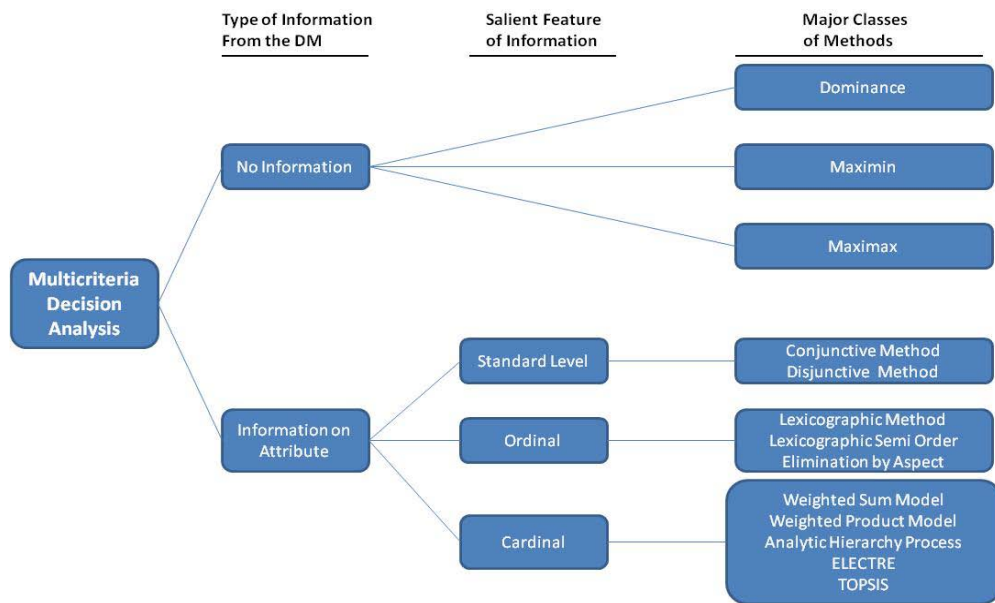


Figure 2 Examples MCDA Methods (Chen & Hwnag, 1991)

Data and number of decision makers are some other ways to categorize MCDA (Triantaphyllou, 2000). Over recent decades, different types of MCDA techniques have been derived. Figueria, Greco & Ehrgott, 2005 includes an overview, foundations, different approaches, applications and software for recent MCDA techniques.

Contrary to MODA, MCDA methods do not explicitly asses a value or utility function. They commonly use mathematical programming techniques to identify recommended alternatives (efficient set). Most of the MCDA techniques do not separate value of utility function from the ranking of alternatives. Instead, the decision maker

examines various alternatives and provides information that a mathematician can use to propose different alternatives. For example, AHP method does not require identifying a value function. It requires pair wise comparisons of alternatives. Then, a mathematical method is required to estimate value function based on the various pair wise comparison. If the number of alternatives is large, then this method requires many pair wise comparison. MCDA methods need computer software or complex algorithms to make evaluations and to give insight to decision maker (Kirkwood, 1997).

2.3 Creativity in Decision Making

In real world decision making problems, most of the time decision makers generates criteria for present alternatives. Hence, they stick with alternatives and do not make the most efficient decision. Creativity is an excellent basis to develop new alternatives. These creative alternatives are determined by considering objectives of decision maker. According to Clemen & Reilly, 2001 “A creative alternative has both elements of novelty and effectiveness, where effectiveness is thought of a decision maker , a group of individuals, or even the diverse objectives held by different stakeholders in a negotiation.” If the decision maker efficiently uses these creative thinking activities, he/she may convert the decision problem to a decision opportunity in addition to developing creative alternatives (Keeney R. L., 1992).

There are several creative thinking techniques. One of them is Value-Focused Thinking (VFT). VFT uses fundamental and mean objectives, to develop decision alternatives. Following section includes detailed clarification of VFT. Fluent and Flexible Thinking is another way of thinking creatively. Fluent Thinking necessitates writing

many new ideas quickly. On the other hand, flexible thinking generates fewer ideas, which includes a broader area. A creative thinking process may use these techniques individually or together. Idea Checklist develops solutions for a decision problem or lists attributes to define alternatives. In addition, it generates strategies by using strategy generation tables. The most known technique is Brainstorming which requires thinking activity among different people. Metaphorical thinking, Nominal Group Technique are some of the other techniques for creative decision making (Clemen & Reilly, 2001).

2.4 Value Focused Thinking

The purpose of decisions is achieving something, which is defined by the values for given decision. Objectives specify those values in detail. VFT keeps attention throughout the decision process on what you hope to achieve. According to Kirkwood, “VFT is a strategic, quantitative approach to decision-making that uses specified objectives, evaluation measures, and value hierarchies.” VFT utilizes the fundamental and mean objectives to specify alternatives and decision opportunities. VFT uses MODA as a mathematical technique (Parnell, 2007). VFT is a MODA process that reverses AFT approach by first defining the values that are important to DM and stakeholders.

Values should be in the center of the decision making processes. Keeney R. L., 1992, as shown in Figure 3, identifies the central role of thinking about values. VFT allows you to explicitly state DM’s objectives, uncover hidden objectives and clarify the problem. With explicit objectives and values, it is possible to create and evaluate alternatives appropriately. After identifying values, useful information can be realized which would be lead better consequences. Discussing values will improve

communication and understanding. By using values, it is possible to manage stakeholders who must be the part of decision process and negotiations.

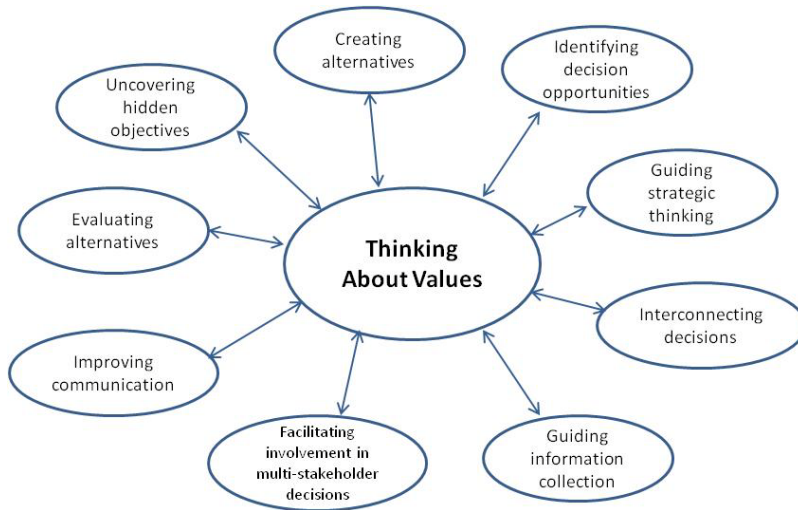


Figure 3 Overview of Value-Focused Thinking (Keeney R. L., 1992)

2.4.1 Value Focused Thinking and Alternative Focused Thinking

VFT and AFT are two methods that apply to decision problems. According to Keeney, 1992, AFT first necessitates figuring out available alternatives and then choosing the best one. By that method, analysis focuses on the alternatives of interest to DM. Yet, sometimes none of the alternatives satisfies DM objectives. On the other hand, DM objectives may not be a direct part to evaluate alternatives (Parnell, 2007). If available alternatives are bad, then the AFT approach will only chose the best of bad alternatives.

VFT consists of two activities first deciding what is desired and then figuring out the ways to obtain it. VFT starts with specifying values that DM and stakeholders define.

It uses values to generate and evaluate alternatives. Hence, VFT is a constraint-free thinking, which ends up with an efficient decision(Bell, Raiffa, & Tversky, 1988).

2.4.2 Elements of Value Focused Thinking

Before applying VFT, we need to understand some basic concepts that will allow thinking systematically.

Objectives

According to Keeney & Raiffa, 1993 “An objective is a statement of something that is desired to be achieved. It indicates the direction in which we should strive to do better.” Some examples are “maximizing profit”, “maximize safety”, “minimize damage” etc. It is different from goal. Since, goal is the specified level of achievement of these objectives.

Objectives Hierarchy

After defining multiple objectives, a systematic structure called objective hierarchy (or value tree) is used. At the higher level of hierarchy, objectives are more general. However, lower levels of hierarchy have specific objectives. For example, “maximize transportation safety” is at the higher level, “minimize fatalities” is at the lower level of the hierarchy. Therefore, we can define lower-level objectives or as the branches of higher-level objectives (Bell, Raiffa, & Tversky, 1988). While constructing hierarchy, fundamental objective approach and means objective approach can be used (Keeney R. L., 1992). Objectives hierarchy should be complete, operational (can be used in analysis), decomposable, nonredundant (no double counting) and minimal (small dimensions) (Kirkwood, 1997).

Attributes

At the lowest level of hierarchy, all of the objectives must have an attribute in order to determine level of objectives achieved. For example, number of fatalities can be an attribute for “minimize fatalities” objective (Bell, Raiffa, & Tversky, 1988). Attribute should be comprehensive, operational and measurable. Keeney & Raiffa, 1993 provides a great explanation of these features. Some of the attributes have direct measurements. However, if we have subjective attribute scales, like prestige, then we need to use some proxy attributes. Proxy attribute measures the objective indirectly (Keeney & Raiffa, 1993).

Single- Dimensional Value Functions

Value or utility functions represent decision maker’s preference structure that evaluates alternatives. These functions transform the attribute levels into a single dimensional value function (SDVF) by considering decision maker’s preferences. By using these single dimensional measures, alternatives’ overall scores become independent from units (Bell, Raiffa, & Tversky, 1988).

Multiattribute Value Functions

Since, it is not possible to satisfy all of the objectives at the same time we need to define value tradeoffs. Tradeoffs are subjective and differ from one decision maker to another. By weighing tradeoffs, decision maker can build his or her tradeoff model. By using weights and single-attribute value functions, we can calculate the overall value score for each alternative.

2.4.3 Steps for Value Focused Thinking

VFT necessitates several steps to construct a structure on decision process. Since, VFT works in conjunction with MODA; we can use a Multi Objective Decision Analysis using Value Focused Thinking approach. This approach necessitates a good communication with decision makers, stakeholders and subject matter experts. Dillon-Merrill, Parnell, Buckshaw, Casweel, J., & Hensley, 2008 summarizes these VFT steps according to Kirkwood, 1997 as shown in Figure 4.

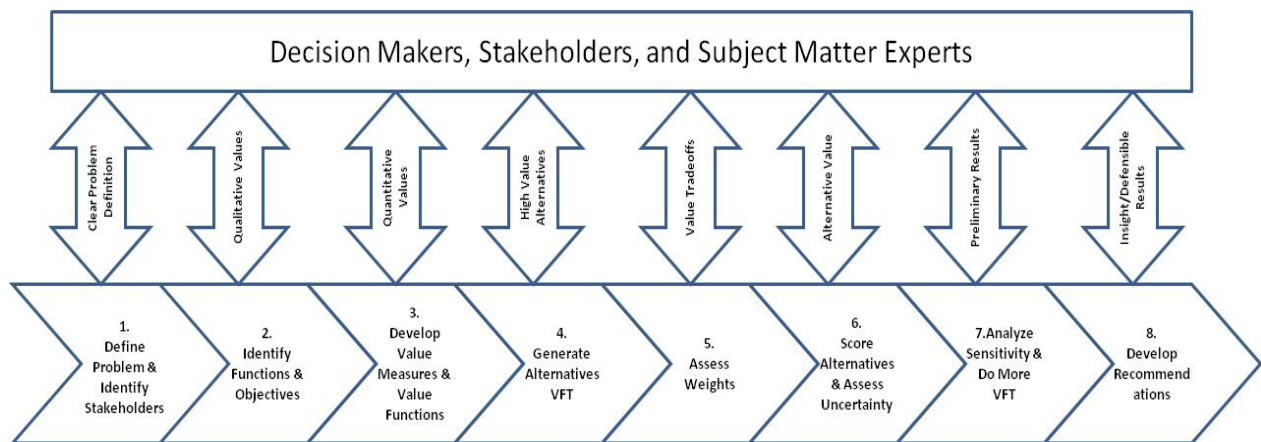


Figure 4 Steps for VFT (Dillon-Merrill, et al., 2008)

Step 1: *Define the problem and identify the stakeholders.*

First, we analyze qualitative part of VFT, which includes fundamental objective, sub-objectives and value measures. We start our analysis by problem definition. Problem definition is very important to clearly establishing the focus of the decision making process. The rest of the process depends on that problem definition part. After defining problem, we need to identify stakeholders who are the actors that can influence or have effects by certain problem or action. For big projects, we can face many stakeholders and this makes decision-making process more complex. By using project stakeholder

management, we can make this problem simpler. Before identifying stakeholders, an easy way to analyze them is to separate them. Customer, financial institution and supplier are some of the internal and external major stakeholder groups. Project stakeholder management assumes that success depends on taking into account the potential impact decisions on all stakeholders during the entire life of the project (Cleland & King, 1998).

Step 2: Identify the appropriate objectives for the problem based on decision makers' and other stakeholders' values and create value hierarchy.

Generating the values related to the overall objective and then organizing them into a value hierarchy is the next step after clearly identifying the problem. In order to construct a successful value model we can use structured techniques for value modeling. There are four structured techniques named gold, platinum, silver and combined standard. Gold standard model depends on an approved vision, policy, strategy, planning or doctrine document. Platinum standard model depends on interviews with decision makers and stakeholders. Many times the gold standard documents are not adequate and we cannot access senior decision makers and stakeholders. As an alternative, the silver standard value model uses data from the stakeholder representatives. For combined standard model, we can combine standards (Parnell, 2007).

The first step of how we will develop the value model is identifying the fundamental objective. Fundamental objective is the most basic objective we are trying to achieve. Without clear and precise fundamental objective, it is difficult to make defensible decisions. By specifying area of concerns, we can specify objectives (Kirkwood, 1997). After that, we need to identify the sub-objectives that define value.

Using affinity diagrams is a good way to determine functions. By using affinity diagrams, we can obtain mutually exclusive and collectively exhaustive functions. Once set of objectives are defined, value measures are required for evaluating how well alternatives will meet each objective (Dillon-Merrill, Parnell, Buckshaw, Casweel, J., & Hensley, 2008).

Step 3: Develop value measures and value functions for each objective.

After completing qualitative analysis, we begin quantitative technique that uses value functions, weights and mathematical equation to evaluate the alternatives. We first begin with value functions.

Each value measure has a different unit of measurement; hence, in order to compare all measures conversion to the same scale is necessary. Value function combines the multiple evaluation measures to single measure. By that conversion, we can scale all measure between 0 and 1 where 0 is the least preferred and 1 the most preferred. We can have discrete value functions, which have a set of discrete value measures, and continuous value functions, which have a continuous range of value measures. Continuous value functions can be piecewise linear or exponential. A piecewise linear value function places specific relative value increments for all possible evaluation measures (Kirkwood, 1997). An exponential value function uses a mathematical formula to represent a continuous range of value increments. This strength of preference functions depends on the attribute range of the alternatives in the decision problem. If another alternative enters to the decision problem with an attribute value outside of the current

range, then it is necessary to formulate and normalize the strength of preference functions again.

Step 4: Identify and develop alternatives using VFT.

Next step is alternative generation. One of the most important parts of VFT is alternative generation by using values. Without generating appropriate alternatives, the decision process cannot produce a good result. The search should focus on the values in order to generate better alternatives than initial alternatives.

Step 5: Assess weights for each measure from relevant decision makers and stakeholders.

Then we can assess weights. “Weights are required to tradeoff the objectives since not all value measures will be equally weighted in the final model (Dillon-Merrill, Parnell, Buckshaw, Casweel, J., & Hensley, 2008)”. Decision maker should make weight assessment. Because the purpose of weighting is to identify which value measures are most important to decision maker. We can assign weights globally or locally. Global weight ensures that sum of each measure weight which is at the lowest tier is equal to 1. Local weight begins from the top of the value hierarchy, which ensures each tier sum to be equal to 1. By multiplying each objective in the same branch, we may find associated global weight.

A critically important task in decision-making is assigning weights to criteria. Several methods have been proposed to weight decision criteria. Indirect weighting methods identify feasible courses of action open to decision maker to define a set of hypothetical decisions. One of them is Hypothetical Equivalents and Inequivalents Method (HEIM). For approximate weighting methods, if a decision maker is uncertain as

to her tradeoffs, attribute weights can be thought of as sampled from a distribution of possible weights. Direct criteria weighting methods identify weights by asking the direct value of that weight. Some of them are scaling, swing weighting and point estimate method. In swing weighing method, decision maker first orders the criteria in terms of their importance and then gives weight the criteria. As an assumption, weights reflect the relative importance of moving an attribute from worst to best level and thus are defined on a ratio scale. Swing weighting method has more potential accuracy than other weighting methods. For further information, refer to Jia, Fischer, & Dyer, 1997 and Nutt, 1979.

Step 6: *Score and rank alternatives on each of the value measures and asses the uncertainty associated with the scores.*

By combining value functions and weights, we can find our overall scores for each alternative. Additive and multiplicative multiattribute value functions are two types of these value functions. Additive value function is the most commonly used multiattribute value function. Since, it is easy to implement. In addition, it reduces the memory storage use. It assumes that single-attribute value score has weight for their importance and then added together. Additive value function gives these overall scores by the following formula.

$$V(x) = \sum_{i=1}^n w_i v_i(x_i) \quad \sum_{i=1}^n w_i = 1 \quad (1)$$

Where $V(x)$ is the multi objective value function, $v_i(x_i)$ is the single dimensional value function i , w_i is the weight of the evaluation measure (Keeney & Raiffa, 1993).

Step 7: Analyze the sensitivity of the analysis to assumptions and consider refining alternatives to create better alternatives.

After scoring the alternatives, a sensitivity analysis should determine if the preferred recommendation is sensitive to small changes in one or more aspects of the model. One sensitivity analysis that is often used is on weights. Because the model constructed on assumption that weighting is properly given and reflect decision maker's preferences. If a model is determined to be highly sensitive to a particular weight or assumption, the decision maker may wish to reconsider carefully that aspect of the model (Dillon-Merrill, Parnell, Buckshaw, Casweel, J., & Hensley, 2008). This type of sensitivity analysis begins by moving a selected measure's weight from zero to one, regardless of the predetermined weight. As the measure's weight changes, the weights of all other evaluation measures proportionally adjust to ensure all weights still sum to one.

Step 8: Provide recommendation and insights.

Preparing, presenting and documenting the recommendation are important as problem definition. The analyst should convey useful information to decision maker with a clear and concise explanation. We cannot expect a decision maker to understand decision analysis language.

2.5 Life Cycle Cost Analysis (LCCA)

Many projects, especially the expensive ones, necessitate a good cost analysis. If only the procurement cost is considered, it is not likely to make a cost effective decision in the long term. Since, most of the studies represent that costs related to the ownership of the system exceed costs of procurement (Dhillon, Life Cycle Costing for Engineers, 2010).

According to Ryan.W.J., 1968 life cycle cost can be 10 to 100 times of procurement cost. Without a proper cost analysis, it is not possible to visualize all of the costs that will affect the project decision. Therefore, not only the acquisition cost but also other costs, as illustrated in Figure 5, need additional interest while making decisions.

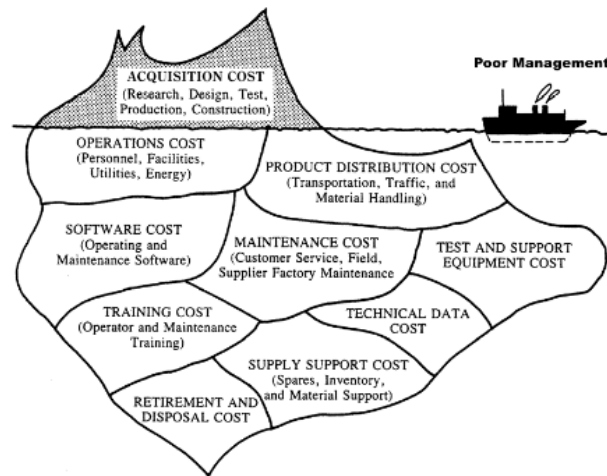


Figure 5 The Problem of the Total Cost Visibility (Fabrycky, J., & Blanchard, 1991)

Fuller & Petersen, 1996 defines LCCA, as “LCCA is an economic method of project evaluation in which all costs arising from owning, operating, maintaining and ultimately disposing of a project are considered to be potentially important to that decision”. Alternatively, simply “Life cycle cost of a system can be defined as the sum of all costs incurred during its life span” (Dhillon, Life Cycle Costing for Engineers, 2010). The main objective of using LCCA is minimizing the total cost of a project over its lifetime (Remer, 1977).

LCCA has many advantages. It is useful to reduce total cost of the system and to control overall process of the program. It is an excellent tool for selecting among the

competing alternatives and contractors. In addition to these advantages, LCCA may reduce the costs related to ownership. By analyzing the future costs, we determine the problematic sides of the project that increase the future costs. Hence, we can define new solutions to solve those problems (Remer, 1977). In addition to these advantages, LCCA has some disadvantages. Estimating the project lifetime is very time consuming and expensive; and inaccurate lifetime estimation may be misleading. Accuracy of the data directly effects the decision; hence, data may be another burden to worry about the accuracy of the analysis (Dhillon, 2010).

Many companies and governmental organizations use life cycle cost techniques to evaluate alternatives and to make cost effective decisions. There are many applications using life cycle cost analysis. Figure 6 (Sage & Rouse, 1999)represents some of the application areas of life cycle cost.

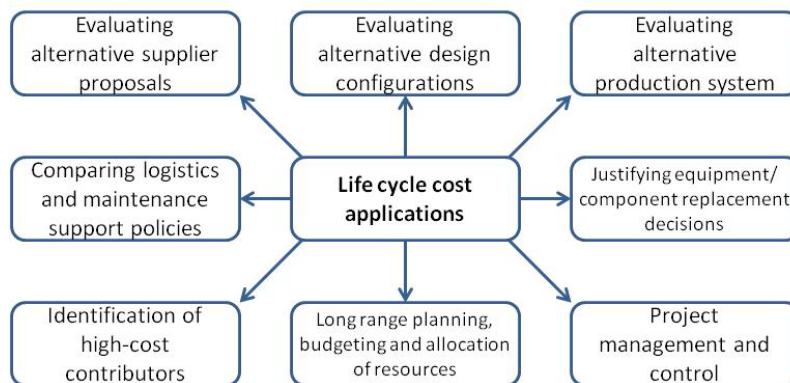


Figure 6 Life cycle cost applications (Sage & Rouse, 1999)

2.5.1 Life Cycle Cost Elements

Life cycle cost has four elements based on the organizational activity over the life cycle. These elements are research and development (R&D), investment, operating and support (O&S), and disposal. These elements are essential for cost estimation of the projects. Figure 7 is an illustration of these elements and their effects on the project's life cycle cost. This illustration may vary for different projects (Fabrycky, J., & Blanchard, 1991).

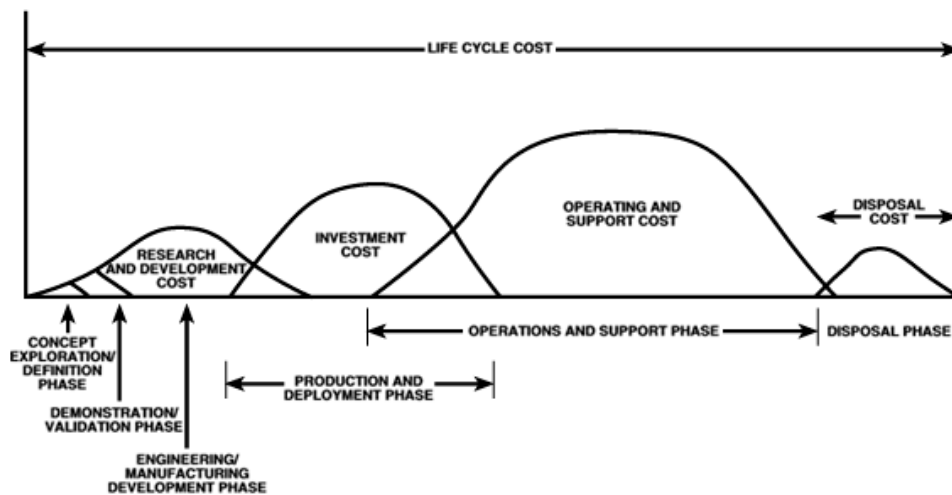


Figure 7 Project Life Cycle (illustrative) (Cost Analysis Improvement Group, 1992)

Research and Development Cost (R&D Cost)

R&D cost consists of costs stem from feasibility studies; market analysis; modeling; trade-off analyses; engineering design; development; software; system tests and evaluation; design data and documentation.

Investment Cost

Investment cost is associated with producing, procuring, and deploying system, initial logistic support requirements, training, data, initial spares, and facility construction.

Operation and Support Cost (O&S Cost)

O&S cost incurred from the costs related to operating, maintaining and supporting the system. It includes costs for personnel, consumable and repairable material, organizational, intermediate and depot maintenance, and all appropriate levels of maintenance, facilities, and sustaining investment.

Disposal Cost

Disposal cost includes costs associated with deactivating a system at the end of its useful life. Because of not having a significant effect on life cycle cost, it is generally excluded from most of the studies except nuclear waste and similar disposal problems.

2.5.2 Steps for LCCA

LCCA provides a systematic approach to obtain a cost effective solution. The analysis process is iterative and applicable to any phase of the system life cycle. Figure 8 illustrates this process.



Figure 8 Steps in a Life Cycle Cost Analysis (Bassford, Voort, Boer, & Pung, 2008)

Step 1: Planning

The first and most essential step is planning. Since, without clear identification of the problem and LCCA objective, it is possible to make inefficient decisions. In addition, the rest of the process depends on that problem and objective definition step. Since, clear problem definition reveals clear cost breakdown structure. On the other hand, identification of the alternatives is important. The analyst, decision maker and stakeholders should define operational requirements and maintenance concepts of alternatives to be a candidate of winning alternative. Since decisions are made by analyzing desired characteristics and performance and the cost of the system. After that, lifecycle cost phases and their related costs need to be examined in general and searched for available data. If data is not available and that is not determined at the beginning of the analysis, it is impossible to accomplish analysis.

Step 2: Definition

The purpose of LCCA is determining the most cost efficient alternative of a specified system. Therefore, system identification is very important in order to construct a systematic relation with outside effects and internal subsystems. With the intention of specifying subsystems, the definition of system and its purpose of use are necessary. After these definitions maintenance necessitations becomes clear for further break down.

Step 3: Development

The next step is to develop a Cost Breakdown Structure (CBS) for evaluating the life cycle cost of alternatives. CBS constructs a systematic relation and communication between objectives, costs and analysis. Main goal for creating CBS is to visualize hidden

costs (Fabrycky, J., & Blanchard, 1991). Systems are different from each other; hence, every system has a different CBS. However, Figure 9 can be a general start point to develop a CBS. Gaps related to each LCCA element are defined by system and associated costs of it. For CBS of different systems refer to Fabrycky, J., & Blanchard, 1991.

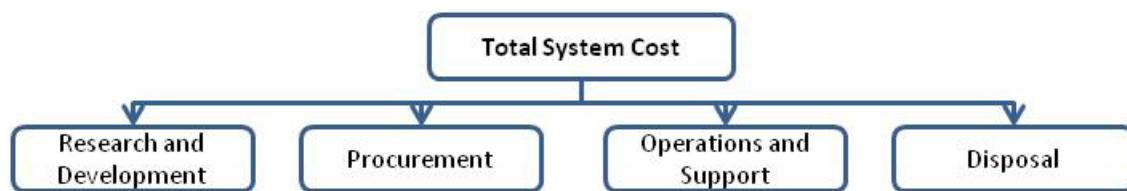


Figure 9 A Start Point for Cost Breakdown Structure (Fabrycky, J., & Blanchard, 1991)

Every system has its own features including different subsystem, inputs and outputs, users, equipments etc. Therefore, it is not possible to define only one general cost model for different systems. Cost model is critical step for life cycle cost analysis; since, if the model is not representing the real system, the analyst cannot obtain a correct result from the analysis. Literature has diverse numbers of cost models; so, selecting a suitable model for the system necessitates attention. Dhillon, 1989 classifies these models with two categories that are general life cycle cost models and specific life cycle cost models. Dhillon, 1989 includes many examples about life cycle cost models of different equipments, particular and general systems.

By using the CBS, analyst can proceed with the cost estimation. Cost estimation should be very close to real data in order to make a suitable and reliable analysis. Because of missing data, generally the experience is necessary to calculate the cost

estimates. Therefore, it becomes a challenging step in the life cycle process. There are many cost estimation methods available in the literature. According to Sage & Rouse, 1999, these estimations can be made by analogy, expert judgment, bottom-up and parametric models.

Estimation by analogy uses data from past system. If the data is robust, this method is easy to imply. Otherwise, the estimation that affects analysis directly will be unreliable. Expert judgment method uses expert view due to their experience to estimate cost. Nevertheless, unreliable experts and new system that cannot yield experience are the problems of this method. Bottom-up model estimates the cost of subsystems and accumulates to find the overall cost of the system. It necessitates data collection from subsystem responsible. Therefore, this is a very time-consuming and people-dependent method (Sage & Rouse, 1999). Parametric model uses statistical techniques. It is possible to calculate total cost by the relation function of different components and their statistical data. Yet, it is generally necessary to use this method in conjunction with analogy and expert judgment methods (Fabrycky, J., & Blanchard, 1991).

Project life lasts for a period. Hence, time is an input for analysis. In order to consider time in the analysis, it is essential to develop cost profile of the system. Cost profile is the graphical or tabular representation showing the distribution of costs over the life cycle of a product (IEC60300-3-3: Life cycle costing). By using the CBS and estimated costs, it is possible to present the cost of each activity year by year. Monetary value represents the purchasing power of the money for the current day.

Step 4: Analysis

In order to compare alternatives, analyst should make an economic evaluation by using the cost profile. The main concern is to find a desirable alternative among the possible ones. We can use a discounted profile by time value of money in order to compare different alternatives. Since today's value of money is not equal to the value of future money. The main idea is discounting the future value to the present value. Assumption of the method is the known discount rate. Many companies and governments specify their discount rates to use in their economic evaluations. Present equivalent evaluation, annual equivalent evaluation, future equivalent evaluation, rate of return evaluation and pay out evaluation are some of the methods that use the time value of money.

Another way to evaluate alternatives is using budget profile with constant money value by year-by-year basis. Monetary value will be in terms of today value. Nevertheless, it is suitable for only one cost profile evaluation. By applying the effects of learning curves and inflation factor to the budgetary profile, we can obtain a different way to evaluate single cost profile (Fabrycky, J., & Blanchard, 1991).

Following these calculations, a break-even analysis may be suitable in order to determine the preferred alternative. Cumulative life cycle cost for program time visualizes the alternatives performances in terms of their life cycle cost. If it is planned to use a system more than the break-even point time, it will be suitable to choose the one with the less cost after that break-even point.

In order to reduce the life cycle cost and improve the system, the analyst should define high-cost contributors. High-cost contributors are the elements of LCCA that has a great impact on system. By using CBS and cost estimates of each element, it is possible to identify the contributors that increase cost. Identification of high-cost contributors reveals specification of their causes. Once these causes are defined, it is possible to identify other effected system contributors.

Decisions are subject to uncertainty. LCCA decreases the level of that uncertainty; yet, it still includes some issues of uncertainty. It is crucial to check LCCA results if they are sensitive to change of major inputs. Sensitivity analysis is a deterministic technique that estimates how changes in the input will change the outcome. It identifies the inputs that have the greatest effect on the system. It is possible to calculate the upper and lower bounds of LCC by the range of outcomes. By simply changing the value of each input and keeping all others constant, change in LCC can be measured (Fuller & Petersen, 1996).

Risk analysis provides an overview of what are the consequences if a decision does not proceed according to program. In order to make suitable recommendations, analyst should consider the risk as a part of analysis. Risk and costs are dependent concepts; because, if risk increases, cost increases as well. In addition, if cost is not controlled, risk of unsuccessful project arises. Therefore, it is essential to identify and eliminate the potential risk areas early. High cost contributors and their causes are the main potential areas of risk in LCC (Sage & Rouse, 1999).

Step 5: Reporting

Reporting LCCA results to decision maker is essential. Since, the decision is dependent to analyst presentation. An executive summary should be included to provide an overview of analysis. The overview should explain basic concepts including definitions, objectives, assumptions and constraints. He/she will not be familiar with most of the concepts that the analysis utilizes. CBS, explanation of elements and cost estimation method should be clear. High-cost drivers, sensitivity and other analysis should be in the report. Regarding the analysis, results conclusions and recommendations should be included for LCCA report (IEC60300-3-3: Life cycle costing).

III. Methodology

This chapter discusses the first five steps of the eight-step VFT process and the first three steps of the five-step LCCA process. The last three steps are included in the analysis and recommendation sections of this research.

3.1 VFT Steps

3.1.1 Step1: Problem definition and stakeholders' identification:

Aerobatic display team is the one of the most important elements of any Air Force all around the world. Since, it is the international presenter of Air Force and country. So selecting aerobatic aircraft has big importance. Therefore, it necessitates a good identification of stakeholders.

Stakeholders of this decision-making process split into three groups: Pilots who are the actual users of the aircraft during flight, maintenance personnel who are the actual user of the aircraft after landing and audiences who are the main purpose of the display. The main purpose of a system is to satisfy stakeholders' demands with appropriate design while realizing objectives optimally. For this research, constructor is not determined as a stakeholder. It is assumed that the available producers could satisfy any demand by stakeholders.

As the decision maker, the requirement officer is chosen. A pilot who is a four-wing leader, a maintenance officer who is the maintenance team chief and audience who are the general Turkish people are designated as stakeholders.

3.1.2 Step 2: Identification of objectives and functions

Among the four different structured techniques for value modeling, silver standard model is selected to develop hierarchy. So interviews made with decision maker and stakeholders.

The fundamental objective is “Selecting the most appropriate aircraft which can supply best representation of Turkish Air Force and Republic of Turkey all around the world”. This is a clear and concise statement of the most basic reason for decision.

After making interview with pilot, maintenance officer and audience, functions are designated by grouping all of the ideas in order to obtain mutually exclusive and collectively exhaustive sub-objectives. Three sub objectives emerged from grouping process: maximize flight performance, minimize withdrawals of logistics issues and maximize prestige. Figure 10 illustrates fundamental objective and sub-objectives.

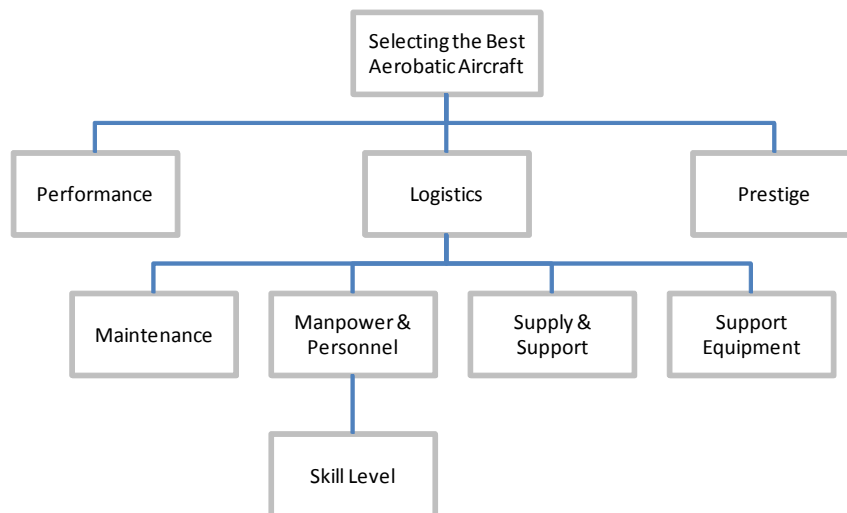


Figure 50 Aerobatic Aircraft Selection Value Hierarchy.

3.1.3 Step 3: Develop value measures and value functions for each objective.

Once the set of objectives is defined, value measures are required for evaluating how well alternatives will meet each objective. Value measures are defined for each objective. Overall value hierarchy is in Figure 11.

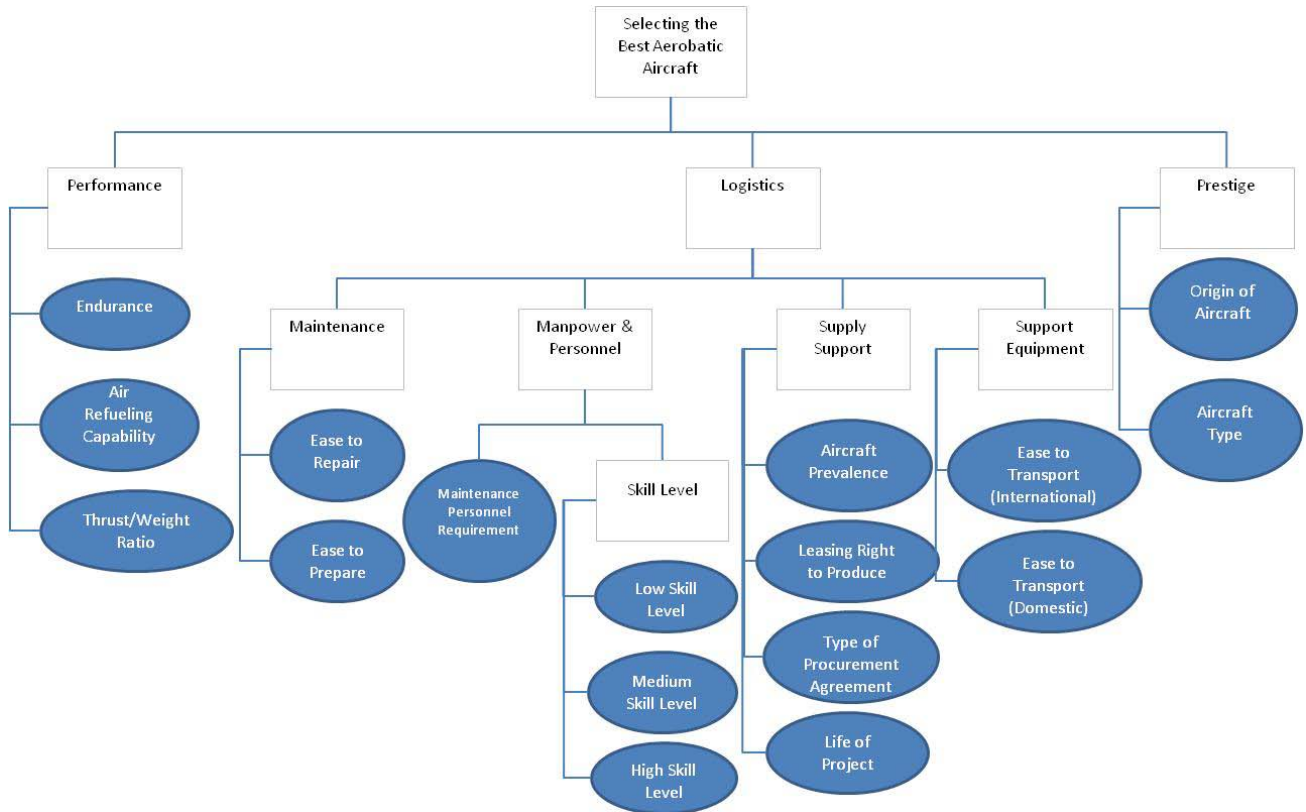


Figure 61 Overall Value Hierarchy

Endurance: It is the length of time, which an **aircraft** can fly without refueling. An aerobatic aircraft may perform shows away from runways. Moreover, a spare aircraft always waits in case of a problem of other aircrafts. In addition, during international deployment for the shows, it is beneficial to make less air refueling activity concerning

safety and cost. Therefore, an aerobatic aircraft should have a high endurance. Minutes express the measurement of endurance.

Maneuverability is not a part of the hierarchy. Since, all of the alternatives are selected by considering requirements of an aerobatic show.

Thrust/Weight Ratio: Thrust is the propulsion of engine. However, it is not a significant measure to evaluate aircraft performance. Therefore, thrust to weight ratio is a better performance measurement. It is directly proportional to the acceleration of the aircraft. An aircraft with a high thrust to weight ratio has high acceleration. An aerobatic display aircraft should have a high thrust to weight ratio in order to perform high performance maneuvers.

Air Refueling Capability: Air refueling is the process of transferring fuel from the tanker aircraft to the receiver aircraft during flight (Bolkcom, 2006). International deployments necessitate air-refueling capability. Because, without air refueling many landings and take-offs are necessary. Every landing and take-off decrease the flight safety and increase cost. Therefore, an aerobatic display aircraft should have air-refueling capability.

Ease to Repair: Mean time to repair (MTTR) which is a basic measure of the maintainability and reliability of a system and is a direct measure for ease to repair. It represents the average time required to complete a corrective maintenance action for each failure. Corrective maintenance actions occur because of an actual or suspected failure to restore an item to a specified condition. Hours express the measurement of ease to repair. Equation 2 illustrates how to calculate MTTR.

$$MTTR = \frac{\text{Total Corrective Maintenance Time}}{\text{Total Number of Failures}} \quad (2)$$

An aircraft should have a low MTTR, which means less work, time consumption and more availability.

Ease to Prepare: For each sortie, preflight and post flight maintenance is necessary for every aircraft. On the other hand, in order to maintain an aircraft some preventive maintenance procedures should apply. Preventive maintenance is the systematic care, servicing and inspection of equipment to improve reliability and increase system lifetime. Lombardo, 1998 includes examples of preventive maintenance. It can directly be measured by maintenance man-hour per flight hour scheduled (MMH/FH(S)). Equation 3 shows how to calculate it MMH/FH(S).

$$MMH/FH(S) = \frac{\text{Total Preventive Man-Hours}}{\text{Total Flight Hours}} \quad (3)$$

An aircraft should have a low MMH/FH(S) that means less work, less time consumption and more availability.

Maintenance Personnel Requirement: It is total number of maintenance personnel needed to support 20 aircraft. Fewer personnel are better.

Skill Level: Maintenance personnel level of skills is crucial to support aircraft and play an important role in the Air Force's ability to accomplish its mission. Turkish Air Force uses three different skill levels that are level-3, level-5 and level-7. Level-3 may accomplish the tasks unsupervised. Level-5 may be assigned to quality assurance positions. Level-7 needs to satisfy different supervisory and management positions such as shift leader and section chief. TurAF assigns different skill levels percentage for different aircrafts depending on the complexity of the aircraft. If an aircraft is complex, it

necessitates more level-5 and level-7 personnel which means increasing cost, increasing time consumption and extra effort to educate personnel.

Yet, every country has its own maintenance skill level system. Hence, we cannot directly use TurAF skill level categories. It is possible to measure that by using skill levels low, medium and high. By examining the skill level systems of candidate countries, it is possible to group maintenance personnel. Percentage of maintenance of each skill level to support 20 aircraft is the measure for skill level. This measure is proxy to determine the complexity of the aircraft. Less high skill level personnel is better.

Aircraft Prevalence: If an aircraft is commonly used, then material supply will be easier and cheaper because of the mass production of parts. Therefore, total number of aircraft used all around the world is a measure for aircraft prevalence.

Leasing Right to Produce: If agreements maintain leasing right to produce for a specific amount, then it will be easier to obtain supply materials. The right of production percentage of each aircraft can measure it.

Type of Procurement: As explained in Turkish Procurement Law, there are different types of procurement agreements. If agreement is domestic, it will be faster and cheaper to obtain material support. If agreement is international FMS and NAMSA procurement procedures will be fast, but expensive. On the other hand, if international agreement is MOA, it will be cheaper to obtain materials, but it will take long time to get them. If PBL (Performance Based Logistics) is type of the international agreement, it will also be cheap and fast, but not as fast and cheap as domestic agreement. Therefore, we can

categorize them domestic procurement, procurement by PBL, procurement by FMS, procurement by NAMSAs and procurement by MOA.

Life of Project: It is the planned time for the production of the aircraft. It should be greater than 30 years, which is the period of usage of these aircrafts by TurAF. By looking at the aircraft production scheduling, we can decide if the production stops in next 30 years. This measure determines the continuity of supply.

Ease to Transport: Because of not being on the home base, each show necessitates specific amount of spare parts and support equipment. Turkish Stars aerobatic display team has one C-130 for domestic and one C-160 for international and domestic material transportation. C-130 maximum number of pallet is eight and C-160 maximum number of pallet is six. Number of pallets change due to the location of the show. International shows necessitate more pallets than domestic shows. Since Turkish Stars deploys all around the world many times, it is desirable to carry few pallets. Therefore, an aerobatic aircraft should necessitate fewer pallets to transport to decrease effort for deployment preparation and cost. Number of pallets for international and number of pallets for domestic shows are the measures of ease to transport.

Origin of Aircraft: The purpose of Turkish Star is to present the TurAF, Turkish Republic, to contribute to the efficiency and discipline of the TurAF, to reinforce the people trust in the Air Force, and to increase the interest of the air force among the young people of Turkey. Hence, people of Turkey should approve the Turkish Star's aircraft. As a result, the origin of the country becomes an effect for selecting the aircraft. Categories for the countries represent the measure for origin of the aircraft. Cat-1 represents Turkey,

cat-2 represents ally countries, cat-3 represents countries with good relationship and cat-4 represents other countries.

Aircraft Type: For aerobatic teams, type of the aircraft is an important issue. Since, it represents the capability of the aerobatic display team and air force. On the other hand, type of the aircraft is crucial for attracting young people. Jet aircraft and propeller aircraft categories are measures for aircraft type.

After constructing the hierarchy, the next step is to create the value functions for each evaluation measure. As stated in previous chapters, it is necessary to convert all evaluation measures to unit less measures between zero and one where one is best and zero is the worst score. Value functions are constructed with the inputs of SMEs and decision maker. A computer software program called Hierarchy Builder (Weir, 2008) was used to simplify the process to create value functions. Hierarchy Builder is verified by previous studies. For detailed information, refer to (Malyemez, 2011). First, the decision maker and SMEs decided whether a measure has discrete or continuous scale. If a measure was defined as discrete, all categories of the measure were defined and given a value. If a measure was continuous, decision maker and SMEs were asked to specify if it has an increasing or decreasing value function. For an increasing value function, the minimum score has value of zero and maximum score has value of one. On the other hand, for a decreasing value function, the minimum score has value of one and the maximum score has a value of zero. After that, the upper and lower bounds were specified the least and the most preferred score of the measure. The reference point 0.8

was used to determine the shape of the value functions which means at what score you obtain the 0.8 value compared to one. All functions are shown in Appendix-A.

3.1.4 Step 4: Identify and develop alternatives using VFT.

After considering a decision maker's values and a value hierarchy, it is suitable to generate alternatives. New alternatives should be better than the current aircraft. Possible candidates to be aerobatic demonstration aircraft of Turkish Stars and their performance measures are generated by using data of different aircrafts. The aircrafts that are data source of generated aircrafts are T-50 Golden Eagle, F-16 Fighting Falcon, Euro-Fighter Typhoon, Mirage-2000, Sukhoi 30 MKI, Gripen JAS39B, F-35 Joint Strike Fighter, Alpha Jet, HAWK, KT-1T, Cessna 208 Caravan and T-6. Data for each alternative with related value measures are shown in Table B. 1.

3.1.5 Step 5: Asses weights for each measure from relevant decision makers and stakeholders.

Weights are assigned to find the more important measure; since, the larger the weight, the bigger the effect of that measure. In order to asses weights swing weighting method is used. Decision makers were asked to rank three sub-objectives performance, logistics and prestige and give points from zero to 100 according to their importance to least preferred one. After that step, the points are normalized to sum to one. For each sub-objective and measures, these procedures are repeated. Table 1 represents the results of the process.

Table 1 Local and Global Weights of the Value Hierarchy

Sub-Objectives	Sub-Objectives and Measures			Points	Local Weight	Global Weight	
Performance				30	0.150		
	Endurance			80	0.308	0.046	
	Air Refueling Capability			80	0.308	0.046	
	Thrust/ Weight Ratio			100	0.385	0.058	
Logistics				70	0.350		
	Maintenance			40	0.154	0.054	
		Ease to Repair		100	0.5	0.027	
		Ease to Prepare		100	0.5	0.027	
	Manpower &Personnel			40	0.154	0.054	
		Maintenance Personnel Requirement		100	0.5	0.027	
		Skill Level		100	0.5	0.027	
			Low	100	0.417	0.011	
				Medium	90	0.375	0.010
				High	50	0.208	0.006
	Supply Support			100	0.385	0.135	
		Aircraft Prevalence		40	0.129	0.017	
		Leasing Right to Produce		90	0.290	0.039	
		Type of Procurement Agreement		80	0.258	0.035	
		Life of Project		100	0.323	0.043	
	Support Equipment			80	0.308	0.108	
		Ease to Transport (International)		100	0.556	0.060	
		Ease to Transport (Domestic)		85	0.444	0.048	
Prestige				100	0.500		
	Origin of Aircraft			75	0.429	0.214	
	Aircraft Type			100	0.571	0.286	

3.2 LCCA Steps

3.2.1 Step 1: Planning

The objective of LCCA for this research is to calculate appropriate cost values for candidate alternatives. By this planned approach, it is not likely to miss important cost factors. TurAF seeks for the most efficient aircraft that means the aircraft that creates the highest score with the appropriate cost. Objectives and fourteen different alternatives considering these objectives are determined by using VFT by including decision maker, stakeholders and their requirements.

Data gathering is the most challenging part of LCCA. Hence, the availability of the data must be verified. In this research real world data of different aircrafts was used to

generate cost data for all aircrafts. Therefore, data may not be accurate. Because the purpose of this research is to construct a decision model; not making a decision recommendation. TurAF procurement procedure requires availability of the data. Hence, before analysis, producers of the candidate aircrafts must supply the desired information and data. During the real procurement procedure, all data will be available.

3.2.2 Step 2: Definition

TurAF plans to procure 20 aerobatic aircrafts for 30 years period. TurAF will not produce the aircrafts and their related systems; thus, outside sources including domestic and foreign producers will provide the aircrafts and their related systems. Procured aircrafts will be used for aerobatic display purpose in domestic and international shows. TurAF will provide flight duty and maintenance service of all of the aspects of the system. Therefore, flight and maintenance personnel need training.

3.2.3 Step 3: Development

The next step is to develop a CBS for evaluating the life cycle cost of alternatives to visualize hidden costs. CBS must include consideration of all costs. A typical fighter aircraft CBS has three categories which are R&D cost, procurement cost and O&S cost. As stated before, every system has its own features and it is not possible to define only one general cost model for different systems. TurAF will not produce the aircrafts and their related systems. Hence, this research will consider only the procurement cost and operations and support cost. Consequently the model is:

$$LCC_{fa} = PC_{fa} + OSC_{fa} \quad (4)$$

LCC_{fa} : Life cycle cost of a typical fighter aircraft.

PC_{fa} : Fighter aircraft procurement cost.

OSC_{fa} : Fighter aircraft operations and support cost.

The CBS assumed for this research is illustrated in Figure 12. Not all of the cost components are critical. The next step will be considering high cost contributors of the LCC.

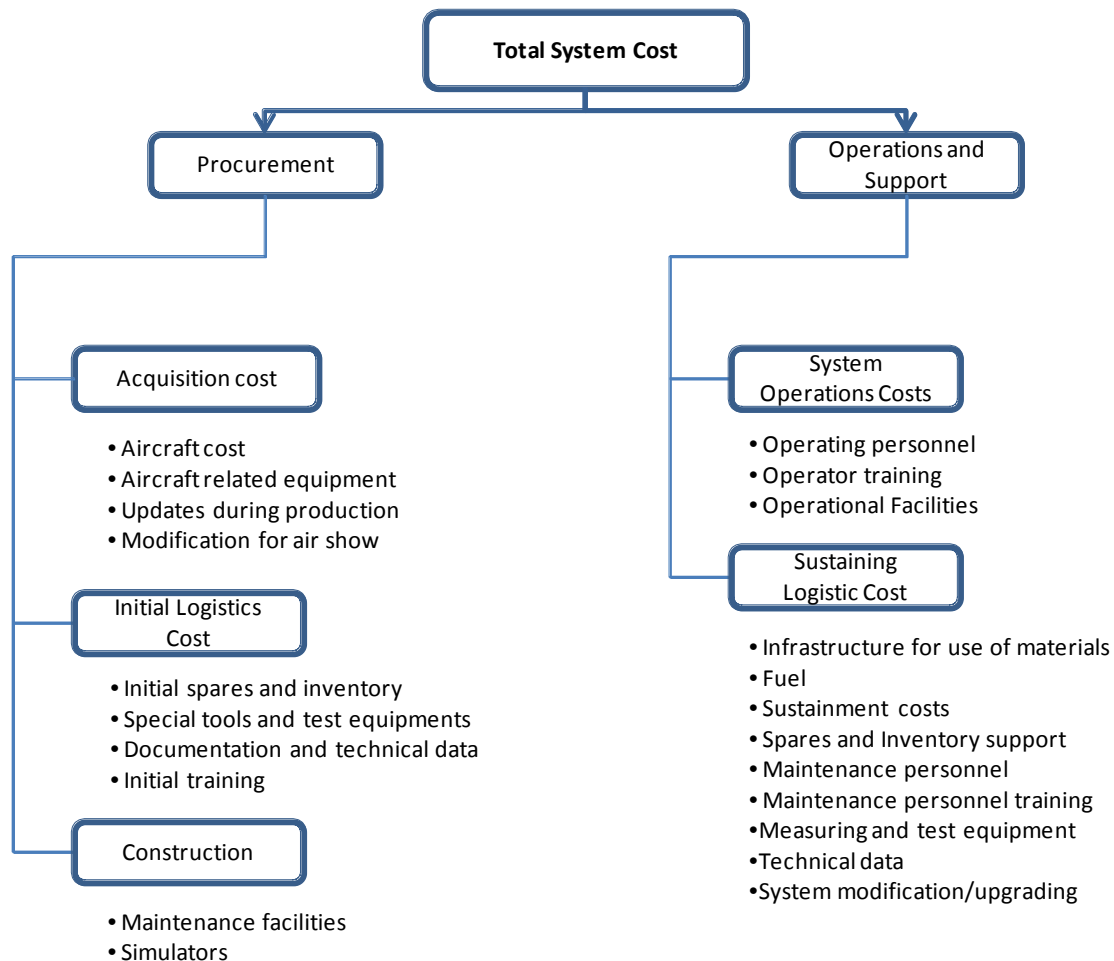


Figure 72 Cost breakdown structure

Procurement Cost Contributors

Aircraft cost includes unit acquisition cost of 20 aircrafts.

Aircraft related equipment cost includes equipments that are necessary to operate aircrafts. So, these equipments should be purchased with aircraft.

Updates during production cost include requirements of TurAF and system enhancement costs caused by project design.

Modification for airshow cost includes special modifications of the aircraft to use it as an aerobatic aircraft. For instance, smoke production system is a part of aerobatic demonstration aircraft.

Initial spares and inventory cost includes the procurement of units to support maintenance activities.

Special tools and test equipments cost includes testing equipment for repaired parts and parts that are in the inventory. These equipments determine the functionality of parts.

Documentation and technical data includes the preparation and publication of system installation and test instructions, operating and maintenance procedures. It is crucial to operate and maintain the system during its lifetime.

Initial training includes training of operating and maintenance personnel to operate and maintain aircrafts. When a system is first introduced, training of operating and maintenance personnel is necessary.

Maintenance facilities cost includes modification of the current facilities and construction of new facilities.

Simulators includes simulator and its related facility construction and modification of the current facilities.

O&S Cost Contributors

Operating personnel cost includes the total costs of operating personnel depending on type of duty.

Operator training includes training of new operators. In addition, system changes necessitate additional training during the lifetime of a system.

Operational facilities cost includes operating cost for simulators and operating personnel training facilities.

Infrastructure for use of materials includes operating cost of maintenance facilities.

Fuel cost includes cost of necessary fuel to fly aircrafts for training, performing and deployment.

Sustainment cost includes all periodical adjustments and inspections, preventive maintenance, minor and major repairs and replacements of components.

Spares and inventory support cost includes cost of spare parts and their inventory. Spare parts are essential to increase the availability of the system. In addition, the inventory is important; since, if inventory level is higher than necessary, then it will increase the cost. On the other hand, if the level is not enough, it will affect the system availability.

Maintenance personnel cost includes the total costs of maintenance personnel depending on type of skill level.

Maintenance personnel training cost includes training of new maintenance technicians.

On the other hand, training of current maintenance personnel is necessary to keep up with upgrades or changes in the system.

Measuring and test equipment cost includes testing and calibration of the system and adequately maintaining the test equipment.

Technical data includes additional and new the preparation and publication of system installation and test instructions, operating and maintenance procedures during system lifetime.

System modification and upgrading cost includes modernization and upgrading of system.

For data generation estimation by analogy and estimation by expert judgment methods are utilized. In order to calculate present value of monetary units time value of the money is used. Since, this is a decision situation involving money flow over time. Interest rate is a crucial element on time value of money. The interest rate is assumed 14% due to Central Bank of the Republic of Turkey reports (www.tcmb.gov.tr, 2011). Table B.2 represents the generated cost data for previously determined alternatives.

IV. Results and Analysis

This chapter analyzes the results obtained by application of VFT process. These steps consist of scoring, ranking and sensitivity analysis on the developed model. Data for VFT is gathered from the real world for different type of aircrafts. Data for LCC is randomly generated by using the real world data for the same aircrafts; since, most of the producer companies refused to supply data. Assumption is made that all data is accurate; because, for the real world situation producer companies are mandated to supply information. Hence, sensitivity analysis is performed on objective weights. Analysis results are obtained by using the Hierarchy Builder (Weir, 2008)

4.1 VFT Analysis

4.1.1 Step 6: Score and rank alternatives on each of the value measures and asses the uncertainty associated with the scores.

A score is calculated for each alternative by summing up the scores from each value function and the corresponding weights for each measure. The scores are then combined using equations 1to give a summation for each alternative and thus used to rank them. Scores are used only for ranking alternatives; they do not represent how much better one alternative is than another one.

Figure 13 shows the ranked alternatives in terms of how well they fulfill each of the decision maker's objectives *Performance*, *Logistics* and *Prestige*. J-10 is the best alternative for Turkish Stars aerobatic team. *Prestige* has the biggest effect on scoring alternatives; since, this aircraft is the domestic and jet aircraft. Although it does not have

very different scores on *Logistics* and *Performance*, it creates difference by prestige. Closest alternatives are J-2 and J-7. If the production of a domestic aircraft will not be possible until the procurement period, then, it is necessary to consider these two alternatives.

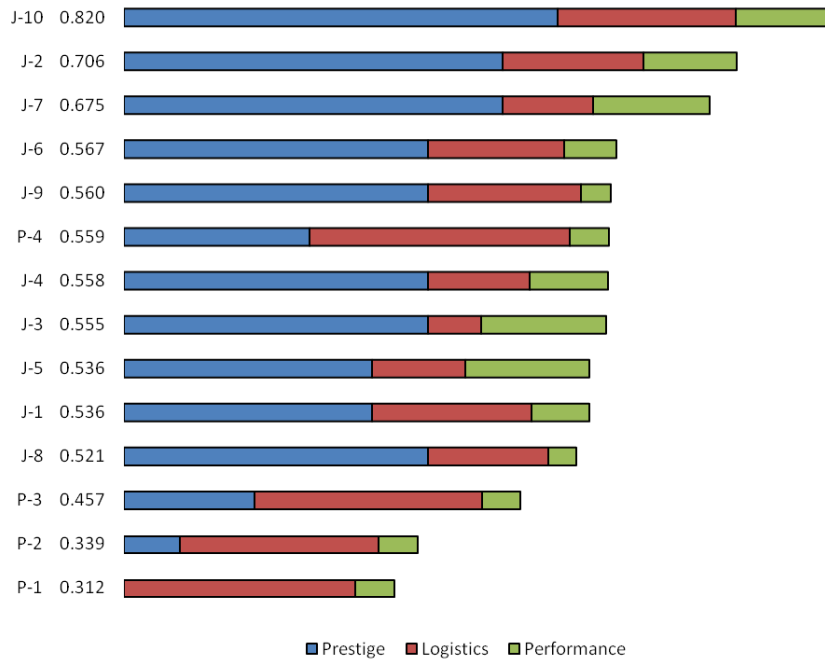


Figure 83 Overall Scoring and Ranking of Alternatives

By looking at the value contributions of individual evaluation measures, it becomes clear which measures differentiated the alternatives from each other. Figure 14 shows how well each alternative performed for the 17 evaluation measures. J-10 has respectively well performance for each of the measures. It creates the difference by origin of the aircraft, leasing right to produce and life of project. The main reason of having a better score is being the domestic aircraft that creates advantage on *Prestige* and *Logistics* objectives.

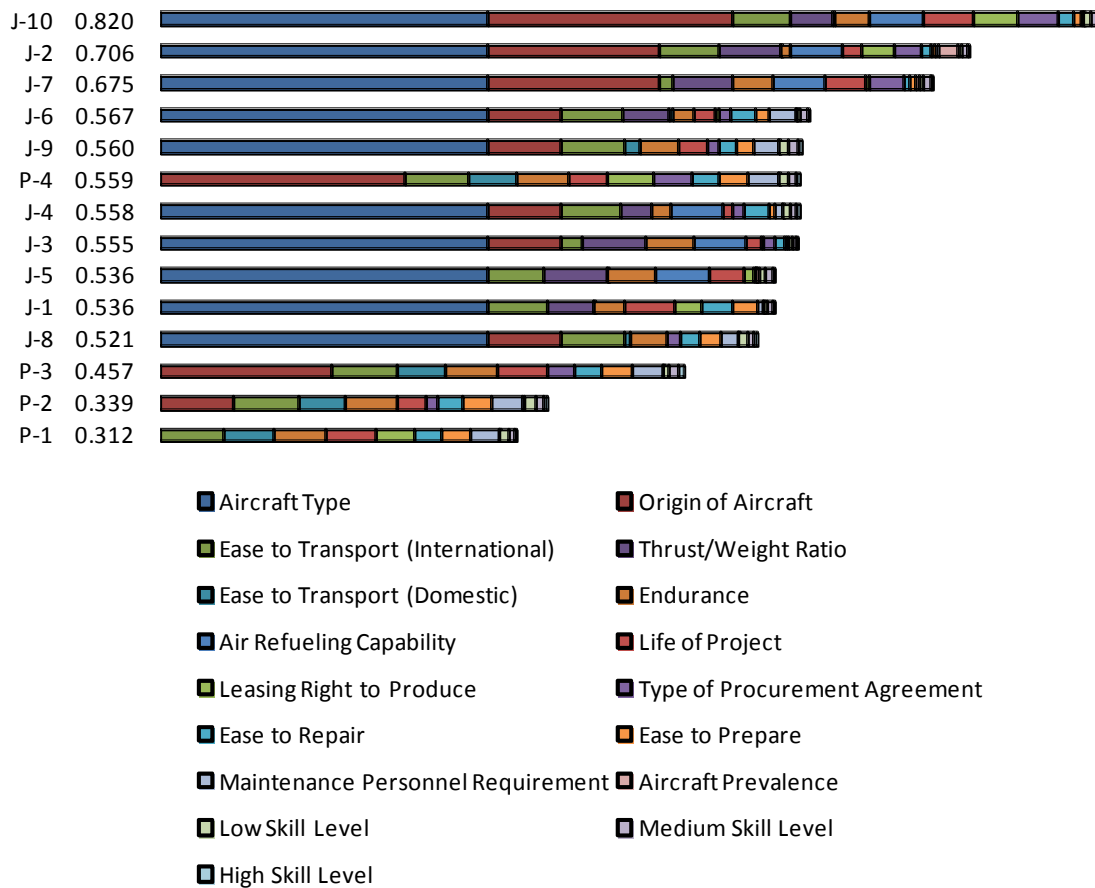


Figure 94 Scoring and Ranking of Alternatives

Figure 15 represents the contribution of each measure on performance objective. The first six alternatives have the advantage of air refueling capability. On the other hand, all of the propeller aircrafts have the drawback of thrust/weight ratio. These two issues may prevent these alternatives to be one of the candidates.

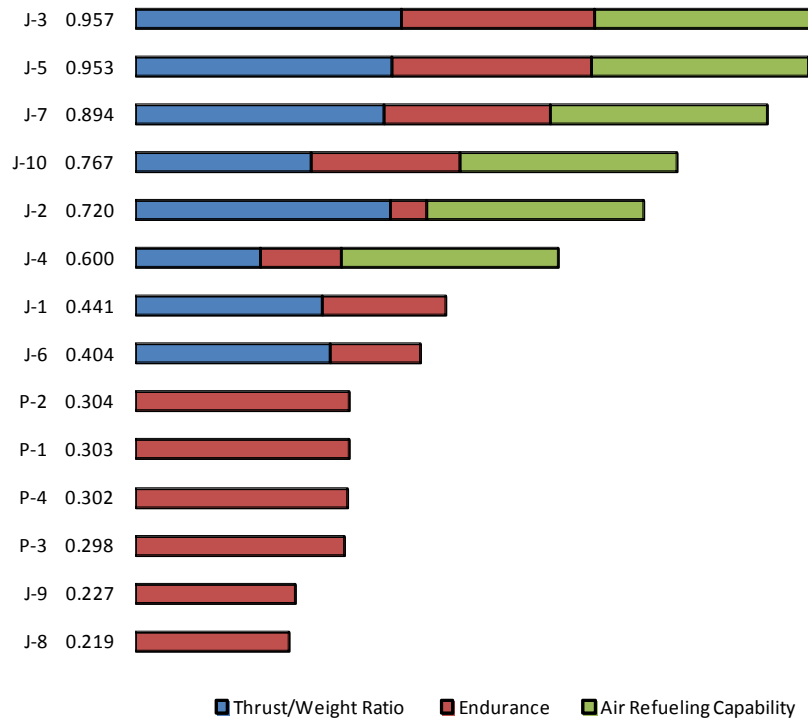


Figure 105 Scoring and Ranking of Alternatives by Performance Objective

By looking at the sub-objectives on objective related to *Logistics* in Figure 16 and Figure 17, propeller aircrafts have the best scores among all other alternatives. P-4 has the advantage of being a domestic aircraft. It is obvious that propeller aircrafts necessitates less personnel and effort to maintain them. They also need less spare parts and less transportation kits, that creates advantage on supply support and support equipment. J-10 has the advantage of being a domestic aircraft on supply support sub-objective.

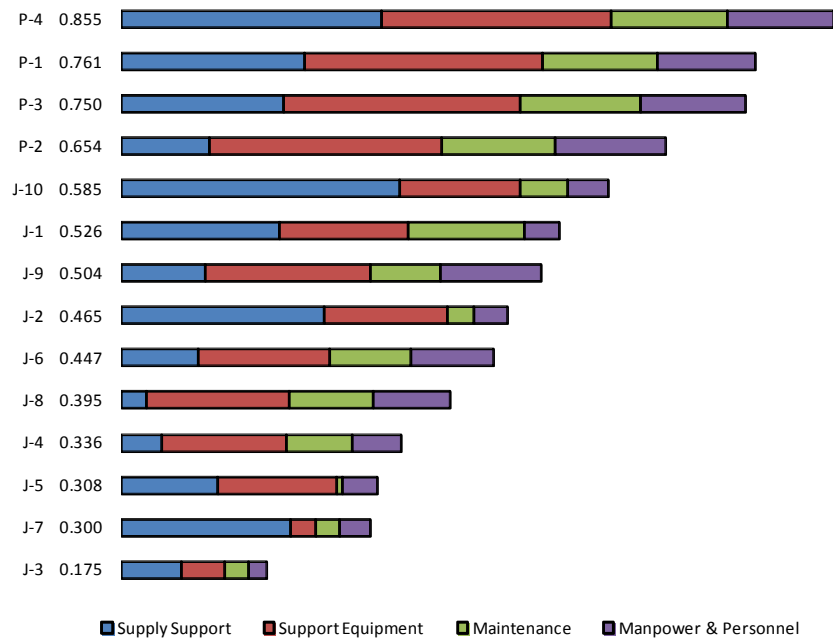


Figure 116 Overall Scoring and Ranking of Alternatives by Logistics Objective

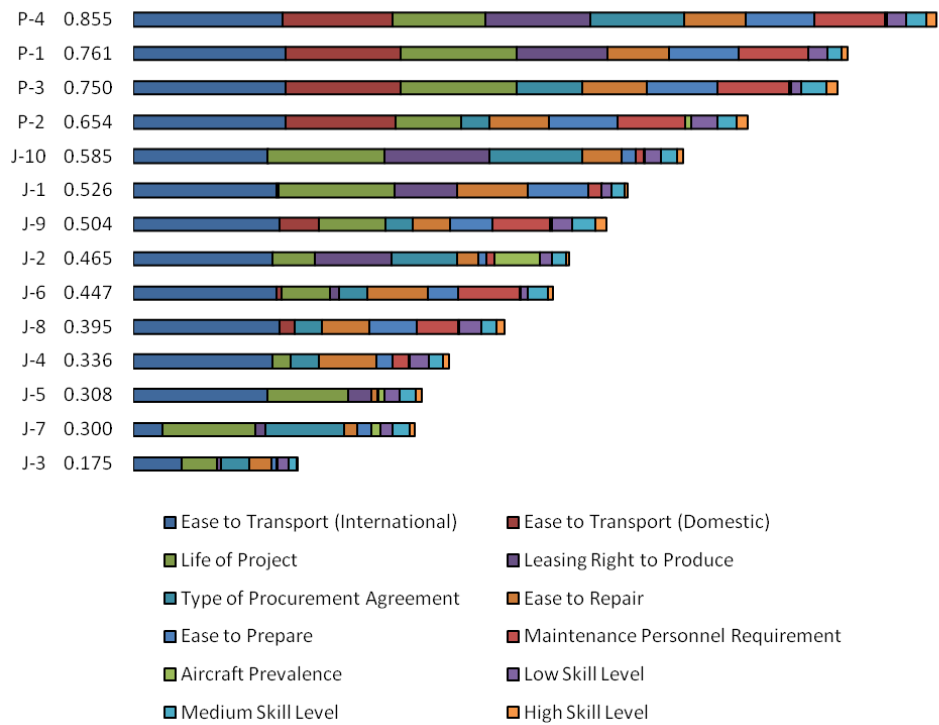


Figure 127 Scoring and Ranking of Alternatives by Logistics Objective

Figure 18 represents the contribution of each measure on prestige objective. J-10 has the advantage of being a domestic and jet aircraft. Alternatives J-7 and J-2 lose points from their origins; but that is not a big loss. Origin of the aircraft is the main measure that separates these two alternatives from others. If we look at Figure 14 that becomes obvious. Prestige objective is the greatest loss for the propeller aircraft. Although their performance is satisfying in terms of other objectives, the importance (weight) of prestige hurts the scores of these alternatives.

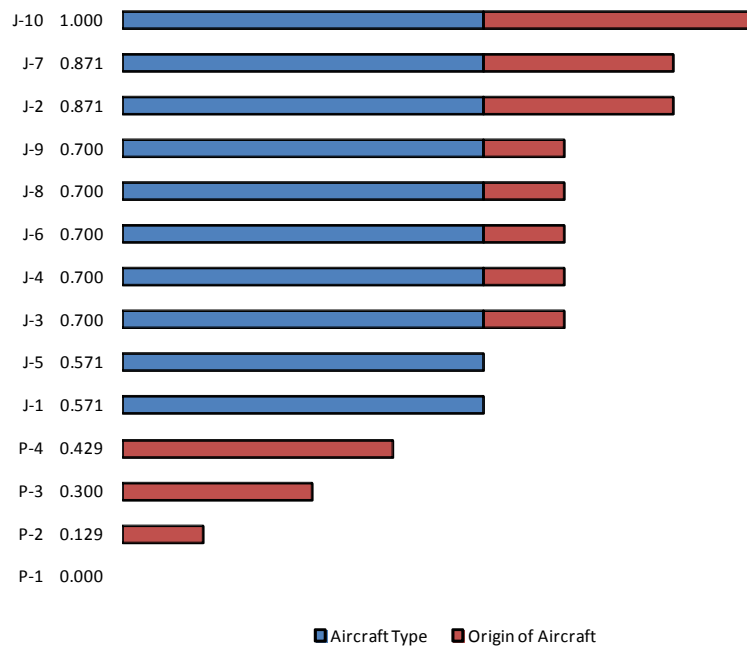


Figure 138 Scoring and Ranking of Alternatives by Prestige Objective

4.1.2 Step 7: Analyze the sensitivity of the analysis to assumptions and consider refining alternatives to create better alternatives.

Sensitivity analysis is a method of verifying that the model is built on proper assumptions. One of the biggest assumptions in the model is that the evaluation measures

have been given the proper weighting and accurately depict the decision maker's preferences. Sensitivity analysis helps the decision-maker verify these weightings by showing how the ranking of alternatives may change based on variations in measure weights.

Graphical demonstration is conducted to illustrate how each alternative will receive more or less value depending on the weight of the selected evaluation measure. Sensitivity analysis will be made for objectives weights that are *Performance*, *Logistics* and *Prestige*. Because, sub-objective weights do not change the results of the current model. On the other hand, decision maker for this model will be a top-level decision maker that deals with the major objectives.

Sensitivity Analysis on Performance Objective

Decision maker's weight is originally 0.15 for *Performance* which is indicated by the vertical line. Alternatives' cross point on this line indicate their respective rankings. Ranking from the top to bottom is the ranking from the best to worst alternative. By visual inspection of Figure 19, it is obvious that J-10 will always be the best choice if the weight of *Performance* stays below 0.6. Between 0.6 and 0.715 J-7 and above 0.715 J-3 will be the best alternative. Hence, if *Performance* gets more important J-7 and J-3 becomes best alternatives. In addition, J-5 has close results to J-3. All other alternatives will be dominated by J-10, J-7 and J-3. If J-10 will not be available during the procurement process, J-2 will be the best alternative below 0.28. Above that weight, J-7 and then J-3 will be the best alternatives.

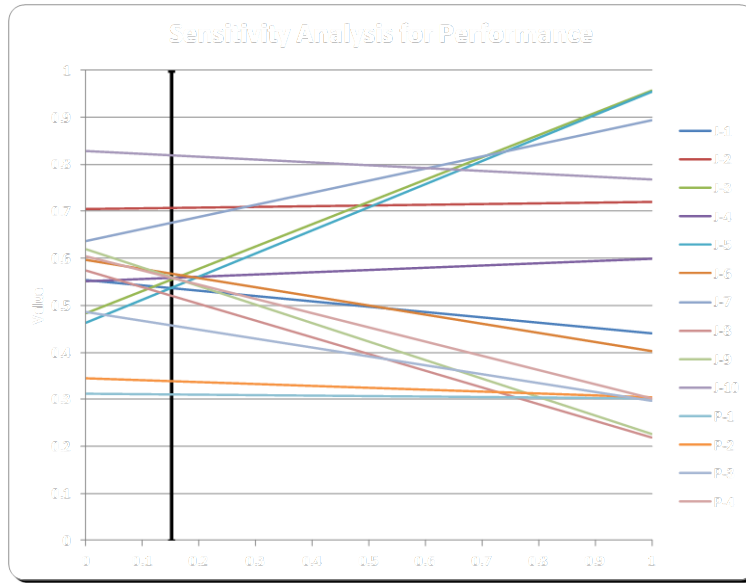


Figure 19 Sensitivity Analysis for Performance Objective

Sensitivity Analysis on Logistics Objective

The next sensitivity analysis is made on the objective of *Logistics*. Decision maker's weight is originally 0.35 for *Logistics*, which is indicated by the vertical line. By visual inspection of Figure 20, it is obvious that J-10 will always be the best choice below 0.675. Above that weight, P-4 will be the best alternative. Other alternatives will always be dominated these two alternatives. If J-10 and P-4 will not be available during the procurement process, J-2 will be the best alternative on the current weight. Between 0 and 0.2 J-7, between 0.2 and 0.654 J-2 and above 0.654 P-3 will be the best alternatives.

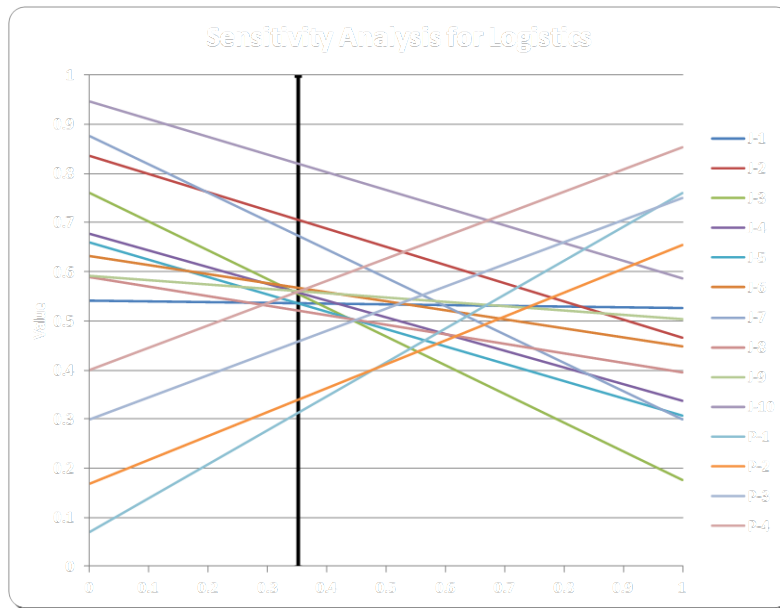


Figure 140 Sensitivity Analysis for Logistics Objective

Sensitivity Analysis on Prestige Objective

Last sensitivity analysis is conducted on the objective of *Prestige*. Decision maker's weight is originally 0.5 for *Prestige*, which is indicated by the vertical line in Figure 21. By visual inspection of Figure 21, it is obvious that J-10 will always be the best choice if *Prestige* gets more important. If it gets less important, P-4 will be the best alternative. This change occurs if weight decreases below 0.08. If J-10 and P-4 will not be available during the procurement process, J-2 will be the best alternative on the current weight. Between 0 and 0.04 P-1, between 0.04 and 0.12 P-3 and above 0.12 J-2 will be the best alternatives.

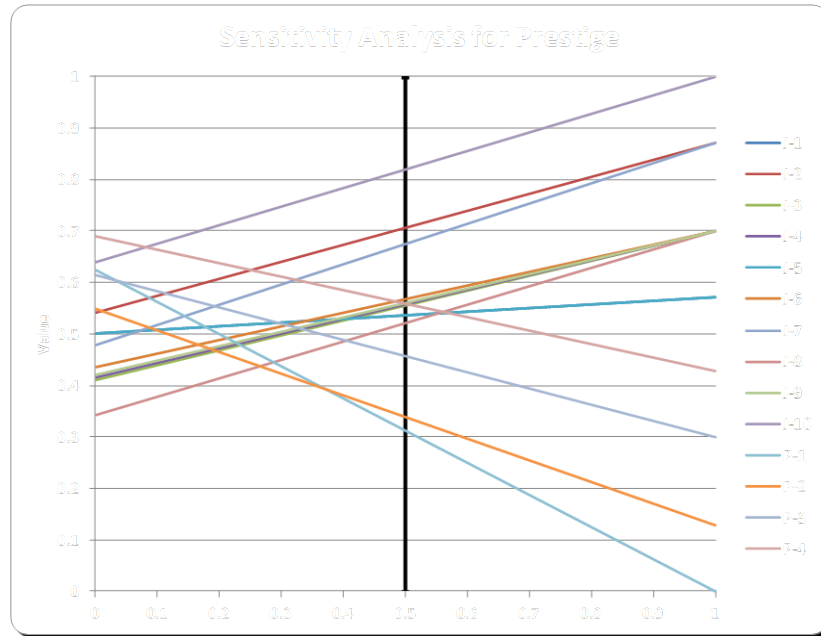


Figure 151 Sensitivity Analysis for Prestige Objective

Overall Sensitivity Comments

J-10, J-7 and J-3 are the best alternatives due to the sensitivity analysis for *Performance*. J-10 and P-4 are the best alternatives by considering sensitivity analysis for *Logistics*. J-10 and P-4 are the best alternatives if we look at the *Prestige*. All other alternatives are always dominated with other alternatives. This gives nearly parallel results to the scoring of the alternatives.

Table 2 illustrates how much the current weight should be changed in order to switch another alternative from J-10 including domestic alternatives. In order to replace J-10, *Performance* requires 300% increase in its weight, *Logistics* requires 92.9% increase in its weight and *Prestige* requires 84% decrease in its weight. Hence, we can conclude that this model has robust results due to the sensitivity analysis on current weights of main objectives.

Table 2 Summary of Sensitivity Analysis with Current Alternatives

Objectives	Current Weight	Adjusted Weight	Percent Change	Current Best Alternative	New Best Alternative
Performance	0.15	0.6	300	J-10	J-7
Logistics	0.35	0.675	92.9	J-10	P-4
Prestige	0.5	0.08	-84	J-10	P-4

Without domestic aircrafts, J-2 and J-7 are the best alternatives due to the sensitivity analysis for *Performance*. J-2, J-7 and P-3 are the best alternatives by considering sensitivity analysis for *Logistics*. J-2, P-1 and P-3 are the best alternatives if we look at the *Prestige*. All other alternatives are always dominated with other alternatives.

Table 3 gives the necessary change on current weight to switch another alternative from J-2 excluding domestic alternatives. In order to replace J-2, *Performance* requires 86.7% increase in its weight, *Logistics* requires 42.9% decrease or 86.9% increase in its weight and *Prestige* requires 76% decrease in its weight. In conclusion, this model again gives robust results due to the sensitivity analysis on current weights of main objectives by excluding domestic alternatives.

Table 3 Summary of Sensitivity Analysis without Domestic Alternatives

Objectives	Current Weight	Adjusted Weight	Percent Change	Current Best Alternative	New Best Alternative
Performance	0.15	0.28	86.7	J-2	J-7
Logistics	0.35	0.2	-42.9	J-2	J-7
		0.654	86.9	J-2	P-3
Prestige	0.5	0.12	-76	J-2	P-3

4.2 LCC Analysis

LCCA requires many assumptions, data collection and estimating relationships between elements. Before making the final recommendation, overall process, data and assumptions should be analyzed. Most of the times DM is interested in all-possible outcomes that can be the result of changes in current situation or based on errors made.

There are many areas of concern due to error, uncertainty and risk. Some decision independent parameters are annual equivalent cost data, present equivalent cost data, inflation rate, interest rate, discount rate and labor rate may affect the future cost. All these parameters should be part of sensitivity analysis. On the other hand, high cost contributors may have important effects on overall cost. By determining the high cost contributors, it is possible to detect their relationships with other factors that may change the result of analysis (Fabrycky, J., & Blanchard, 1991). Inclusion of other information over the time will cause changes; since, analysis is made in a limited amount of time.

In order to include all uncertainties, a high and low level estimation can be useful. By assuming DM's tolerance is a 10% change from the present costs, we can define a lower and upper value for present cost of each alternative. If past data is available, it is possible to use statistical regression analysis to determine these upper and lower values. Simply by increasing and decreasing the present cost of each aircraft by 10%, lower and upper estimates are found. Table B.3 illustrates results after the calculation.

4.3 Cost-Effectiveness Analysis

Cost-effectiveness analysis deals especially with the problems that the output cannot be measured by market prices. It is used for the problems that aims to maximize effectiveness subject to a resource constraint measured in monetary units. Cost-effectiveness analysis is suitable if it is not possible to evaluate the outputs of alternatives with a market evaluation and the resource inputs can be evaluated by market prices (Goldman, 1967).

DM has two objectives that are minimizing cost and maximizing the value by a proper decision. Although the results determine fourteen different alternatives, not all of them are the preferable. If alternatives are possible solutions for that decision problem, we may define preferable alternatives as noninferior solutions. A noninferior solution is better on all objectives than other solutions.

Figure 22 illustrates the results of LCCA and VFT. Graphically, the noninferior solutions are the outer border of the feasible solutions in the direction of improving objectives (Neufville, 1990). The preferred alternative should be one of the noninferior solutions; since, only the noninferior solutions are worthwhile.

Inspection of graph defines J-10, J-2, J-6, J-9, P-4, P-3 and P-2 as the noninferior solutions. In the absence of alternatives J-10 and P-4, the noninferior solutions will be J-2, J-6, J-9, P-3 and P-2. The line between the alternatives approximately represents the efficient frontier. If there were many alternatives, it would be necessary to construct a trade-off function between value and cost. Yet, for this study, it is not useful.

All other alternatives are dominated by these noninferior solutions. J-10 has the best performance on value and P-2 has the best performance on cost. Therefore, these two alternatives represent a major alternative group. Other alternatives lie between these two alternatives; hence, they construct a compromise group. If DM has specific thresholds, some alternatives may be excluded from consideration. Propeller aircrafts have close results. By increasing budget by \$318000 per aircraft, it is possible to increase value by 0.1 from P-3 to P-4. On the other hand, \$6.6 million budget increase per aircraft leads 0.22 value increase from P-2 to P-4. Yet, this graph uses data that is assumed true.

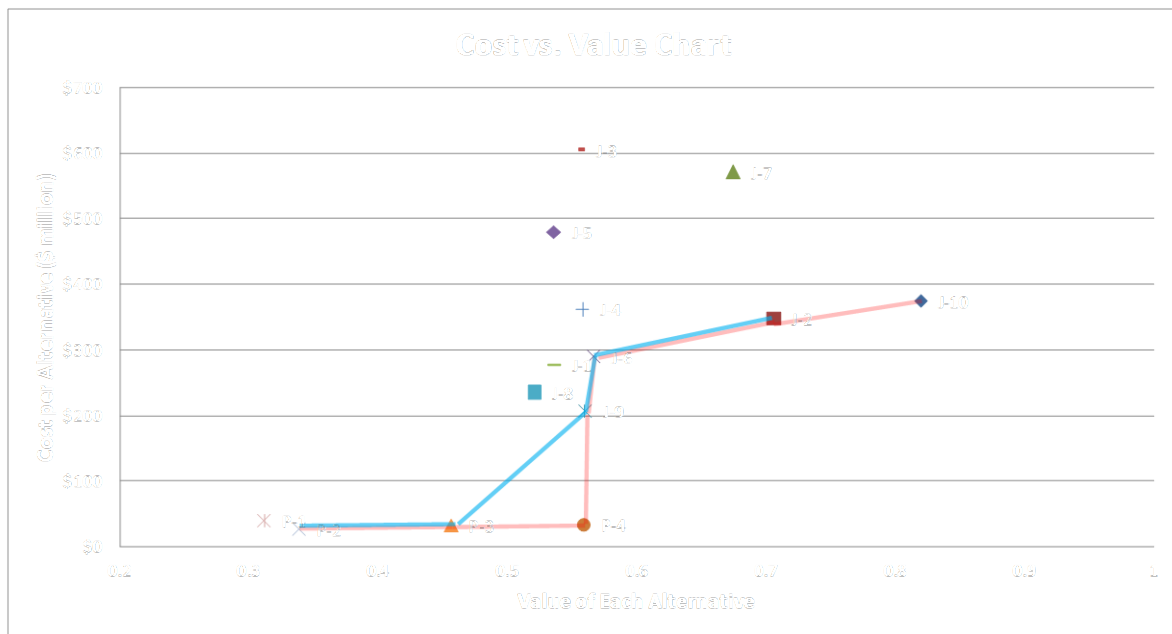


Figure 162 Cost- Effectiveness Analysis

By inspecting the same graph, it will be obvious that there is big gap between alternatives J-2 and P-4 as illustrated in Figure 23. In order to fill that gap, different strategies may be applied to the analysis. It is possible to miss some other appropriate

alternatives from this analysis. There may be different alternatives that have more value for less cost. Hence, it can be appropriate to search for new alternatives. From a different point of view, some of the current alternatives may be taken to noninferior solutions. For instance, with different modifications enhancing the thrust/weight ratio for J-8 we may increase its value with an increase in cost. Adding an air refueling system to J-1 may carry that alternative to efficient frontier.

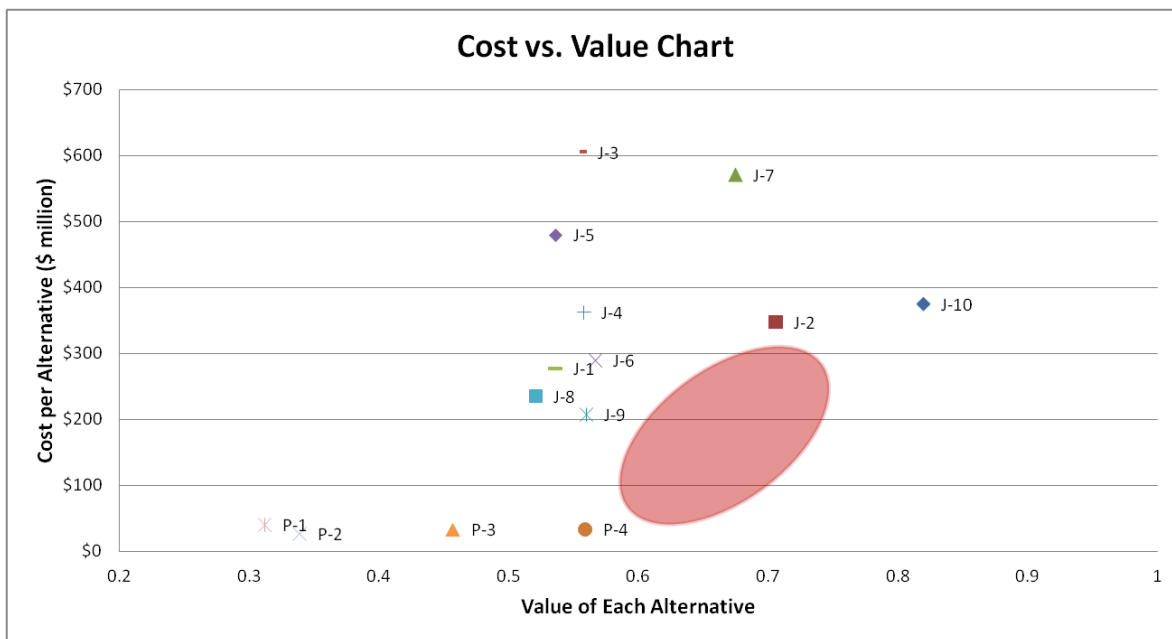


Figure 173 Gap between Cost and Value

Figure 24 illustrates result of LCC and VFT sensitivity analysis to see the model reflection to possible changes. Possible uncertainties cause intersections between some of the alternative areas; hence, it is not clear which alternative is the preferred one. As indicated in the Figure 24 where there intersections occur across alternatives, there is uncertainty as to which system will be a better decision in terms of cost and value. This may cause risky decisions. If DM does not have the insight of cost uncertainty, it is most

likely he or she will choose the alternative that has lowest cost estimate due to the budget constraint.

Value ranges are calculated by taking minimum and maximum limits for sub-objective weights. Sensitivity analysis is based on the range from zero to one. However, this situation is not very realistic. If an objective has a zero weight, it is not logical to put it into the hierarchy. Therefore, it is assumed that weight on *Prestige* may differ between 0.1 and 0.3, weights on *Logistics* may differ between 0.15 and 0.55 and weights on *Prestige* may differ between 0.3 and 0.7.

Due to these weight ranges, alternatives J-3 and J-7 may have big changes on value. It is possible to have values of 0.438 and 0.672 by spending \$665.2 million per J-3 aircraft. By inspecting values for J-7, it is possible to make same comments. Propeller aircraft data produce the same conclusion. Especially P-1 may have the value between 0.174 and 0.45 that means a significant uncertainty for this type of big project decision. J-1 has the least uncertainty in terms of value. By inspecting the attribute data for J-1, it is obvious that it has average data for each attribute. Hence, changing objective weights does not hurt this alternative. Yet, it does not produce value as much as the other noninferior solutions among jet aircrafts.

As stated before, intersections between alternative areas are another issue to consider. All of the dominated solutions from previous table will be dominated most of the time. Yet, it is not obvious which alternative is better than other one at some points. By calculating the percentage of intersection area among the total area of intersecting alternatives, it is possible to obtain the probability of considering both alternatives. If DM

needs make a choice between J-2 and J-10, 8.18 % of the time he or she will be indifferent between these two alternatives. If these aircrafts are J-1 and J-6, then the percentage will be 22.23 % that implies more uncertainty. On the other hand, DM will be indifferent between J-1 and J-8 9.22% of the time and For J-8 and J-9 20.1% of the time. For the propeller aircrafts, 30.24 % of the time decision maker may be indifferent between P-3 and P-4.

On the other hand, there is a big difference between most of the jet aircrafts and propeller aircrafts in terms of value and cost. By paying more, DM increase the value of the alternative. In addition, propeller aircrafts has a big range on value sensitivity in comparison to jet alternatives. Therefore, it is possible to conclude that by paying more DM increases the value and decreases the risk.

Adding thresholds may be useful. By that way, it is possible to exclude the alternatives that do not satisfy the DM's lower limit for value and upper limit for cost. Exclusion of these alternatives makes the analysis easier and other alternatives more visible. There are only fourteen alternatives for this research; so, it is not too challenging to observe the alternatives. Yet, different studies with greater number of alternatives may be more difficult to draw conclusions without these thresholds.



Figure 184 Cost-Effectiveness Analysis with LCC and VFT Sensitivity Analysis

V. Summary and Conclusion

This chapter provides a brief description of this research, answers the questions stated in Chapter 1, states conclusions that are obtained from the research and suggestions for future work.

5.1 Summary of the Research

In Chapter 1 problem definition, research questions, research approach and assumptions are stated.

Chapter 2 includes techniques and related studies for these techniques. At first, a brief description of Turkish Procurement Law illustrates procedures used for governmental and military procurements to look for possible limitations of the law for techniques. VFT technique is used to create different alternatives that have appropriate attributes for DM and stakeholders of that decision problem. LCCA is conducted to estimate and analyze the present cost of each alternative. Steps are briefly described and different information sources are recommended.

Chapter 3 presents methodology and implementation of VFT and LCCA. First, a value hierarchy is created to define desired attributes of alternatives. Then DM and SMEs stated SDVF for each measure of the hierarchy. Alternative identification is made due to the measures of the hierarchy. After defining weights, the additive value model is used to find the overall score and ranking of each alternative. LCCA steps describe the definition and CBS of the current problem. Data for VFT and LCCA are generated by using different real world aircraft data.

Analysis phase is presented in Chapter 4. VFT sensitivity analysis is made on main objectives. Since the most important assumption is the proper weight data. For LCCA sensitivity, many issues should be taken into account. By just simply assuming only a specific amount of deviation is acceptable, cost range for each alternative is calculated. In order to combine VFT and LCCA results, cost-effectiveness analysis is conducted. All these analyses are made to conclude if the model is robust.

5.2 Conclusions

Difficulty of the decision-making process stems from its complexity, uncertainty, multiple objectives, and integration of different data types. In addition, results of that process affect a large number of people, a large amount of resources and a long period. On the other hand, all of the DM wants to make a decision that they may achieve their objectives. Hence, a systematic technique is needed to analyze this process. VFT in conjunction with MODA provides this systematic approach.

The purpose of this research effort is to evaluate the alternatives that maximize cost effectiveness in the decision process of TURAF by using a VFT approach with LCCA. Eight steps of VFT that are stated by Kirkwood are used to develop a robust model for TURAF decision problem. The robustness of the model is checked by sensitivity analysis. For this research, DM and SMEs are satisfied by the results for weighting and weights reflect their preference ranking. Hence, results are verified.

In addition to VFT, LCCA steps are utilized to calculate LCC of each alternative. LCCA gives a different perspective for DM. Since, LCCA determines the cost effectiveness of the alternatives by analyzing long term costs by using time-value of money. If only the VFT results are considered, there will be less than three alternatives

that the DM should consider. Yet, combination of these two techniques provides a better insight. Because of the fact that circumstances may change over the time, it may be necessary to make tradeoff between cost and value depending on the budget. Combination of VFT and LCCA shows other alternatives that may be considered regarding that tradeoff. This methodology may be used for similar decision processes.

This research shows that VFT with LCCA is a suitable methodology for analyzing different alternatives. However, the results are only a recommendation; every DM has to base their final decision on a variety of factors. The value model aids the decision making process by identifying the core values and measures that should be considered while selecting alternatives. Too many factors have varying impacts on this decision-making process.

5.3 Strengths

Decision Analysis process may be a complicated process for most of the decision makers. Most of the points can be misunderstood without the presence of decision analysis background. VFT overcomes all of these drawbacks of DA. By defining the attributes and their values, alternatives are selected based on the DM considerations by reducing biases of choosing alternatives directly from the real world. Therefore, using this technique allows an objective analysis for the DM in comparison to other techniques in the literature.

In addition, DM does not have to know decision analysis issues; and VFT does not necessitate the explanation of terms in the DA terminology. That makes communication between analyst and DM easy and time efficient. DM and SMEs contribute decision-making process from different standpoints and makes the analysis

interactive. This participation makes the results of the research easy to explain and easy to implement to similar problems. Hence, the model provides an objective and repeatable process. Combination of VFT and LCCA present a good visual illustration of alternatives besides scoring and ranking.

5.4 Limitations

This research has some limitations. First, data for both aircraft attributes and costs should be based on the prospectively collected data from the manufacturers. The data limitation for this study stems from the unwillingness of the manufacturers to give the available data. Thus, for this study, data used comes from a variety of diverse sources and data generation. On the other hand, collecting suitable data for an appropriate analysis necessitates a long amount of time.

The results of the sensitivity analysis provide insight into which aircrafts were most compatible with different weighting values. However, this analysis is among the limited amount of alternatives. Depending on the different circumstances, different types of alternatives should be considered.

The other limitation is the deferrable weights and measures to score the alternatives. Since these depends on the current DM, SME and leading of analyst. Weighting can make value model very sensitive due to given weight by decision maker. The other limitation of the model is bias introduced by a single decision maker after the determination of alternatives. That bias may be on the origin of the aircraft or similar objectives. It may be reduced by using different procedures; nevertheless, this bias may not be removed from the current analysis.

5.5 Future Work

For future work on the same problem or similar problems, the following research can be done;

- Cost drivers of the model can be defined to reduce and analyze the overall cost of each aircraft.
- Optimization procedures can be applied to LCCA after determining the cost drivers.
- Sensitivity analysis can be conducted on each parameter that affects cost.
- The same model can be utilized with the real world data.
- Simulation techniques can be used to analyze the long-term performance of the data and the model and to generate data to validate and verify the theoretical model.
- Instead of single representative of stakeholders, group stakeholders can be considered.

Appendix A. Value Functions

The minimum score (90) has value of zero, the score 180 has value of 0.8 and the score of 350 has value of one.

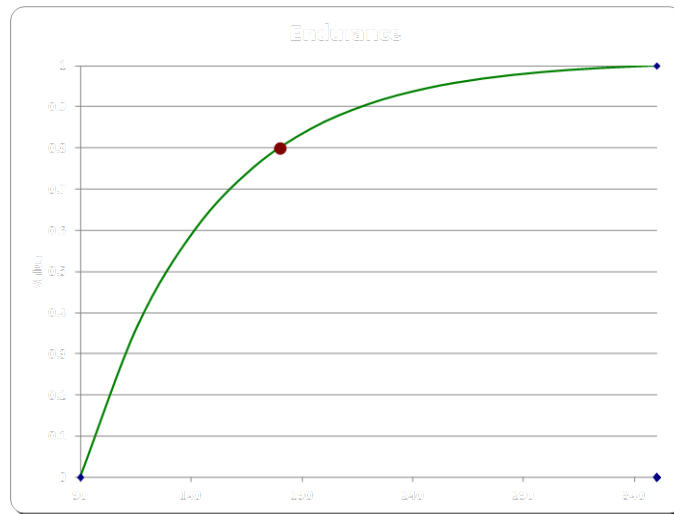


Figure A. 1 Value Function of Endurance

The most preferred capability is having air refueling; hence, if an aircraft has air refueling capability the score will be one. Otherwise, the score will be zero.

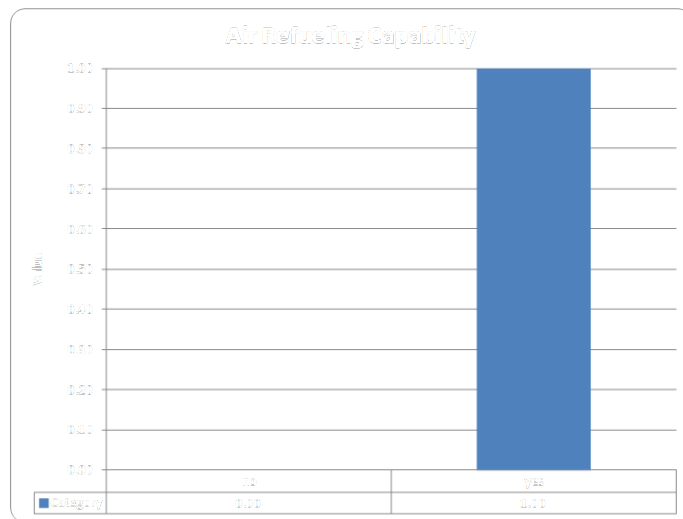


Figure A. 2 Value Function of Air Refueling Capability

The minimum score (0.85) has value of zero, the score 1 has value of 0.8 and the score of 1.2 has value of one.

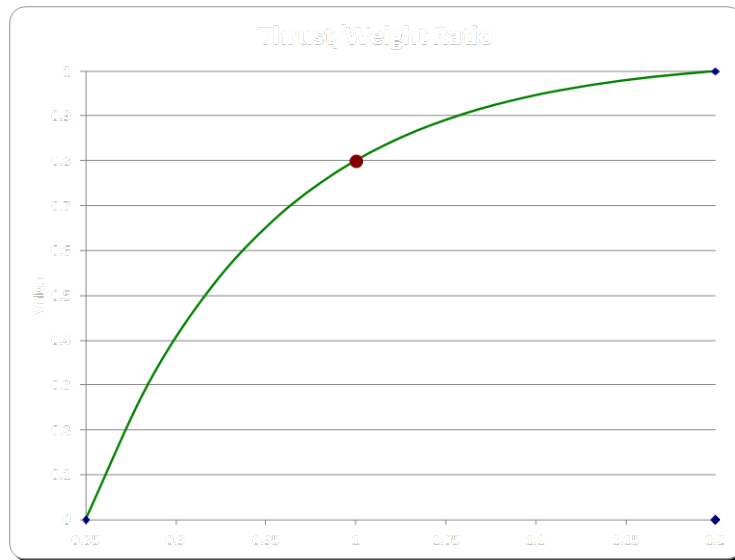


Figure A. 3 Value Function of Thrust/ Weight Ratio

The minimum score (75) has value of one, the score 180 has value of 0.8, the score 230 has value of 0.3 and the score of 300 has value of zero.

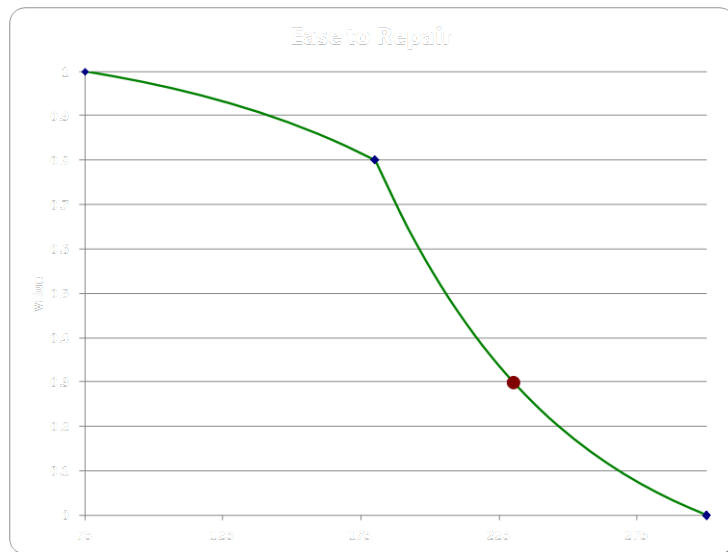


Figure A. 4 Value Function of Ease to Repair

The minimum score (120) has value of one, the score 400 has value of 0.8, the score 530 has value of 0.3 and the score of 1100 has value of zero.

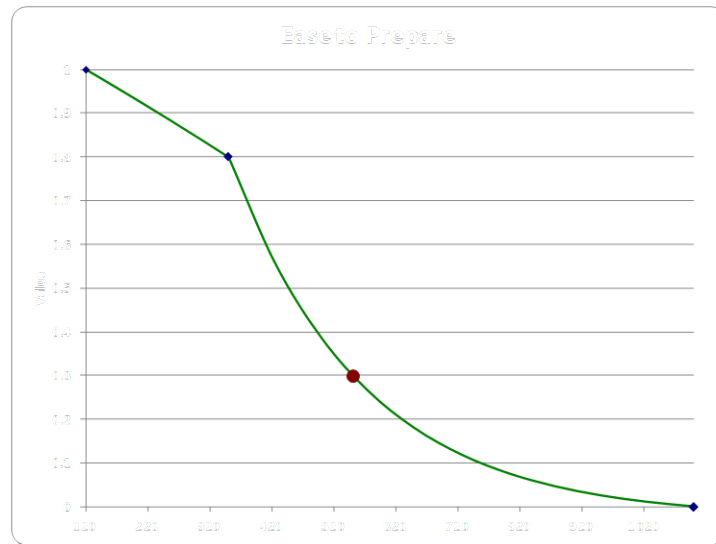


Figure A. 5 Value Function of Ease to Prepare

The minimum score (30) has value of one, the score 800 has value of 0.8, the score 110 has value of 0.3 and the score of 230 has value of zero.

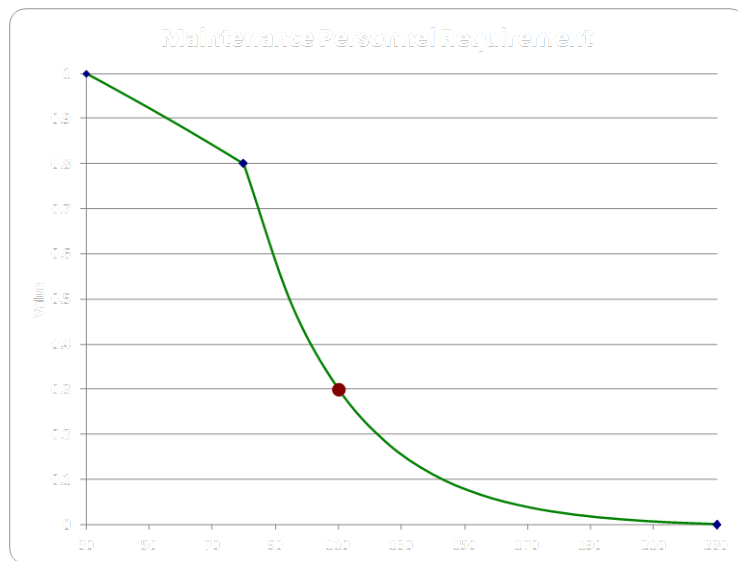


Figure A. 6 Value Function of Maintenance Personnel Requirement

The minimum score (0.1) has value of zero, the score 0.3 has value of 0.8 and the score of 0.4 has value of one.

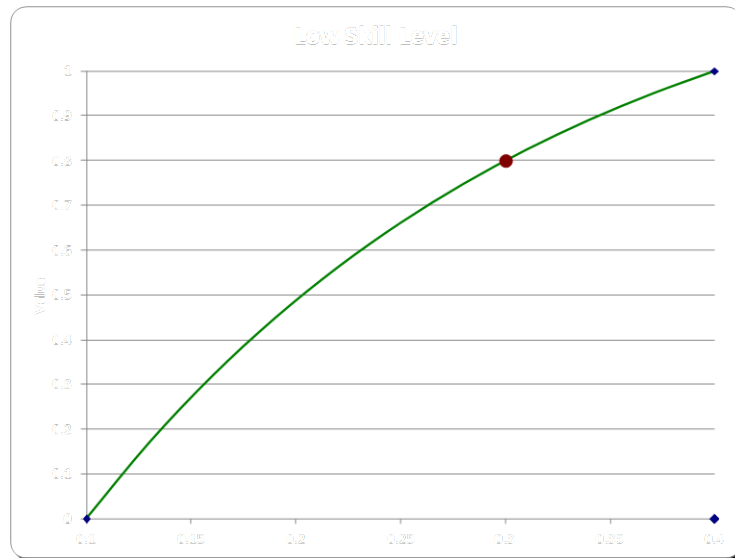


Figure A. 7 Value Function of Low Skill Level

The minimum score (0.1) has value of zero, the score 0.4 has value of 0.8 and the score of 0.6 has value of one.

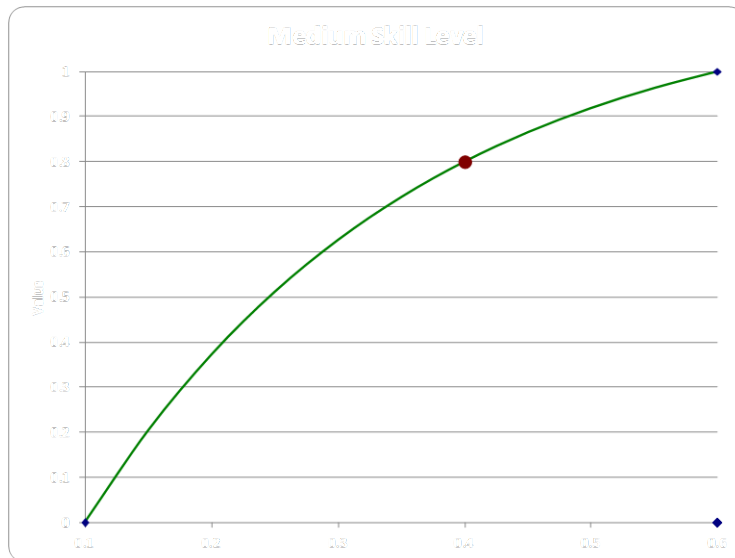


Figure A. 8 Value Function of Medium Skill Level

The minimum score (0.2) has value of one, the score 0.3 has value of 0.8 and the score of 0.7 has value of zero.

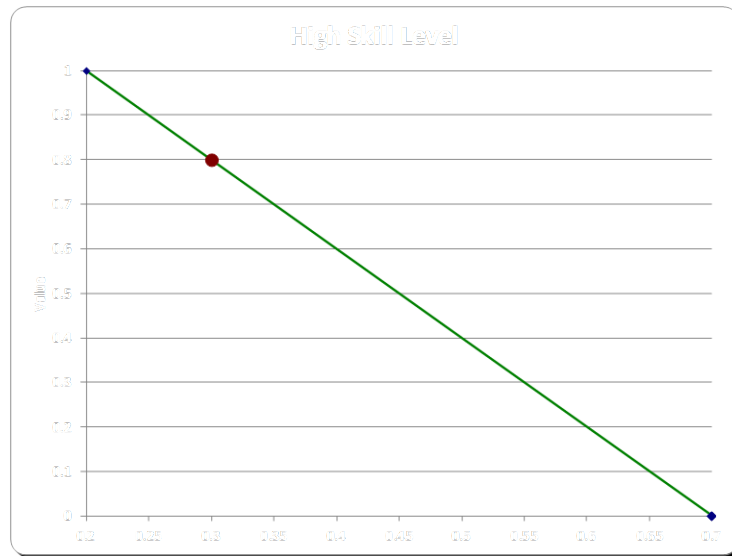


Figure A. 9 Value Function of High Skill Level

The minimum score (150) has value of zero, the score 4000 has value of 0.8 and the score of 4500 has value of one.

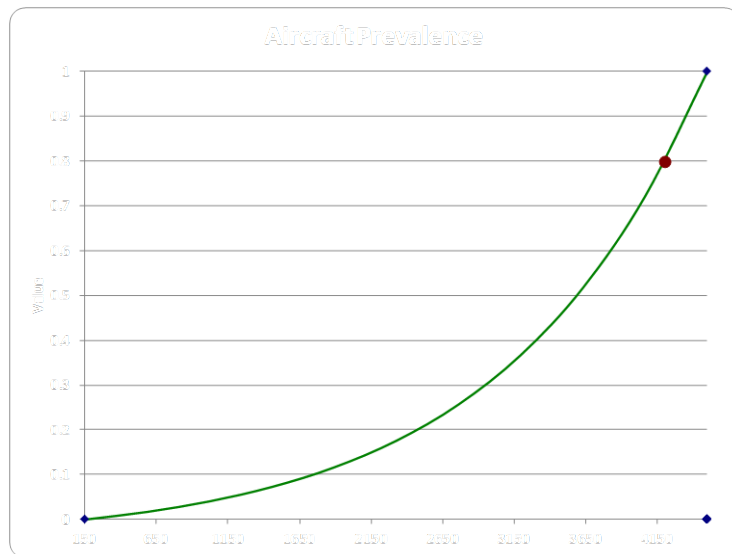


Figure A. 10 Value Function of Aircraft Prevalence

The minimum score (0) has value of zero, the score 0.5 has value of 0.3, the score 0.9 has value of 0.8 and the score of 1 has value of one.

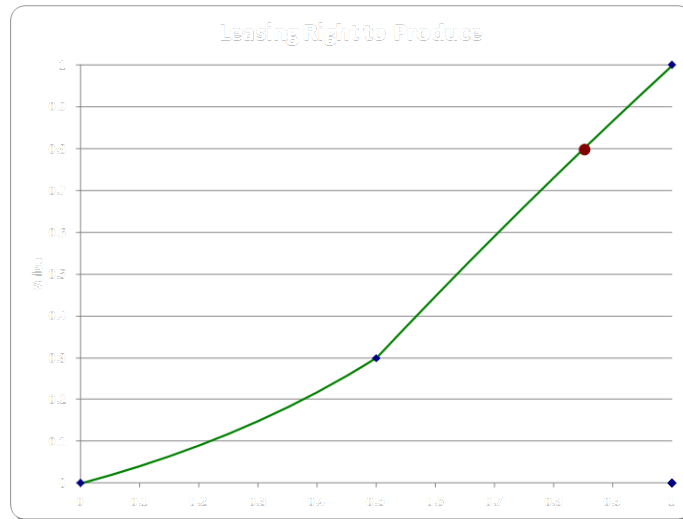


Figure A. 11 Value Function of Leasing Right to Produce

The most preferred one is making an agreement with domestic suppliers; hence, if an aircraft has domestic procurement agreement the score will be one. Otherwise, the score will be 0.85 for PBL, 0.7 for FMS, 0.3 for NAMSA and 0 for MOA.

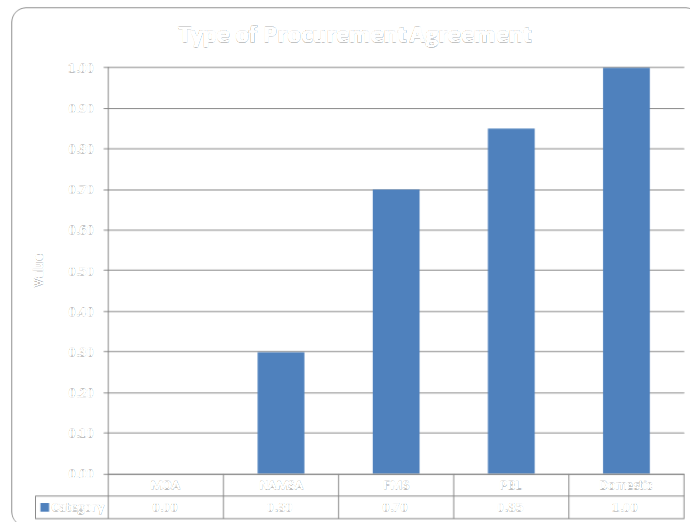


Figure A. 12 Value Function of Type of Procurement Agreement

The minimum score (0) has value of zero, the score 30 has value of 0.8 and the score of 40 has value of one.

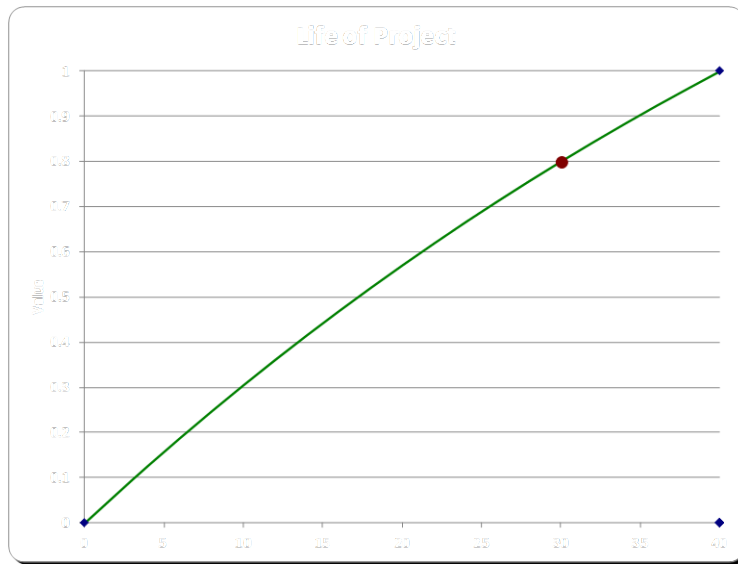


Figure A. 13 Value Function of Life of Project

The minimum score (0) has value of one, the score 10 has value of 0.8, the score 12 has value of 0.3 and the score of 20 has value of zero.

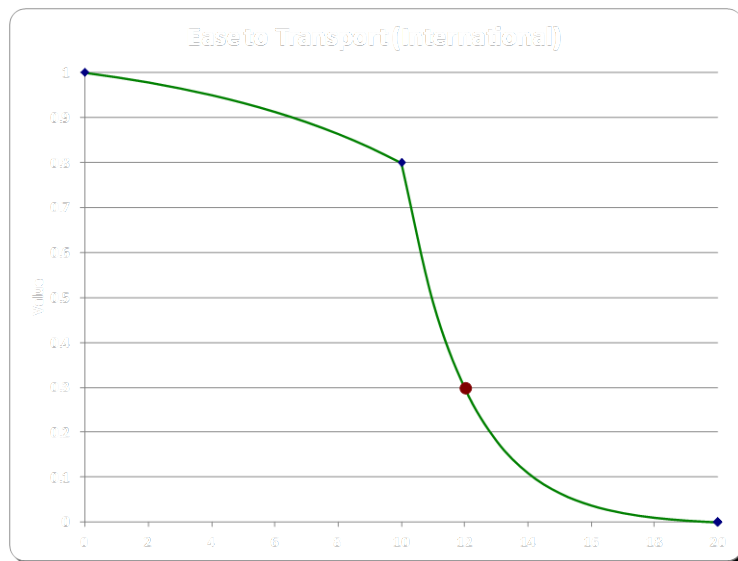


Figure A. 14 Value Function of Ease to Transport (International)

The minimum score (0) has value of one, the score 8 has value of 0.8, the score 9 has value of 0.3 and the score of 14 has value of zero.

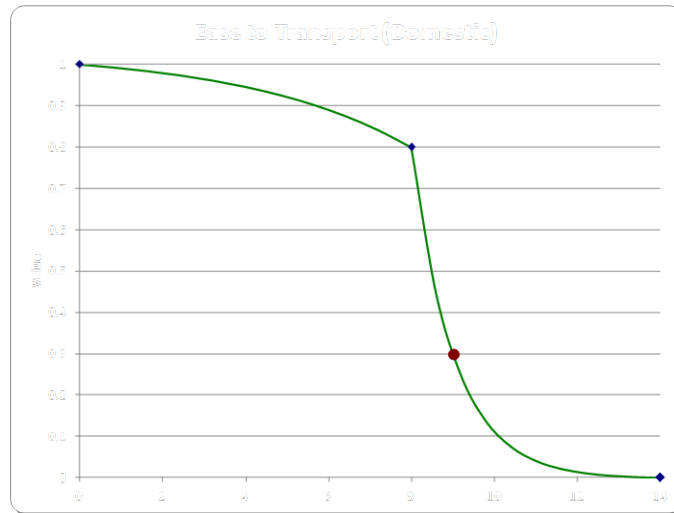


Figure A. 15 Value Function of Ease to Transport (Domestic)

The most preferred one is cat-1 that is the domestic aircraft; hence, if an aircraft is domestic the score will be one. Otherwise, the score will be 0.7 for cat-2, 0.3 for FMS, 0.3 for cat-3 and 0 for cat-4.

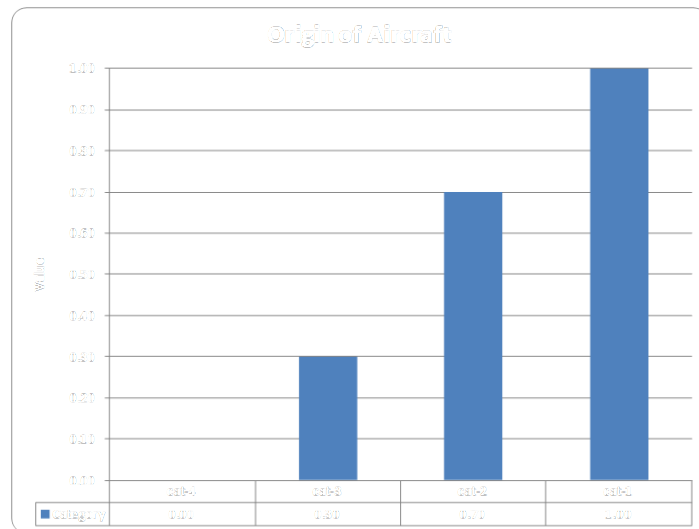


Figure A. 16 Value Function of Origin of Aircraft

The most preferred aircraft is the jet aircraft; hence, if an aircraft is a jet aircraft the score will be one. Otherwise, the score will be zero.

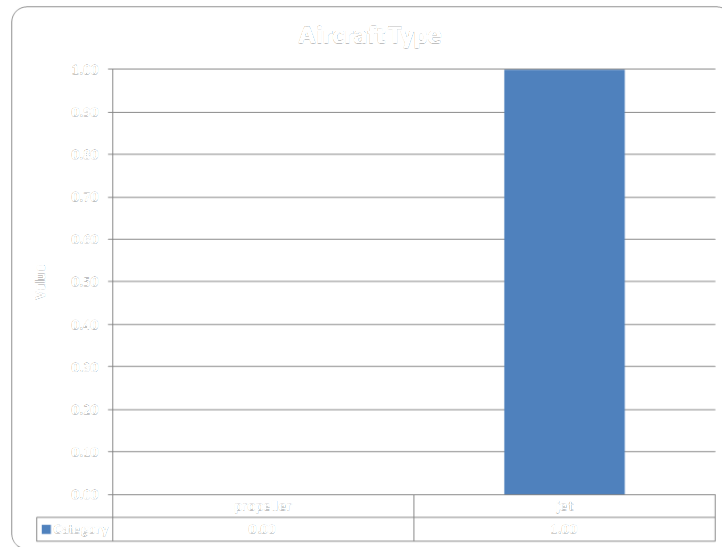


Figure A. 17 Value Function of Aircraft Type

Appendix B. Aircraft Attribute and Cost Data

Table B. 1 Aircraft

Attribute Data

Table B. 2 Aircraft

Cost Data

Table B. 3 Base,
Each Aircraft

Min and Max Cost of

	J-1	J-2	
Cost of Each Aircraft w 10% Increase	305.09	382.05	66
Total Cost of Each Aircraft	277.35	347.32	60
Cost of Each Aircraft w 10% Decrease	249.62	312.59	54

J-10	P-1	P-2	P-3	P-4
412.47	44.42	29.56	36.47	36.82
374.98	40.39	26.87	33.15	33.47
337.48	36.35	24.18	29.84	30.12

	j-1	j-2	j-3	j-4	j-5	j-6	j-7	j-8	j-9	j-10	j-11	j-12	j-13	j-14	PROCUREMENT COST FOR 20 AIRCRAFT (\$ million)									
aircraft cost	500.0	1749.0	2757.8	1302.4	1853.3	2266.5	3718.5	300.0	473.0	1652.3	98	40,449	119											
aircraft related equipment	0.59	80.0	79.6	76.9	157.2	47.3	81.6	90.0	94.0	92.7	9.4	9.6	4.2	7.07										
aircraft related equipment spare and inventory support cost	8.11	62.1	47.6	27.3	19.8	30.6	1.2	3.5	4.5	13.2	6.56	5.9	1.2	4.55										
modification for airshow	27.7	21.7	17.8	8.6	5.6	13.1	38.4	3.5	4.7	15.7	2.3	1.95	0.8	1.68										
aircraft spares and inventory	295.2	328.8	854.0	311.5	594.5	211.2	168.7	400.0	220.0	376.0	32.2	29	5.58	22.26										
special tools and test equipments	56.3	66.3	62.6	67.9	88.0	47.9	58.1	41.6	36.8	38.4	11.8	10.9	6.5	9.7										
documentation and technical data	804.9	971.7	1099.7	72.8	178.2	56.1	163.2	342.1	321.9	641.2	12.3	11.1	9.5	11.0										
aircraft training	18.0	21.0	42.7	45.0	82.5	28.2	164.3	12.0	15.0	47.6	5.4	3.5	3.2	4.08										
aircraft maintenance	94.5	100.0	91.6	129.1	27.0	72.8	76.4	80.0	90.0	108.0	5.67	4.5	3.5	4.56										
aircraft maintenance facilities	52.1	46.2	46.4	46.8	84.4	35.8	64.6	35.0	41.0	51.5	4.58	3.8	2.3	3.56										
aircraft maintenance simulator	2052.7	3412.8	5071.3	2088.3	3300.5	2759.4	6014.0	1307.7	1500.9	3005.4	188.21	118.689	155.73	154.21										
TOTAL PROCUREMENT COST FOR 20 AIRCRAFT																								
	OPERATING AND SUPPORT COST FOR 20 AIRCRAFT (\$ million)																							
operating personnel	81.5	62.4	438.8	254.0	394.0	120.0	206.7	70.0	78.0	193.9	19	21	18	1934										
training of operating personnel in Turkey	4.3	4.3	9.3	6.2	6.2	3.6	6.3	3.2	2.8	4.8	1.2	0.5	0.7	0.8										
training of operating personnel in country	176.2	178.1	476.4	167.0	224.0	193.1	165.4	122.0	138.0	204.3	34.8	28.4	17.8	32.6										
users simulator	100.3	101.4	162.7	152.3	278.0	145.6	135.1	95.0	11.5	142.8	4.8	21	33	32.67										
infrastructure for use of material	302.7	346.6	792.1	425.8	734.0	16.9	588.4	8.2	7.8	369.0	3.8	1.8	2.4	2.67										
infrastructure for use of material	407.0	431.8	451.2	852.0	557.9	331.7	627.1	156.0	186.0	447.9	105	115	102	107.34										
aircraft support	934.0	944.4	1328.3	1224.4	1426.0	1156.2	2241.3	1400.0	845.0	1277.7	125	52	98	96.67										
spare and inventory support cost	167.1	169.0	311.2	392.2	448.0	159.5	113.3	248.0	165.0	234.5	48.1	22.7	30.8	33.8										
aircraft maintenance personnel	849.4	858.9	2014.9	1256.0	1157.0	401.9	972.1	780.0	820.0	1022.8	152	125	127	1345.7										
training of maintenance personnel	61.2	61.9	111.9	18.0	186.0	45.1	31.4	50.0	54.0	81.1	19.56	14.1	12	15.22										
aircraft maintenance and test equipment	6.4	6.5	14.8	8.5	28.4	35.0	4.4	5.8	4.3	12.7	3.4	0.9	1.1	1.8										
aircraft maintenance technical data	64.9	65.7	108.4	40.8	82.5	50.5	52.8	28.4	32.4	58.5	10.7	7.0	2.7	8.5										
aircraft maintenance system modification and upgrading	79.4	282.5	794.0	310.0	714.1	267.2	244.0	437.2	192.3	383.4	53.0	20.0	42.0	38.4										
TOTAL OPERATING AND SUPPORT COST FOR 20 AIRCRAFT	3094.4	3533.6	7031.0	4153.4	6294.0	3086.2	5403.1	3403.8	3640.6	4445.1	619.5	507.29	515.17											
TOTAL COST FOR 20 AIRCRAFT	5457.1	6946.4	12102.3	7232.7	9949.5	5755.6	11471.1	4711.6	7484.5	8077.1	537.44	663.02												
TOTAL COST FOR EACH AIRCRAFT	272.74	347.31	605.1	362.0	497.97	288.8	570.9	235.6	370.1	403.85	26.87	33.19												

Alte



Value Focused Thinking In Developing Aerobatic Aircraft Selection Model For Turkish Air Force



INTRODUCTION

•The mission of an aerobatic team is to enhance government recruiting, and credibly represent an Air Force.

•Turkish Air Force Command plans to replace the current aerobatic aircraft, which have completed their lifetime.

•A decision making process will be used by TurAF to select the best cost effective alternative while taking into account the values of the decision maker and stakeholders.



RESEARCH FOCUS

•The purpose of this research is to lessen the potential human errors by using decision analysis and cost analysis techniques.

•This research uses Value- Focused Thinking in conjunction with Multi-Objective Decision Analysis and Cost Analysis.

•It creates a decision-making model that allows decision makers to interact with analysts by specifying his/her objectives, values and preferences.

•Cost analysis process determines cost effective alternatives are.

1st Lt. Emel Bengoz(TurAF)

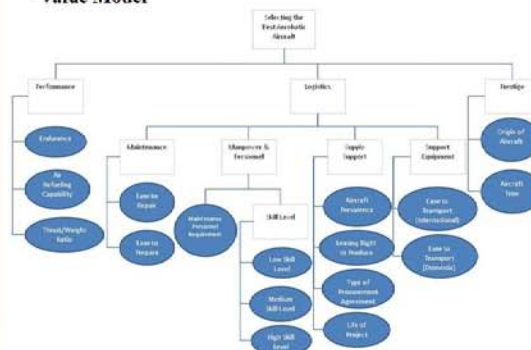
Advisor: Dr. Jeffery D. Weir

Reader: Lt.Col. Doral E. Sandlin, PhD

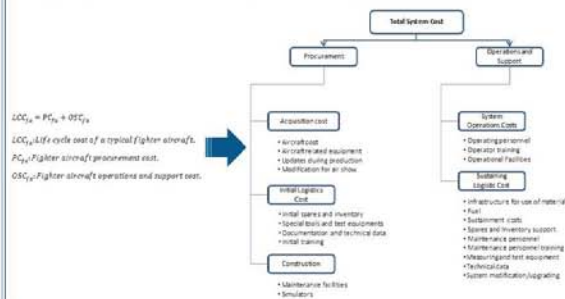
Department of Operational Sciences (ENS)

Air Force Institute of Technology

• Value Model



• Cost Model and Cost Breakdown Structure



$$LCC_{FA} = PC_{FA} + OSC_{FA}$$

LCC_{FA} : Life cycle cost of a typical fighter aircraft.

PC_{FA} : Fighter aircraft procurement cost.

OSC_{FA} : Fighter aircraft operations and support cost.

CONCLUSION

•The purpose of this research effort is to evaluate the alternatives that minimize cost and maximize value.

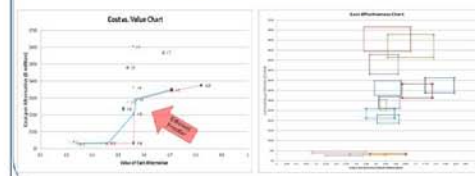
•The value model reflects the main concerns of the DM, stakeholders and SMEs.

•VFT provides a systematic approach and it overcomes the drawbacks of DA.

•This methodology may be used for similar decision processes.

•This technique allows for an objective analysis for the DM.

•Combination of VFT and LCCA present a good visual illustration of alternatives.



FUTURE RESEARCH

•Cost drivers of the model can be defined.

•Optimization procedures can be applied to Life Cycle Cost Analysis.

•Sensitivity analysis can be conducted on each parameter that affects cost.

•Real world data can be utilized.

•Simulation techniques can be used to analyze the long-term performance.

•Group stakeholders can be considered.

DEPARTMENT OF OPERATIONAL SCIENCES

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Vita

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14. ABSTRACT The purpose of this research is to lessen the potential human errors by using decision analysis and cost analysis techniques. This research uses Value- Focused Thinking in conjunction with Multi-Objective Decision Analysis and Cost Analysis. It creates a decision-making model that allows decision makers to interact with analysts by specifying his/her objectives, values and preferences. On the other hand, cost analysis process determines cost effective alternatives. Alternatives are scored using 17 evaluation measures that are identified by interviews with the decision maker and stakeholders. Robustness of the model is tested by sensitivity analysis. Results of sensitivity analysis on current weights indicate that this model has robust results. Nevertheless, sensitivity analysis on cost indicates that many issues may influence the robustness of cost estimates and the best cost effective alternative.					
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